Sunday, 16:30-18:30

■ SF-01

Sunday, 16:30-18:30 - Room: Great Hall

Opening

Stream: Opening and Closing
Invited session
Chair: *Rita D'Ecclesia*

Monday, 8:30-10:00

■ MA-01

Monday, 8:30-10:00 - Room: Great Hall

Francisco Aragón Artacho

Stream: Keynotes
Keynote session
Chair: *Giancarlo Bigi*

1 - Split and conquer!
Francisco Javier Aragón Artacho

When an optimization problem is structured, it is normally advantageous to use this feature when designing algorithms to solve it. Following the divide-and-conquer paradigm, splitting algorithms iteratively solve simpler problems that are defined by separately using some parts of the original problem. In this talk, we will recall some classical methods and present some recent advances in this subject, such as splitting methods devised by graphs, algorithms in nonconvex settings, and even some heuristics. These methods have relevant real-world applications in different areas, including some problems in data science.

■ MA-03

Monday, 8:30-10:00 - Room: Esther Simpson 1.01

EDDA 1

Stream: EURO Doctoral Dissertation Award
Award Competition session
Chair: *Marjan van den Akker*

1 - On the Interplay Between Data and Decisions in Discrete Location Problems
Hannah Bakker

The Capacitated Facility Location Problem (CFLP) is a core problem in location science and has been studied from various angles. Yet, key questions remain: Why does the runtime of state-of-the-art MIP solvers differ drastically between seemingly similar problem instances? Why does modeling temporal dynamics in a multi-period setting significantly improve the objective in some cases but is negligible in others? When the model and algorithm are fixed, such differences must stem from the problem data. We propose a novel methodology that characterizes instances by analyzing the degree of interdependence among facility location decisions in well-performing (optimal or near-optimal) solutions. By distinguishing between instances with mostly independent facilities and those with strong interdependencies, we can anticipate and explain differences in algorithm performance and the impact of modeling extensions. It further allows us to partition candidates and customers into regions with high internal interdependence, offering new insights for algorithm design. Our approach combines the use of state-of-the-art MIP solvers on simplified (relaxed or restricted) problem versions with efficient analytics tools. The results demonstrate how advances in computational power not only expand solvability but also open up new perspectives on long-studied problems like the CFLP.

2 - Semilocal Lipschitz Stability in Linear Optimization
Jesús Camacho

In the realm of mathematical programming, particularly optimization, the concept of stability has gained significant importance. When faced with a choice between a perfectly optimal solution that is highly sensitive to small changes in the problem parameters and a slightly suboptimal solution that remains reliable under such variations, practitioners often prefer the latter. This is because real-world problems are often subject to uncertainties and approximations. This work delves into the quantitative stability of solutions to linear optimization problems, a field with theoretical roots dating back to the 1950s. We explore how the set of feasible solutions and the set of optimal solutions change when the parameters defining the problem are altered. Understanding these changes is crucial for assessing the reliability and robustness of our optimization models. We investigate different ways to measure this stability, categorized by the extent of the parameter and solution variations considered. Local stability measures focus on how solutions behave under small changes in the parameters around a specific nominal problem and solution. Semilocal measures examine the variation of the entire solution set when the parameters undergo small perturbations. Finally, global stability measures are concerned with the behavior of solutions across all possible parameter values. These different types of stability can be quantified using associated sharp Lipschitz constants, often referred to as moduli. Our analysis covers various aspects of linear optimization problem stability under different types of perturbations. A significant portion is dedicated to perturbations of the right-hand side (RHS) of the constraints, as well as perturbations of the objective function. For these scenarios, we derive formulas for different stability moduli, often expressed as the maximum of finitely many local stability measures. We also address the more complex case where the left-hand side coefficients of the constraints are subject to change. This is approached using the framework of the "radius theorem," which seeks to determine the smallest perturbation that would cause a certain desirable property (related to stability) to fail. Furthermore, this work explores the connection between monotone operator theory and feasibility problems. By leveraging concepts from convex analysis and monotone operators, we provide new perspectives on analyzing and solving feasibility problems, including finding the smallest perturbation to an inconsistent system to make it feasible. This includes developing procedures to estimate and calculate the distance to feasibility for inconsistent convex inequality systems. In summary, this work provides a comprehensive analysis of the stability of linear optimization problems under various types of perturbations. It offers tools and insights for quantifying this stability through different moduli and explores novel approaches to feasibility problems using concepts from variational analysis and monotone operator theory. The results aim to bridge the gap between theoretical analysis and practical considerations in optimization, enabling a better understanding and management of the sensitivity of optimization solutions to problem variations.

■ MA-08

Monday, 8:30-10:00 - Room: Clarendon SR 2.08

Advances in preference learning methods

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: *Milosz Kadzinski*
Chair: *Salvatore Corrente*

1 - Advancing Value-Based Preference Learning through Neural Network Architectures and Transfer Learning
Michał Fredrych, Milosz Kadzinski

We introduce novel methods in value-based preference learning, extending traditional decision-aiding models within deep learning frameworks. This enhances robustness, interpretability, and adaptability while addressing inconsistencies inherent in preference data. Additionally, we explore transfer learning to improve model performance across diverse decision contexts.

Our primary contribution is a neural network-based reinterpretation of the UTADIS method, incorporating granular function layers to model both monotonic and non-monotonic utility functions. This architecture improves flexibility and robustness while preserving explainability in multi-criteria decision-making.

The study systematically applies transfer learning within the neural network framework, using techniques such as parameter fine-tuning

and characteristic point reconstruction. For comparison, similar transfer techniques are applied to mathematical programming models, enabling an evaluation of their effectiveness. While the focus remains on the neural model, the benchmark analysis provides insights into the trade-offs between structured optimization and deep learning.

Experimental results indicate that the proposed neural model performs comparably to traditional UTADIS while offering advantages in handling complex decision structures. Its ability to integrate transfer learning highlights its potential for scalable and interpretable decision support, advancing explainable AI in decision-aiding.

2 - Preference learning augmented by graph structure for multiple criteria sorting with varying interactions
Zhen Zhang, Yuan Gao

Data-driven preference learning has emerged as a trend in supporting multiple criteria sorting problems, extending the traditional multiple criteria decision aiding methods to elicit complex preferences, such as capturing interaction effects between criteria. However, most existing studies fail to capture complex dependencies among criteria, especially when criteria interactions may vary with criteria performance. This study proposes a novel preference learning model augmented by graph structure, which enhances the value-driven threshold-based sorting procedure within a neural network framework, aiming to model varying criteria interactions. The preference model considers both the main effects of individual criteria and the interaction effects of pairwise criteria. Specifically, the additive value function is used to evaluate the main effects of individual criteria by aggregating marginal value functions obtained through piecewise linear approximation on individual criteria. Detection and attention mechanisms within the graph structure are further designed to detect and quantify varying criteria interactions that are beneficial for predicting sorting outcomes. To conduct the sorting procedure, the preference model and ordinal class thresholds are learned using a threshold-based loss function. Numerical experiments on real-world and synthetic data sets are conducted to validate the performance of the proposed preference learning model.

3 - Federated deep preference learning for Multiple Criteria Decision Aiding
Krzysztof Martyn, Milosz Kadzinski

In this study, we propose novel approaches for developing collaborative decision models that involve multiple decision-makers. Each of them possesses private alternatives and preference information that they either cannot or prefer not to share. Consequently, local models are trained using these private datasets and are never exchanged between decision-makers. Instead, only model-related information and learning parameters are transmitted during training to a central coordinator, who then constructs a comprehensive model subsequently evaluated by all decision-makers. The proposed framework has been validated using neural network-based UTADIS and outranking methods applied to the threshold-based sorting problem, which employs holistic preference information to assign alternatives to classes. We explore various strategies for developing a shared decision-making approach, balancing different levels of data security with the time required to reach a consensus. Extensive experiments on large datasets demonstrate that our approach effectively preserves privacy while facilitating collaboration, thereby offering a viable solution for real-world decision-making scenarios.

4 - A multi-criteria group decision making and consensus reaching webtool for synchronous deliberations using 2-tuple TOPSIS
Konstantinos Koasidis, Anastasios Soursos, Georgios Xexakis, Álvaro Labella, Anastasios Karamaneas, Alexandros Nikas

Stakeholder engagement facilitation in research projects typically relies on qualitative frameworks or simplified quantitative approaches such as surveys, rendering elicitation of tangible and actionable outcomes challenging. Although group decision making can leverage the capacity of multi-criteria decision aid to address this gap, software solutions implementing such processes in real-life remain scarce. In this research, we present a group decision making and consensus reaching stakeholder elicitation webtool that can be used live in workshops to facilitate synchronous deliberations. The tool relies on easily comprehensible linguistic variables and employs the 2-tuple TOPSIS group decision making method to prioritise alternatives. It also introduces an algorithm that fleshes out differences among the voting patterns of different groups of voters and calculates a consensus metric to shed light on conflicts among participating stakeholders. Through targeted tips and suggestions provided live within the software and based on multiple rounds of stakeholder voting supported by discussions during the workshop, the tool can improve consensus and help synthesise multiple perspectives in the produced outcomes, assisting towards bridging the conflicts and producing widely accepted solutions. We validate the functionalities of the webtool in advancing stakeholder dialogue, in use cases in sustainability research aimed at prioritising climate solutions and interventions.

■ MA-09

Monday, 8:30-10:00 - Room: Clarendon SR 2.01

Innovation in Insurance and Financial Risk Management

Stream: OR in Finance and Insurance
Invited session
Chair: Fabio Baione

1 - Life-cycle consumption, investment, and housing decisions under subjective survival beliefs with deferred annuities and home equity release
Chul Jang, Seung Yeon Jeong, Iqbal Owadally

We examine life-cycle consumption, investment, and housing decisions when a risk-averse individual holds subjective survival beliefs. Younger individuals often exhibit pessimistic survival beliefs, whereas older individuals tend to be more optimistic. Numerical analysis using multistage stochastic programming shows that the subjective survival beliefs can lead young individuals to save less, invest less in equity, and prefer renting to ownership for housing. This results in lower wealth accumulation over their lifetime and reduced consumption in retirement. We also investigate how the decisions change when deferred annuities and home equity release are available as retirement income sources. Availability of these products can lead individuals with subjective beliefs to reduce consumption in early ages, increase housing ownership, and improve wealth accumulation over their lifetime. Overall, these products narrow the welfare gap between individuals with subjective and objective survival beliefs across different ages.

2 - Volatility Modelling of Climate Benchmarks: A Long-Short Term Memory Network Approach
Salvatore Scognamiglio, Francesca Battaglia

In recent years, the growing importance of climate benchmarks in sustainable finance has highlighted the need for robust and accurate volatility modeling of these indices. Traditional econometric methods often struggle to capture the complex, nonlinear, and dynamic behavior of climate-related financial data. This paper proposes a novel approach using Long-Short Term Memory (LSTM) networks, a class of recurrent neural networks well-suited for time series prediction, to model and forecast the volatility of climate benchmarks. We train the LSTM model on historical climate index data, capturing both short-term fluctuations and long-term dependencies. The model's performance is evaluated against conventional models, such as GARCH and stochastic volatility models, demonstrating superior predictive accuracy and adaptability to regime shifts and extreme events. Our findings suggest that LSTM networks offer a powerful tool for investors and policymakers to assess climate-related financial risks, enhancing decision-making processes in sustainable finance. Numerical experiments performed on some climate benchmarks validate the proposed approach.

3 - Shapley risk sharing in peer-to-peer insurance
Susanna Levantesi, Gian Paolo Clemente, Gabriella Piscopo

Peer-to-peer (P2P) insurance is an innovative model that leverages digital technology to connect individuals with similar insurance needs, creating a pool to share risks. This paper introduces a P2P insurance model in which participants pay an ex-ante contribution determined by the Shapley value, with Value-at-Risk of the aggregated claim amount used as the risk measure. We also evaluate the Tail Value-at-Risk as an alternative risk measure. Based on common assumptions in non-life insurance regarding the aggregate claim amount, we derive closed-form solutions for the Shapley value. The model includes a cashback mechanism that ensures that all participants contribute equally to covering realized losses. We apply the model numerically to a portfolio of motor third-party liability policies to illustrate its practical implementation.

4 - Integrating energy-related risks in Bitcoin's price
Rosella Castellano

Bitcoin, the world's leading cryptocurrency, exhibits substantial return volatility and an energy-intensive mining process, raising concerns about energy costs, sustainability, and environmental policies among investors and policymakers. This study explores the interactions between Bitcoin price dynamics, energy prices, and network metrics through a hybrid approach combining GARCH(1,1) econometric modeling and advanced machine learning techniques like Random Forest and XGBoost. Using a comprehensive dataset of Bitcoin log returns, energy prices, and network activity, the analysis highlights the critical role of temporal aggregation. Shorter aggregation periods fail to capture meaningful relationships due to the mismatch between daily energy prices and miners' fixed monthly rates. Conversely, monthly aggregations reveal robust medium-term dependencies, with energy prices and network hash rate emerging as key drivers of Bitcoin volatility. Explainability tools such as Shapley values and partial dependence plots allow us to explore the role of energy consumption and costs in shaping Bitcoin's market dynamics and emphasize the nonlinear response of volatility to energy price fluctuations, providing a deeper understanding of energy-related risks in the cryptocurrency market. This work helps regulators and stakeholders understand the level of integration of cryptocurrency markets within the global financial system.

■ MA-10

Monday, 8:30-10:00 - Room: Clarendon SR 1.06

Timetabling

Stream: Automated Timetabling
Invited session
Chair: *Sanja Petrovic*

1 - A Scenario-Based Optimization Approach for Long-Term Railway Capacity Planning: Tracing Shifting Bottlenecks
Chimeta Mulambia, Gemma Nicholson

Railway capacity is a fundamental metric for evaluating how efficiently a network can accommodate current and future transport demand. Traditional capacity assessment methods often rely on detailed timetable overlays on existing infrastructure models. While effective for short-term operational analysis, these methods face significant challenges in long-term strategic planning (5-30 years) due to uncertainties in future timetables, evolving demand, and technological advancements. The reliance on static timetables limits the ability to anticipate network bottlenecks under future operational scenarios.

This study presents a scenario-based optimization approach for tracing shifting bottlenecks in railway networks without requiring predefined timetables. We employ a Macro-Mesoscopic Infrastructure Track Model combined with demand scenarios and train service specifications to simulate long-term changes in network topology. The methodology integrates network modifications, including station expansions, track reconfigurations, and rolling stock evolution. Using Gurobi-based optimization, we analyze capacity utilization (both practical and residual) and assess network robustness under varying operational conditions.

The proposed approach enhances railway capacity planning by providing a computational decision-support framework for long-term investment and policy decisions.

2 - Multi-Objective Railway Timetabling: A Comparison of Weighted Sum and Augmented Chebyshev
George Brooks

British railways have experienced significant changes to passenger behaviours following the Covid-19 pandemic, with a decrease in commuter traffic and an increase in leisure travel. This has led to challenges in how an efficient timetable is devised and managed, often tackling multiple conflicting objectives. The most common approach for solving multiple-objective problems for an integer linear program is to use a weighted sum of the objectives, which is computationally fast and well suited to problems where the Pareto front is known to be convex. One key issue with weighted sum is that it is known not to be able to distinguish weakly dominated solutions, and therefore it is not possible to locate all solutions in a non-convex front. Other approaches such as augmented Chebyshev can discover these solutions while maintaining comparable performance in convex problems. In our work, we created a macroscopic representation of rail networks with competing objectives to test the performance of both weighted sum and augmented Chebyshev for multi-objective timetabling. We compare the number of solutions found, produced hypervolumes, and time complexity to analyse the benefit of moving from one approach to the other. We are currently working on incorporating demand in our framework and timetable symmetry, which are desirable features to both Train operating companies and passengers.

3 - Scheduling EURO Conference Leeds 2025
Thomas Stidsen

The EURO series of conferences is the second largest OR conference in the world, only dwarfed by the INFORMS (US) conferences. Given the size of the EURO conferences, the centralized scheduling only makes an overall schedule of the assignment of sessions for streams, to time-slots and rooms. A stream is an overall theme of research, with one or two assigned stream organizers. When an article is submitted, it is either submitted to a specific stream or assigned by the program chair to the most appropriate stream. Each stream is allocated a number of sessions, corresponding to the number of submissions divided by 4 rounded up. For each stream, a number of patterns are generated, specifying consecutive sessions. The variables in the Mixed Integer Program are then the the binary variables, selecting the best set of patterns, one for each stream and allocating this to a room. The objective is to avoid overlap of similar streams, ensure enough seats and make sure that streams in the same areas are located close to each other. Since the actual planning is not yet finalized at the time of abstract submission, we expect more objectives and constraints to be added, and these will also be presented. The final schedule will be developed at the EURO committee meeting in Leeds 24/4 and 25/4 2025.

■ MA-11

Monday, 8:30-10:00 - Room: Clarendon SR 1.03

Kidney Exchange

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Rachael Colley*
Chair: *David Manlove*

1 - Complexity and Manipulation of International Kidney Exchange Programs with Country-Specific Parameters
Rachael Colley, David Manlove, Daniel Paulusma, Mengxiao Zhang

Kidney Exchange Programs (KEPs) facilitate the exchange of kidneys, and larger pools of recipient-donor pairs tend to yield proportionally more transplants, leading to the proposal of international KEPs (IKEPs). However, as studied by Mincu et al. (2021), practical limitations must be considered in IKEPs to ensure that countries remain willing to participate. Thus, in this talk, we present IKEPs with country-specific parameters, represented by a tuple Γ, restricting the selected transplants to be feasible for the countries to conduct, e.g., imposing an upper limit on the number of consecutive exchanges within a country's borders. We present a complete complexity dichotomy for the problem of finding a feasible (according to the constraints given by Γ) cycle packing with the maximum number of transplants for every possible Γ. Following this, we explain the potential for countries to misreport their parameters to increase their allocation. As manipulation can harm the total number of transplants, we introduce a novel individually rational and incentive compatible mechanism M-order. We first give a theoretical approximation ratio for M-order in terms of the number of transplants and then show that the approximation ratio of M-order is asymptotically optimal. We then use simulations to demonstrate that, in practice, the performance of M-order is significantly better than this worst-case ratio.

2 - A Branch-Price-and-Cut Algorithm for the Kidney Exchange Problem
Maxime Ogier, Claudia Archetti, Diego Cattaruzza, Matteo Petris, Frédéric Semet

We study a Kidney Exchange Problem (KEP) with altruistic donors and incompatible patient-donor pairs. Kidney exchanges can be modelled in a directed graph as circuits starting and ending in an incompatible pair or as paths starting at an altruistic donor. For medical reasons, circuits and paths are of limited length and are associated with a medical benefit to perform the transplants. The aim of the KEP is to determine a set of disjoint kidney exchanges of maximal medical benefit or maximal cardinality.

We consider a set packing formulation for the KEP with exponentially-many variables associated with circuits and paths, and develop a Branch-Price-and-Cut algorithm (BPC) to solve it. We decompose the pricing problem into a subproblem to price out the path variables and several subproblems to price out the circuit variables. We strengthen the linear relaxation via the inclusion of a family of non-robust inequalities.

We perform extensive computational experiments to assess the performances of the BPC algorithm on three sets of instances from the literature and on a newly generated set of challenging instances. On the easiest instances, it yields comparable results with the literature, while on the other sets it clearly outperforms the previous results. Hence, contrary to the existing literature, the BPC algorithm is the only exact approach able to effectively solve various and difficult instances with both objective functions and long chains and cycles.

3 - Dynamic simulation of KEPs: statistics, tools, and visualisations
William Pettersson, Rachael Colley, David Manlove, Matthew Robb

Kidney exchange programmes (KEPs) allow patients requiring a kidney transplant, and with a willing but incompatible donor, to exchange their donor with another pair in a similar situation so that both patients can recieve a kidney transplant. By using OR techniques, a KEP can gather hundreds of such pairs, find an optimal set of such exchanges, and facilitate the corresponding transplants, improving patient outcomes and reducing medical costs. However, it is not always clear what should define an "optimal set of exchanges". In this talk we show how dynamic simulation can showcase various different criteria for optimality. This talk will include detailing what statistics were necessary to generate the scenarios tested, a description of OR techniques used to improve the speed of the simulations, and also a demonstration of visualisation tools used to present the results to decision-makers.

4 - Computing Balanced Solutions for International Kidney Exchange Schemes
Xin Ye, Márton Benedek, Péter Biró, Gergely Csáji, Matthew Johnson, Daniel Paulusma

In a kidney exchange programme (KEP), patients may swap their incompatible donors leading to cycles of kidney transplants. Nowadays, to improve the total social welfare, countries may try to merge their national patient-donor pools leading to an international kidney exchange program (IKEP). To ensure fairness for participating countries in the long term while maximizing the total number of transplants, IKEPs may use a credit-based system. Such a system prescribes, in each round, a target number of kidney transplants for each country, which is determined by an initial "fair" allocation and adjusted by credits. The goal is to find, in each round, an optimal solution for the participating countries that closely approximates the target allocation. We perform large-scale simulations for IKEPs with maximum cycle lengths 2, 3 and unbounded, respectively. To obtain the initial allocations, we use six different solution concepts from cooperative game theory. In this way we are able to give a clear picture on how the stability and total social welfare of an IKEP is affected by the choice of solution concept and the maximum cycle length. This is joint work with Márton Benedek, Péter Biró, Gergely Csáji, Matthew Johnson and Daniel Paulusma.

■ MA-12

Monday, 8:30-10:00 - Room: Clarendon SR 1.02

Mathematical Programming in Project Scheduling

Stream: Scheduling and Project Management
Invited session
Chair: Norbert Trautmann
Chair: *Nicklas Klein*

1 - Several Dantzig-Wolfe reformulations for solving an integrated project and personnel scheduling problem
Brede Sørøy, Henrik Andersson, Anders N. Gullhav

We consider an integrated project and personnel scheduling problem with resource transportation for a construction company. It consists of one or more projects, all of which have preemptive and multi-modal activities that require both multi-skilled personnel and transportable equipment to be completed. Moreover, there are precedence relations between the activities that must be respected in the schedule.

As solving the problem in an integrated manner is demanding, we propose three different Dantzig-Wolfe reformulations. The first reformulation schedules the personnel and equipment allocation in the master problem, and the projects are scheduled in separate subproblems as there is no dependency between the projects. In addition to having the projects in subproblems, the second reformulation also includes the allocation of equipment in separate subproblems based on equipment types. Finally, the third reformulation extends the latter by adding a subproblem for personnel. We investigate the performance of these three reformulations to assess how much better their bounds are compared to our original formulation of the problem.

Preliminary results indicate that the proposed reformulations achieve tighter bounds in the LP relaxation of the problem. However, more research is necessary to make the process more efficient compared to running the original formulation in a commercial solver.

2 - A combinatorial Benders decomposition approach for a scheduling problem arising in a sports institution
Javier Marenco, Ivo Koch, Luciana Skakovsky

In this work we consider the following scheduling problem. We are given a set of tasks, a set of employees, and a set of days. Each task has a priority, a length in hours, and a number of needed employees who must be scheduled to perform the task simultaneously. We also have a compatibility matrix between tasks and employees, specifying which employees can perform each task. The problem consists in determining which tasks are to be scheduled and determining a day, a starting time, and a set of employees for each scheduled task in such a way that (a) no employee performs two tasks at the same time, (b) task constraints are obeyed, and (c) the total priority of the scheduled tasks is optimized. We present a computational approach for this problem based on the combinatorial Benders decomposition. We show that this approach is effective, outperforming a commercial integer programming solver over a natural formulation for real instances coming from a sports institution. As part of this decomposition, we consider the problem of explaining the compatibility task-employee matrix in terms of skills. We seek to assign a minimum-sized set of skills to tasks and employees, in such a way that an employee is compatible with a task if and only if the skills set of the employee is included in the skills set of the task. The resulting explanation of the compatibility matrix is used as a means to strengthening the primary subproblem in the combinatorial Benders decomposition described above.

3 - Integer programming for multi-mode resource-constrained project scheduling
Nicklas Klein

Projects typically consist of activities that require time and scarce resources for execution. In many projects, there are trade-offs between the resource requirements and activity durations that can be represented via multiple execution modes of the activities. The multi-mode resource-constrained project scheduling problem (MRCPSP) comprises determining the start times and execution modes of all project activities in order to minimize the project completion time while respecting precedence relations and availabilities of renewable and nonrenewable resources. We analyze several mixed-integer linear programming (MILP) models for the MRCPSP, which are based on models for the single-mode resource-constrained project scheduling problem (RCPSP). We first analyze the LP relaxations of the models and identify a trade-off between the objective function value of the relaxation and the CPU time required to solve it. We then compare the computational performance of the models on benchmark instances. Our results indicate that a novel continuous-time model outperforms the state-of-the-art models on relatively large problem instances, while it is competitive on smaller problem instances.

4 - A Two-Stage Approach for Workload-Balanced Scheduling of Resource-Constrained Projects
Loris Trotter, Nina Ackermann, Tamara Bigler, Norbert Trautmann

In project management, the determination of an appropriate schedule for the project is a pivotal task. To reduce the project's time to market, project scheduling models often aim to minimize the project duration while considering scarce resources and precedence relations among the project's activities. Project resources typically comprise specialized teams, for which ensuring a balanced workload is essential to maintain team productivity and cohesion. Therefore, in addition to minimizing the project duration, we consider a balanced workload as an additional criterion in project scheduling. In contrast to other areas of operations research, such as machine scheduling, workload balancing has not been extensively discussed in the literature on project scheduling. We present a novel two-stage successive goal programming approach, which minimizes the project duration in the first stage and optimizes the workload balance in the second stage. An experimental computational analysis indicates that with the novel approach, the workload balance in project schedules can be improved considerably without increasing the project duration.

■ MA-15

Monday, 8:30-10:00 - Room: Esther Simpson 1.08

Applications to Logistics and Supply Chain Management

Stream: Combinatorial Optimization
Invited session
Chair: Francisco Saldanha-da-Gama

1 - Joint optimization of assembly line and on-site renewable energy implementation under uncertainty
Yuchen Li

Utilizing the on-site renewable energy (RE) resource (e.g.,photovoltaic (PV) and wind power (WP)) is one of the significant strategies among the initiatives that address the challenges of decarbonization. For example, Ford announced that the existing 4.64MWh per year solar installation at its Almussafes plant in Valencia, Spain, would be augmented by a further 3.76MWh per year.

In this paper, we aim to provide a decision framework for a manufacturer's energy plan and production scheduling for its production system, namely, assembly line (AL) system. The decisions are to find the number of renewable energy apparatus (wind and solar), assign robots and tasks to the workstations. The objectives are the cycle time, total carbon footprint, the total cost. Given the output of each renewable energy apparatus is uncertain, the problem is formulated mathematically. A customized deep Q-learning algorithm (DQA) , which features an experiment replay and a fixed-Q target treatment, is proposed to solve the problem. A real-life case study concerning engine production is conducted and some management insights are obtained.

2 - The latency location-or-routing problem
Alan Osorio-Mora, Eduardo Álvarez-Miranda, Francisco Saldanha-da-Gama

The latency location-or-routing problem (LloRP) is a variant of the location-or-routing problem (LoRP) and an extension of the latency location routing problem (LLRP). The LLoRP consists of selecting a set of depots to open to serve a set of customers. The latter can be served as part of routes also to be decided. Nevertheless, direct allocation service is allowed for customers lying within a certain coverage range from an open depot. A set of homogeneous capacitated vehicles is available. The goal of the problem is to minimize the latency, i.e., the sum of the waiting times of the customers. Two mixed-integer-linear-programming formulations are developed for the problem. Extensive computational experiments are conducted over instances with up to 100 customers. The impact over the waiting times of the customers from considering a hybrid transportation system (vehicles and direct allocation) instead of a vehicle-based one (LLRP) is highlighted. The tradeoff between latency and two design parameters related to the coverage range and direct allocation, is analyzed. Furthermore, the effect that the maximum number of depots to open and the capacity of the vehicles has on the latency and on the structure of the solutions is analyzed. Finally, a tradeoff between LLoRP and LoRP is considered within a bi-objective modeling framework that is tackled using the e-constrained method. The structural differences between the optimal solutions of both problems are analyzed.

3 - The clustered multimode set covering problem
Andrea Mancuso, Antonio Manuel Rodriguez-Chia, Francisco Saldanha-da-Gama, Claudio Sterle

Covering problems optimize facility placement to serve demand points while minimizing costs or maximizing coverage. Classical models, such as the set covering (SCP) and maximal covering location problems, achieve this by either minimizing the number of facilities required to cover all demand points or maximizing coverage with a fixed number of facilities. However, they usually assume a single facility type, which overlooks real-world scenarios where individuals require access to multiple services. In these cases, multiple facility types may compete for locations, preventing the problem from decomposing into independent subproblems. Moreover, ensuring proximity to facilities

of each type may be insufficient, as individuals often visit several facilities on a single trip. Thus, facilities should also be located to accommodate multi-purpose trips. To address this challenge, we introduce the clustered multimode set covering problem, an extension of the SCP that ensures coverage by multiple facility types while promoting spatial clustering. Specifically, we propose an ILP formulation that forms clusters composed of different facility types, allowing each facility to belong to multiple clusters. By using cluster compactness as a proxy for routing, our approach optimizes facility placement and travel efficiency. Additionally, we develop a branch-and-cut algorithm to solve large scale instances. Experimental results demonstrate the effectiveness of our method in real-world settings.

4 - Time-dependent decisions in hub location and routing
Francisco Saldanha-da-Gama, Afaf Aloullal, Raca Todosijevic

This paper investigates the relevance of time-dependent decisions in hub-location routing problems. A multi-period planning horizon is considered during which the system is to be phased in. In addition to hub location, hub network decisions are also considered. The origin-destination flows are assumed to be time-dependent as well as the costs underlying the problem which include, setup costs for hubs and hub edges and variable operational costs at the hubs. An optimization model is discussed for the problem. For small instances, it can be solved up to proven optimality using a general-purpose solver. For larger instances, a four-phase matheuristic combining principles of relax-and-fix, variable neighborhood descent and local branching schemes is proposed. Two variants of the algorithm are discussed. The model and proposed procedure are tested using data generated by extending existing hub location instances to our problem. The results are analyzed. The major conclusion to draw is that by capturing time in the decision-making process, one may find solutions that better hedge against parameter changes throughout time. Furthermore, the overall procedure presented in this paper is quite general in the sense that it can be easily adapted to other multi-period decision making problems and different objective functions.

■ MA-17

Monday, 8:30-10:00 - Room: Esther Simpson 2.08

Combinatorial bilevel optimization 1

Stream: Combinatorial Optimization
Invited session
Chair: *Ivana Ljubic*

1 - Unboundedness in Bilevel Optimization
Bárbara Rodrigues, Margarida Carvalho, Miguel Anjos, Nagisa Sugishita

Bilevel optimization has garnered growing interest over the past decade. However, little attention has been paid to detecting and dealing with unboundedness in these problems, with most research assuming a bounded high-point relaxation. In this presentation, we address unboundedness in bilevel and multilevel optimization by studying its computational complexity. We show that deciding whether an optimistic linear bilevel problem is unbounded is strongly NP-complete, even without linking constraints. Furthermore, we extend the hardness result to the linear multilevel case, by showing that for each extra level added, the decision problem of checking unboundedness moves up a level in the polynomial hierarchy. Deciding unboundedness of a mixed-integer multilevel problem is shown to be one level higher in the polynomial complexity hierarchy than the decision problem for linear multilevel problem with the same number of levels. Finally, we introduce two algorithmic approaches to determine whether a linear bilevel problem is unbounded and, if so, return a certificate of unboundedness. This certificate consists of a direction of unboundedness and corresponding bilevel feasible point. We present a brief computational comparison of these algorithmic approaches.

2 - Solving Multi-Follower Mixed-Integer Bilevel Problems with Binary Linking Variables
Vladimir Stadnichuk, Arie Koster

We study multi-follower bilevel optimization problems with binary linking variables, where the second level consists of multiple independent integer-constrained subproblems. To solve these efficiently, we propose a novel branch-and-cut decomposition method that begins by solving the first-level problem and iteratively generates second-level feasibility and optimality cuts. These cuts are derived by solving a modified version of the second-level problem. Unlike many existing methods, our approach does not rely on solving the high-point relaxation of the bilevel problem. Instead, we fully project out the second level, providing significant computational advantages, particularly when the second-level problem is large or has a weak LP relaxation. Additionally, our method can be fully automated within a MIP solver, making it accessible to users who do not wish to design problem-specific algorithms. Our computational results demonstrate that our approach efficiently solves instances with hundreds of subproblems within minutes, significantly outperforming Benders-like decomposition methods from the literature on challenging instances.

3 - Exact and Heuristic Methods for Gamma-Robust Mixed-Integer Linear Min-Max Problems
Yasmine Beck, Ivana Ljubic, Martin Schmidt

Due to their nested structure, bilevel problems are intrinsically hard to solve—even if all variables are continuous and all parameters of the problem are exactly known. In this talk, we study mixed-integer linear min-max problems with a binary lower level and a Gamma-robust treatment of lower-level objective uncertainty. We present an exact branch-and-cut approach to solve these Gamma-robust min-max problems, along with cuts tailored to the important class of monotone interdiction problems. Given the overall hardness of the considered problems, we additionally present a heuristic approach. The latter relies on solving a linear number of deterministic min-max problems so that no problem-specific tailoring is required. The performance of our approaches is assessed in an extensive computational study on instances of the Gamma-robust knapsack interdiction problem. Our results show that the heuristic closes the optimality gap for a significant portion of the considered instances and that it often practically outperforms both heuristic and exact benchmark approaches. In particular, we report considerable speed-up factors when compared to our problem-tailored and exact branch-and-cut approach, while also solving more instances to global optimality.

■ MA-18

Monday, 8:30-10:00 - Room: Esther Simpson 2.09

OR for Sustainable Development I

Stream: OR for Sustainable Development
Invited session
Chair: *Sarfaraz Hashemkhani Zolfani*

1 - Optimizing Human-Centric Robot Collaboration in Manual Assembly Lines for Industry 5.0.
Rhitankar Saha Roy, Mahdi Bashiri, Benny Tjahjono

Over the last few years assembly line operations have become more complex due to product variation, order mix, volatile demand and the need for fast and error-free productivity while simultaneously trying to achieve the UN 2030 Sustainability Goals. Although human operators continue to be considered as a valuable and irreplaceable resource, collaborative robots are increasingly becoming more prevalent in the age of Industry 5.0 leading to a growing need to research ways to improve interactions and collaboration between robots and humans. This study focuses on optimizing human-robot collaboration (HRC) for assembly line manufacturing using a real-world case study. In this study a multi-criteria decision-making model (MCDM) is first used to obtain sustainability scores for each resource type. The score is then further

utilized in the mathematical model for resource allocation at each level of Human Robot Interaction (HRI). Finally, different resource allocation mathematical models are developed to minimize cycle time, reduce total cost, maximize Rosenberg's scale of esteem and maximize sustainability score for the four levels of HRI - traditional, coexistence, cooperation and collaboration. To solve the problem, pre-processed algorithms were developed, followed by solving the model using an exact solver (GUROBI optimization). The results offer a new framework and insight for human robot resource allocation to perform tasks in parallel or in collaboration.

2 - Waiting time reduction of re-processed e-waste at maker-spaces
Sheeba Pathak

Minimising time is a key factor in ensuring speedy results leading to customer satisfaction. In the case of e-waste, the CReW concept proposed the addition of maker-spaces for e-waste dis-assembly, segregation and initial repairs and maintenance. Innovations are also expected to be undertaken here to create new products. For these, customers should not have to wait long and thus this work explores queueing theory as an Operations Research method to ensure a lean supply chain with satisfied customers.

3 - A Strategic Approach to Energy Cost Minimization through Multi-Objective Decision-Making
Tanushree Pan, Ravi Kumar

Modern technology installed in residential buildings is driving up electricity consumption and giving rise to the idea of "Smart Buildings". A significant barrier to sustainability is the enormous quantities of energy we use on a daily basis, especially electrical power. However, the huge consumption of energy, especially in the building sector, is a major contributor to global greenhouse gas and carbon emissions, which are expected to rise by 50% by 2040. To decrease the impact of carbon, both academicians and business organizations face significant challenges while preserving operational effectiveness. The majority of research has been done to minimize energy use in order to lower direct emissions. Nevertheless, as such, no study has looked into both direct and indirect emissions, and this study will take both emissions into account. The goal of this study is to develop a Multi-Objective Mixed-Binary Linear programming model capable of optimizing a smart building's cost and energy usage while taking direct and indirect emissions into account. The suggested methods explore the best way of finding a balance between conflicting goals, including lowering prices and energy use at the same time. The model guarantees that, given various constraints, objectives are satisfied to the greatest extent possible by interacting with the Goal Programming approach. We analyze a smart building composed of multiple units, each exhibiting unique energy consumption patterns. The building integrates solar panels, a battery energy storage system, an electric vehicle with charging stations, and advanced energy management systems to optimize efficiency and sustainability.

4 - Evaluating the Technical and Economic Performance of Legume-Rich, Low-Pesticide Farming Systems: insights from French DEPHY Farms
Salomé Kahindo, Jean-philippe Boussemart, Romain Escassut-nandillon, Maé Guinet, Nicolas Munier-jolain, Raluca Parvulescu

Crop diversification is widely recognized as an effective strategy to address food security and environmental challenges in modern agriculture. This study evaluates the technical and economic performance of diversified cropping systems incorporating legumes, which enrich the soil by fixing atmospheric nitrogen, reducing reliance on fertilizers and pesticides. We compare three strategies: maximizing plant protein production, minimizing pesticide use, and optimizing profit margins. Using a non-parametric FDH efficiency frontier, we assess the potential expansion of legumes in a dataset issued from the DEPHY network comprising 699 cropping systems across France, categorized by production type and soil water retention. A spatial constraint (75 km) ensures meaningful efficiency comparisons. First, we evaluate each strategy's potential by identifying best practices. Results show that only protein maximization and pesticide minimization foster diversification, while profit maximization does not (legume production increases by 44.7% in the first two scenarios, compared to only 3.8% under profit maximization), as legume prices remain too low. To address this, we simulate legume price increases (5%-200%) to determine the threshold at which legumes become economically viable. Price simulations suggest that an 85% price increase (EUR 1.45/kg protein) would enable diversification levels comparable to the other two strategies. This shift would also reduce pesticide and fertilizer use, amplifying environmental benefits. Our findings highlight the need for market-oriented policies to enhance legume profitability and incentivize their adoption.

■ MA-21

Monday, 8:30-10:00 - Room: Esther Simpson 2.12

Packing with practical constraints

Stream: Cutting and packing (ESICUP)
Invited session
Chair: David Álvarez-Martínez

1 - A multi-objective evolutionary model for the generalised bin packing problem
Rosephine Georgina Rakotonirainy, Andrea Plumbley

This study investigates the multi-objective optimization of the generalized bin packing problem, which involves allocating both compulsory and non-compulsory items into a set of bins. The items possess various characteristics, such as weight, width, height, and due date, while the bins have attributes including capacity and cost. The primary goal of the problem is to minimize the total cost, which is typically achieved by minimizing the number of bins used. In many practical scenarios, however, multiple competing objectives need to be addressed, such as minimizing item lateness or balancing the load across bins. This work proposes a multi-objective evolutionary model for solving the generalized bin packing problem. The proposed model simultaneously optimizes multiple objectives, presenting decision-makers with a Pareto front of trade-off solutions. Two specific objective combinations were considered: cost and item lateness, and cost and load imbalance. The model was tested on both one-dimensional and two-dimensional problem instances, demonstrating its capacity to minimize the relevant objectives while also generating a set of conflicting solutions in certain cases.

2 - Optimization of Packaging and Three Dimensional Package Arrangement Decisions in Shipment Processes in Pharmaceutical Industry
Seray Çakırgil, Eda Yücel

This study focuses on packaging and three-dimensional package arrangement decisions in the shipment process, inspired by a real-world challenge faced by a leading Turkish pharmaceutical company. The problem entails determining the necessity of bundling (shrink-wrapping) for solid, semi-solid, and liquid drug products, optimizing bundle sizes when required, and selecting the most suitable carton size, three-dimensional carton arrangement, pallet size, and three-dimensional pallet arrangement. The primary objective is to minimize operational costs—including packaging material, shipping, and warehouse handling costs—while optimizing warehouse space utilization and reducing carbon emissions. To address this problem, a preprocessing algorithm is developed, followed by a mixed-integer linear programming model. The effectiveness of the proposed solution method is evaluated using real-world data sets.

3 - Optimized Reel Utilization in Make-to-Order Production by 3D Printing
Ilayda Celenk, Willem van Jaarsveld

We study a variant of bin packing problem that arises in 3D printing. In particular, this study focuses on 3D printing in a make-to-order production system, where a limited number of slots for fixed-weight pieces of stock materials, called reels, are considered to manufacture components with 3D printers. We assign components to reels for production as the component requests arrive one by one. The aim is to determine an assignment policy that minimizes the average loss on reels in terms of weight, which occurs when the remaining weight on a reel is too low to produce a component and has to be discarded. Due to the online nature of the problem, we formulate it as a Markov Decision Process. We propose an index policy based on analytical insights into the problem. Moreover, we propose to use that index policy as a starting point for applying deep reinforcement learning to the problem, and find that this yields policies that have close-to-optimal loss.

4 - Integrating GRASP and Beam Search for the Container Loading Problem Under Practical Constraints
David Álvarez-Martínez, Francisco Parreño, Germán Fernando Pantoja Beanvides

This study addresses the Container Loading Problem (CLP) by incorporating practical constraints such as valid box orientations, multi-drop loading, load-bearing, and vertical stability into a hybrid algorithm that combines the Greedy Randomized Adaptive Search Procedure (GRASP) with Beam Search. A key innovation of this approach is the use of Static-Mechanical-Equilibrium (SME) equations to model load-bearing and stability. Since SME equations can result in underdetermined systems, this study proposes a novel solution by introducing additional equations that distribute an item's weight based on the contact area of its supporting boxes. This methodology enables partial support and the placement of overhanging items, increasing packing flexibility. Furthermore, a merging-and-expanding procedure for maximal spaces enhances space utilization by reducing redundancy and expanding available packing areas throughout the process. Computational experiments demonstrate that the proposed method performs competitively with state-of-the-art approaches, achieving superior results in certain instances. These findings highlight the effectiveness of integrating SME-based stability modeling, partial support, and space optimization within a GRASP-Beam Search framework to address complex CLP scenarios.

■ MA-24

Monday, 8:30-10:00 - Room: Esther Simpson 3.02

Tutorial: Community OR and Social Value: Empowering Marginalised Communities through Socially Trading Organisations

Stream: Tutorials (and Workshops)
Tutorial session
Chair: Sanne Wøhlk

1 - Community OR and Social Value: Empowering Marginalised Communities through Socially Trading Organisations
Foteini Stavropoulou

Community OR seeks to address complex socio-economic issues faced by socially disadvantaged populations or communities, considering their distinct needs, characteristics and aspirations. These issues often arise due to policy failures at regional or national levels, coupled with insufficient public funding. Community OR application areas include family support services, literacy and education, housing, community and urban planning, as well as humanitarian logistics. Multi-stakeholder and community engagement is key in community OR, ensuring that the voices and needs of marginalised groups are central to problem-defining and solving processes. This tutorial focuses on social value and Socially Trading Organisations (STOs). STOs are a distinct type of organisation whose primary purpose is to benefit their local community and often fill the gap left by retreating public services. Being social, charitable, or community-oriented organisations, STOs rely on volunteers and have limited access to funding. They are expected to demonstrate their social value to access resources. Social value, whilst generally referring to the positive impact or benefit activities have on individuals, communities, or society, remains a contested concept, with multiple definitions. In this session, we will delve into operationalising social value concepts and data requirements. This interactive discussion will encourage knowledge exchange and inspire new research avenues in Community OR for social good.

■ MA-26

Monday, 8:30-10:00 - Room: Maurice Keyworth 1.33

OR In Action: lightning talks for a whirlwind tour of our OR world

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: Jane Parkin
Chair: Ruth Kaufman

1 - 90' of OR in Action: Lightning Talks for a whirlwind tour of our OR world
Ruth Kaufman, Paul Deuker, Jutta Geldermann, Anna Nagurney, Alena Otto, Slawomir Pietrasz, Abimbola Falodu, Craig Poku, Meltem Sanisoğlu, Fredy Troncoso, Samuel Ward, Gary Preece, Marie Baratto, Jiyin Liu

At a conference like EURO, it is impossible to catch up with everything; and all too easy to stick to a single stream within your usual professional specialism. This session showcases some of the breadth of OR in action, with a set of 5-minute presentations handpicked to inspire, interest and extend your knowledge. Speakers include Anna Nagurney on Tariffs, Trade and OR; Jutta Geldermann on emergency response; Gary Preece on biodiversity; Meltem Sanisoğlu on cross-border logistics; and a host of others covering subjects including crop breeding for resilience, addressing biodiversity loss and climate change, speeding up emergency response times, managing district heating systems, using evolutionary AI for job scheduling, and solving the curse of poor data quality. Full details of speakers and abstracts will be found on the 'Making an Impact' page on the main conference website: https://euro2025leeds.uk/making-an-impact/

This is always a hugely popular session at EURO conferences - intense, eye-opening and fun.

Some of the presentations are designed for this session only, others are abbreviated versions of full talks appearing elsewhere in the conference. Kick off your conference with this session, so you can catch up with the speaker later on, and maybe go to see their full talk.

■ MA-28

Monday, 8:30-10:00 - Room: Maurice Keyworth 1.03

Supply Chain and Logistics Management

Stream: Decision Support Systems
Invited session
Chair: Uchitha Jayawickrama
Chair: Abhijit Gosavi

1 - Bridging Theoretical Advancements and Practical Implementation in Data-Driven Supply Chain Management: A review
Hermenegildo Baptista, João Gonçalves, Sameiro Carvalho

Supply Chain Management (SCM) has evolved from a logistical function to a strategic pillar, driven by the need for efficiency, cost reduction, and resilience in complex global networks. As supply chains grow more interconnected, companies face pressure to optimize operations while mitigating disruptions. Data-driven approaches, leveraging advanced analytics, AI, and operations research, have emerged as key tools for enhancing decision-making. However, a significant gap persists between theoretical advancements in SCM analytics and their practical implementation. Previous literature points out that 40% of analytical methods proposed in academia lack real-world application, highlighting discrepancies between theoretical assumptions and practical realities. This study aims to address two objectives: i) analyze the evolution of analytical methods (descriptive, diagnostic, predictive, and prescriptive) in SCM, focusing on their role in data-driven decision-making across industries; ii) identify and categorize limitations hindering their adoption, distinguishing between theoretical and practical challenges. Using a systematic literature review from the Scopus database, the research introduces the SCM-Data analytics Constraints Matrix, a framework organizing limitations from both academia and industry. Future steps include industrial surveys to validate findings and develop a strategic roadmap for mitigating constraints, fostering greater adoption of data-driven methods in SCM

2 - Optimizing parcel locker reservations under uncertain pickup times.
Gijs Bakker

In this project, we study the reservation management system of parcel lockers. Parcel lockers offer a sustainable last-mile delivery solution. Yet, a complicating factor for lockers' utilization rates is the uncertain parcel pickup times. Existing approaches in the literature are constrained by assuming deterministic parcel pickup times, leading to conservative reservation strategies that yield low utilization levels. In our research, we account for the inherent uncertainty of pickup times and propose data-driven policies that relax these constraints without compromising service levels. Through collaboration with European logistics providers, we gain practical insights and develop data-driven policies. Our findings indicate that incorporating the stochastic nature of parcel pickup can substantially enhance locker utilization without compromising service levels.

3 - Enhancing Supply Lead Time Prediction with a Novel Hybrid Machine Learning Approach: Insights from a Retail Case Study
Kezban Mutlu

In supply chain management (SCM), supply lead time (SLT) is a crucial factor influencing inventory management and overall supply chain performance. Conventional methods often struggle to capture the complex, multivariate nature of SLT prediction, limiting their effectiveness in dynamic environments. This study proposes a novel hybrid machine learning approach, integrating supervised and unsupervised techniques to enhance predictive accuracy. Principal Component Analysis (PCA) is employed for dimensionality reduction and feature extraction, while the Gradient Boosted Trees (GBT) algorithm serves as the primary regression model alongside various other machine learning regression techniques. Using historical data from a retail company, the hybrid model achieved a superior predictive accuracy of 93% and a mean absolute error of 1.46 days, outperforming models without PCA transformation. These results demonstrate the efficacy of combining PCA and GBT for improving SLT estimation, providing valuable insights for inventory management and supply chain optimization. The study underscores the potential of advanced machine learning techniques in addressing real-world supply chain challenges and advancing data-driven decision-making processes.

4 - Hybrid Warehousing for Industry 4.0
Abhijit Gosavi, Jacob Nyhagen

In the era of the fourth industrial revolution, also referred to as Industry 4.0, warehouses, where finished products are stored temporarily, are required to swiftly adapt to evolving demand data and to markets that change rapidly. Because of this necessity, warehouses are employing a hybrid storage policy in which some finished products, selected on the basis of high turnover rates, are placed in random storage for a finite period of time before being transferred to a suitable area in the dedicated storage section of the warehouse. An important unresolved problem observed in industries that employ hybrid storage is to determine the amount of dedicated storage space for each product. This problem is commonly observed in many industries; however, there is limited literature on it. First, this work proposes a model for accurately quantifying the amount that needs to be transferred from random to dedicated storage to meet customer demand and ensure smooth flow. This is an integral part of the underlying logistics and the first step towards determining the optimal space. Second, this paper develops two models for determining the dedicated storage area: one model is heuristic and the other is exact and cost-optimal. The models proposed can be incorporated into the logistics of a modern warehouse management system (WMS). Computational examples are provided to illustrate the effectiveness of these models in practice.

■ MA-29

Monday, 8:30-10:00 - Room: Maurice Keyworth 1.04

Machine learning in pricing and revenue management

Stream: Pricing and Revenue Management Innovations
Invited session
Chair: Yue Su

1 - Integrating Predictive and Prescriptive Analytics for Assortment Optimization: A Machine Learning Approach Using Conjoint Data
Niloufar Sadeghi, Siamak Khayyati, Cornelia Schoen

The assortment optimization (AO) problem seeks to determine the optimal product set that maximizes profit while incorporating customer preferences. Traditional methods follow a sequential predict-then-optimize approach, where demand estimation and optimization are performed separately, often leading to suboptimal decisions due to prediction errors. We develop an integrated optimization model that simultaneously estimates parameters of a multinomial logit (MNL) choice model from conjoint data and optimizes the assortment to enhance both profit and empirical fit, measured by maximum likelihood or hit rate. By aligning estimation with decision-making, our approach mitigates the impact of prediction errors on optimization outcomes, leading to more robust decisions. Our formulation results in a mixed-integer linear program for hit-rate maximization and a mixed-integer convex optimization problem for maximum likelihood, both solvable with commercial solvers. For larger instances, we propose heuristic methods for computational efficiency. Our preliminary numerical experiments demonstrate that integration significantly improves assortment decisions, achieving revenue gains of 39.2% (hit rate) and 15.8% (maximum likelihood). We analyze trade-offs between statistical fit, solution quality, and computational complexity, providing insights into when and to what extent integration outperforms traditional methods.

2 - Online Learning for Dynamic Pricing in Consumer Electronics Trade-in Program
Sean Xiang Zhou, Zhuoluo Zhang, Wenhao Li

The electronics trade-in market is large and has experienced rapid growth in recent years, generating significant value for both companies offering trade-in programs and individual consumers seeking to upgrade their used devices at favorable prices or purchase high-quality pre-owned devices. A key operational decision for the firm is setting the "right" upgrade prices for used products and the resale prices for

refurbished products. Due to the lack of prior knowledge of how supply and demand depend on prices, companies need to learn the supply and demand functions while making pricing decisions. In this paper, we consider joint learning and pricing for an electronics trade-in platform that buys and sells multiple types of used products. Both supply and demand functions belong to a general class of parametric family. We propose a Parametric Batched-Adjustment Control (PBC) Policy and analyze its theoretical performance.

3 - From Booking to Service: Adaptive and Learning-Driven Pricing for Hotel Revenue Growth
Aysajan Eziz

Dynamic pricing for hotel rooms involving multi-night stays presents unique challenges due to complex capacity interactions across consecutive nights. Traditional revenue management methods that consider single-night stays fail to capture these intricacies, resulting in suboptimal pricing decisions. This research introduces a dynamic pricing approach specifically designed to address multi-night stay complexities. We propose two innovative and complementary solutions: a stochastic approximation algorithm (SAA), which uses simulation-driven learning to optimize prices without exhaustive enumeration, and a quadratic programming (QP) approximation that aggregates demand for computational efficiency. Our methodology effectively balances practical implementation with theoretical rigor, yielding near-optimal revenue performance. Extensive numerical experiments demonstrate that our SAA solution consistently achieves near-optimal revenue outcomes, significantly outperforms traditional benchmarks, and reduces computational complexity by approximately 90%. This research provides revenue managers practical tools for capturing previously untapped revenue potential in real-time hotel operations.

4 - Learning-based pricing policies for substitutable itineraries
Yue Su, Antoine Désir, Axel Parmentier

In airline revenue management, dynamic pricing for substitutable itineraries presents significant challenges due to the stochastic nature of customer choices. The dynamic pricing problem can be conceptualized as a Markov Decision Process with the objective of maximizing the total expected revenue over a finite selling horizon. However, the complexity of this model, characterized by its multi-dimensional state and action spaces, makes it computationally prohibitive to solve exactly, even for small-to-medium-sized instances. As a result, classic methods such as dynamic programming (DP) prove inefficient in addressing the dynamic pricing problem for larger instances. In this work, we introduce learning-based policies tailored to the dynamic pricing problem of substitute itineraries. We proposed two different machine learning (ML) pipelines to encode pricing policy and designed tailored training processes for each of them. Compared to existing methods, our approach has two advantages:(1) Benchmarking the proposed policies against the optimal pricing policy, we show that learning-based policies seem to be a good approximation for the optimal policy,(2) Our learning-based policies can lead to huge speed-up in solving large-scale instances (with up to million-magnitude state space) by moving all CPU time offline.

■ MA-30

Monday, 8:30-10:00 - Room: Maurice Keyworth 1.05

Lot-sizing models

Stream: Advanced Lot Sizing and Inventory Strategies
Invited session
Chair: Matthieu Gruson

1 - Dynamic lot sizing model with remanufacturing and separate setup costs: Time complexity and optimality
Chee Khian Sim

We introduce the dynamic lot sizing model with remanufacturing and separate setup cost. The novelty of the model is separate setup cost for manufacturing and remanufacturing, unlike other models proposed in the literature. It is claimed in the literature that finding the optimal policy of the model is NP-hard. By formulating the model as a dynamic program, we show that its optimal policy can be found with pseudo polynomial time complexity. We also propose a feasible inventory policy which has polynomial time complexity and which approximates the optimal policy well. Numerical results are finally provided which end the presentation.

2 - Heuristics for the one-warehouse multi-retailer problem
Matthieu Gruson, Félix Houdouin, Marilène Cherkesly

In this work, we address the One Warehouse Multi-Retailer (OWMR) problem. In the OWMR, a central warehouse replenishes multiple retailers that face a dynamic and deterministic demand for a single item over a discrete and finite time horizon. We design several simple yet efficient heuristics to solve the problem. The heuristics we designed are significantly faster than the best-known exact methods, with the most effective among them achieving feasible solutions that typically have costs less than 1% higher than the optimal solution, while being a hundred times faster. Our heuristics leverage the uncapacitated lot sizing and two-level uncapacitated lot sizing algorithms extensively. We introduce heuristics with low polynomial complexity, specifically O(NT2 log(T)) and O(NT log(T)) where N and T denote the number of retailer and time periods, respectively. Additionally, we newly introduce a powerful process to improve any feasible solution in almost-linear time. While most of our heuristics do not have theoretical guarantees on their approximation ratios, we propose a dynamic method to estimate an approximation guarantee using a heuristic to compute a lower bound. This approach typically yields approximation guarantees around 1.4, which is tighter than the current best-known constant-approximation heuristic that has an approximation guarantee of 1.8.

3 - Approximation Algorithms for Lost-sales Inventory Systems with Remanufacturing
Suting Liu, Xiting Gong

In this paper, we develop approximation algorithms for two classes of lost-sales inventory systems with remanufacturing. For pure remanufacturing inventory systems with general replenishment lead times, we develop a modified dual-balancing policy and show that the expected cost under this policy is at most twice the optimal cost under a broad class of associated demand processes and mild conditions on system parameters. For hybrid manufacturing/remanufacturing inventory systems with general identical lead times, we develop a dual-balancing policy and show that the expected cost under this policy is at most four times the optimal cost under similar conditions. When lead time is zero, the expected cost under the dual-balancing policy is at most twice the optimal cost for the general demand and return process. Our numerical study shows that both policies perform well and much better than their theoretical worst-case performance bounds.

4 - A graph-based algorithm for the non-stationary lot-sizing problem with penalty scheme
Xiyuan Ma, Roberto Rossi, Thomas Archibald

We introduce a graph-based algorithm for solving single-item, single-location inventory lot-sizing problems under non-stationary stochastic demand using the (Rt, St) policy and a penalty cost scheme.

The proposed method relaxes the original mixed-integer linear programming model by eliminating non-negative order quantity constraints and formulating it as a shortest-path problem on a weighted directed acyclic graph. A repetitive augmentation procedure is proposed to resolve any infeasibility in the solution. This procedure consists of three stages: (1) filtration, (2) repeated augmentation by redirecting, reconnecting, and duplicating between newly introduced and existing nodes to adjust the graph and eliminate negative replenishment orders, and (3) re-optimising.

The effectiveness and computational efficiency of the proposed approach are assessed through extensive experiments on 1,620 test instances across various demand patterns and parameter settings. The results show that 195 instances required augmentation, mainly those with

high penalty costs, low fixed ordering costs, large demand variability, and extended planning horizons. The efficiency of the algorithm for instances with extended planning horizon scenarios demonstrates its suitability for use in real-world scenarios.

■ MA-31

Monday, 8:30-10:00 - Room: Maurice Keyworth 1.06

Optimization under uncertainty in Scheduling and Supply Chain

Stream: Stochastic and Robust optimization
Invited session
Chair: *Roberto Bargetto*

1 - Horizontal labour sharing in supply chain networks under uncertain prices
Qiongyuan Cao, Thomas Archibald, Aakil Caunhye

Whether in competition or not, firms performing similar activities are increasingly taking advantage of opportunities to share resources to improve performance. The benefits of horizontal collaboration provide incentives for firms to form coalitions to increase overall profitability. The COVID-19 pandemic highlighted the impact of labour shortages on supply chain activities and labour shortages remain an important consideration for planning decisions today due to factors including illness, extreme weather and global conflict. In general, decisions affecting the coordination of supply chain activities are taken under great uncertainty about prices in the final demand markets. In this context, it is interesting to consider which coalitions should form and how to ensure a fair division of a coalition's profits. In this paper, we study horizontal labour sharing under uncertain prices in the supply chain networks of competing firms. We develop a robust optimization model to maximize supply chain profit and use mathematical programming approaches to identify stable coalitions. Our findings provide insights on the stability of coalitions under different profit sharing methods.

2 - A Two-Stage Stochastic Programming Model Integrating Flexibility for Designing a Resilient Supply Chain Network
Francisco J. Tapia-Ubeda, Pablo A. Miranda, Elias Olivares-Benitez

Designing the Supply Chain Network impacts the long-term and may condition the company's performance and competitiveness. Furthermore, the occurrence of disruptive events may compromise the adequate functioning of the entire network. Therefore, designing the Supply Chain Network integrating different aspects related to resilience is crucial for knowing how to operate when a disruptive event occurs and its potential effects. This research is focused on presenting a Two-Stage Inventory Location Problem model incorporating flexibility to obtain a more resilient design of the network. Disruptive events affect warehouse availability during a certain period of time. The strategy considered is based on an assignment of customers to a warehouse for the first stage and each of the potential scenarios. Particularly, all the customers assigned to warehouses that become unavailable must be temporarily reassigned to other available warehouses. Additionally, it is assumed that customers assigned to available warehouses under a specific scenario remain assigned to the same warehouses. A solution approach based on Generalized Benders Decomposition is proposed for solving the proposed model, properly addressing the mathematical complexity of the model. Optimal solutions are obtained in competitive times for the tested synthetic instances of different sizes.

3 - Capacity Planning and Supplier Selection Under Uncertain Contract Fulfillment
Roberto Bargetto, Teodor Gabriel Crainic, Guido Perboli, Walter Rei

The shipping industry has recently transitioned from long-term contracts between shippers and carriers to a more dynamic environment of short-term contracts and spot-market transactions. This shift has been driven by recent global disruptions, such as the pandemic and geopolitical conflicts, which have increased volatility in transportation rates. Nowadays, carrier suppliers offer "contract rates" for planned operations and higher "spot rates" for last-minute deliveries. We study the problem of a shipper planning the cost-effective delivery of orders through a combination of pre-contracted suppliers and additional capacity acquired at spot rates. The shipper's problem is characterized by uncertain decision factors. Knowledge of future orders is limited, carriers may experience mechanical failures, undelivered orders can clog storage centers, and unexpected events can impact transportation prices, increasing the variability of spot rates. The problem is two-stage by definition. In the first stage, the shipper selects suppliers and determines the capacity to secure at contract rates. In the second stage, any shortfall is covered through spot-rate purchases. We model this two-stage capacity planning problem as a variant of the stochastic variable cost and size bin packing problem. We provide its stochastic integer programming formulation, as well as a solution framework based on state-of-the-art optimization techniques.

4 - Robust inventory routing problem under demand uncertainty
Yuqiang Feng, Ada Che

This study investigates the inventory routing problem (IRP) under ambiguous demand distribution. Compared with existing research that assumes the demand distribution is either predefined or lies in an ambiguity set, we adopt a globalized distributionally robust approach. We construct both inner and outer ambiguity sets to describe distributional ambiguity, regardless of whether retailer demand follows a discrete distribution or an unspecified type. This approach ensures performance of the delivery solution is maintained even when the retailer demand distribution extends beyond the inner ambiguity set. Additionally, we introduce more flexible soft constraints, coupled with a budget violation metric, to manage the gaps between actual holding and penalty costs and the budgets of retailers, particularly when demand distribution lies outside the inner ambiguity set. The analysis of our model demonstrates its ability to generalize distributionally robust, robust, or stochastic IRP models through appropriate input settings, and thereby we establish the bounds for the objective values of these models. Numerical studies, based on a real-case scenario, show that the delivery solutions from our proposed models are more effective in mitigating the impact of retailer demand uncertainty and achieve superior out-of-sample performance compared to other benchmark models.

■ MA-32

Monday, 8:30-10:00 - Room: Maurice Keyworth 1.09

Seaside Planning-1

Stream: Maritime and Port Logistics
Invited session
Chair: *Frank Meisel*
Chair: *Rosa G. González-Ramírez*
Chair: *Eduardo Lalla-Ruiz*

1 - Simulating Just-In-Time Arrival with a Rolling Horizon Optimization Model
Rommert Dekker, Reinier van Uden, Rolf Jansen

Improved coordination between shipping lines and terminals through speed optimization is a candidate measure to reduce fuel emissions in the international shipping industry, according to the International Maritime Organization. To quantify the potential benefits of this instrument, we integrate speed optimization in the berth allocation problem in a dynamic, rolling-horizon setting. Before our simulation runs, we determine a tactical-level baseline schedule, in which each vessel is assigned a time slot and berthing location. We propose two variants of speed optimization: one where the baseline order of service and berthing locations are unchangeable and one where they can be

changed. If speeds can be adjusted during the last 1,500 nautical miles of sailing, we find that speed optimization can result in a 4% to 6% reduction in total cost. However, while deadline violation cost is reduced, fuel usage increases. Besides quantifying the benefits, we introduce a system of penalties and compensation through which the cost savings are distributed fairly across vessels and which ensures that both the terminal and ships profit.

2 - Game Theory to achieve sustainable RoRo shipping through competition
Michell Queiroz, Dario Pacino, Seyed Parsa Parvasi

Short Sea Shipping (SSS) is a transportation mode that has garnered attention for its potential to alleviate the negative externalities associated with road transport. SSS offers several advantages, including increased safety, reduced infrastructure investment, and environmental benefits. This research specializes in Roll-on/Roll-off (RoRo) freight shipping, focusing on wheel-based cargo such as trucks and trailers. SSS is often underestimated by stakeholders in the logistics and transport sector, as they do not view it as a viable alternative. To encourage a shift of cargo from road to sea, we employ Game Theory to model the competitive freight transport market. Structured as a multi-leader-common-follower game, carriers set prices and service frequencies, and shippers allocate demand based on perceived utility. This problem setting allows carriers to react to the competition's decisions in an effort to maximize their payoff. Understanding the cause-and-effect relationships between actions in different modes is essential, as an attempt to attract more demand can trigger adjustments from competitors who wish to maintain market position. The solution approach iteratively computes best responses for each carrier, ensuring convergence to a stable strategy. The study also provides insights into how carriers can optimize their decisions by prioritizing the stability and predictability of long-term contracts, while still considering the flexibility offered by short-term contracts.

3 - Vessel arrival planning under uncertain berth availability
Pim van Leeuwen

Efficient and timely vessel arrival planning is crucial for the smooth operation of maritime transportation networks, ensuring optimal resource utilization and minimizing operational costs. When pro-forma schedules are disturbed by arrival deviations of vessels, waiting time and unnecessary fuel consumption become problems that shipping lines are faced with. Using a simulation model of a single berth terminal, we test speed selection strategies for vessels that aim to minimize fuel, sailing and waiting costs under varying availability of information. In different scenarios, we find optimality gaps ranging from 0.1% to 19.6% and show that knowing and communicating service end time to the vessel calling next could be valuable to integrated shipping lines and terminals.

4 - A MILP Model for berth scheduling on terminals with high transshipment volume
Alberto Delgado, Ignacio Blanco, Alexandre D. Jesus

As terminals and liner shipping companies face increasing congestion and tighter berth line-ups, the effective scheduling of vessel operations in terminals has become a critical factor in port operations. To tackle this challenge, we introduce a mixed integer linear programming (MILP) model designed to optimize berth scheduling in maritime terminals with high transshipment volume. This model prioritizes the liner's operational efficiency by optimizing schedule reliability, transshipment success, and bunker consumption, as well as respecting terminal resources availability, i.e., crane availability and yard capacity.

The main contributions of this work are twofold: (i) include transshipment success as part of the objective function to optimize berth line-ups in terminals with high transshipment volume, (ii) constrain berth line-ups to respect yard capacity limits. The former has a considerable impact on the liner's commercial performance and has only been studied in a small number of previous works. The latter adds a new capacity dimension that is critical for terminals handling high levels of transshipments and has not been addressed in previous work.

The proposed MILP model has demonstrated substantial business value by ensuring that thousands of containers are successfully transshipped, while reducing delays on vessel schedules and bunker consumption.

■ MA-33

Monday, 8:30-10:00 - Room: Maurice Keyworth 1.31

Social Networks and Decisions

Stream: Decision Analysis
Invited session
Chair: Rakesh Sarin

1 - Universal Fairness
Rakesh Sarin

Suppose you could be anyone in the world. You do not know your income, social class, gender, race. Particulars of your circumstance are hidden from you, so you are behind a veil of ignorance. In the choice of an economic arrangement, you face decision making under uncertainty. You wish to maximize your expected utility. You recognize that an excessive redistribution lowers total output. What is the optimal plan that you would choose?

I have obtained some results for optimal redistribution that a rational person would /should choose to maximize her happiness over lifetime. Redistribution reduces total output because of inefficiency and incentive effects. So, there is an optimal tradeoff. Nevertheless, everyone desires security and basic necessities to live a life of dignity and self-respect.

The key result is that a social minimum is derived (not assumed exogenously). I will argue that capitalism tempered by redistribution as in many European countries is preferred over laissez faire economic system.

2 - Resource Allocation Optimization: Maximizing Revenue and Ensuring Fairness
Mosayeb Jalilian, Hamed Jalali, Mozart Menezes, Roel Leus

Resource allocation involves distributing resources among customers who derive utility from them. Resources can be allocated either dynamically, over time, or statically in a single-shot process. This study examines revenue and fairness trade-offs by focusing on static multi-resource allocation problems. We consider two types of decision-makers: fairness-aware, who prioritize fairness among allocations with the same revenue, and fairness-unaware, who focus solely on revenue. To quantify this trade-off, we define sacrifice as the percentage reduction in fairness or revenue necessary to optimize the other objective. We identify two scenarios where fairness and revenue can be simultaneously optimized: when customers prefer more expensive resources or when the number of customers exceeds the number of resources, and all customers value having a resource. However, a trade-off between fairness and revenue is unavoidable where the total number of resources exceeds the number of customers and customers favor cheaper resources. Experimental results reveal that fairness-unaware decision-makers face a higher risk of poor fairness in popular events. Additionally, increasing the price of resource categories reduces fairness for customers preferring cheaper resources while minimally affecting those favoring expensive ones. Moreover, a diverse customer base with evenly distributed preferences amplifies the fairness-revenue trade-off for fairness-aware decision-makers.

3 - Data-Driven Decision Making in a Social Network Environment
Yu-wang Chen, Tao Wen, Ting Wu

Data-driven decision-making is widely recognised as fundamental to enhancing decision-making process and outcomes in business and management. On one hand, it enables decision-makers to respond more efficiently to uncertain and rapidly changing environments, improving both the decision-making process and outcomes. On the other hand, social network interactions have become an integral part of daily

life, adding complexity to the analysis of decision-making behaviours. In a social network environment, individuals often have diverse prior beliefs and communicate with their social connections to make informed decisions.

In this study, we aim to develop a holistic framework for analysing decision-making in a social network. This framework explores how individual decision-makers implicitly form their initial beliefs within the paradigm of multiple criteria decision-making, interact with others, and exchange beliefs, leading to dynamic belief updating. Ultimately, individuals make decisions, shaping group opinion dynamics and decision behaviours within the social network. The framework is expected to provide valuable insights into analysing decision-making in social networks and offer guidance for future research and real-world applications that integrate decision sciences with social network analysis.

4 - A novel dynamic trust network analysis method for consensus reaching in social network group decision making
Yan Xu, Xinzhu Wu

Trust relationships constitute fundamental concept in social network group decision making (SNGDM). This study proposes a novel trust network analysis method addressing dynamic trust relationships in SNGDM. During consensus reaching processes, DMs adjust their opinions based on those they trust more, which reciprocally influences trust levels. Direct trust relationships between DMs are quantified through trust degrees measuring reliability or credibility within the network structure. Opinion adjustments impact these relationships, resulting in adjusted trust degrees derived from initial trust values and opinion similarity. Indirect trust relationships are determined through direct trust and propagation pathways. Given the multiplicity of overlapping paths with common intermediaries, path interactions must be considered. We employ the Choquet Integral to capture interacting effects between trust paths, calculate path weights and aggregate indirect trust degrees. By integrating both adjusted direct and indirect trust degrees, we develop a trust network-based consensus model that enhances stability in consensus building. The proposed method provides precise representation of indirect trust propagation through path interaction modeling and establishes a comprehensive framework integrating both direct and indirect trust relationships. A comparative analysis is conducted to validate the method, demonstrating its efficacy in managing dynamic trust relationships in GDM scenarios.

■ MA-38

Monday, 8:30-10:00 - Room: Michael Sadler LG19

Automating the Design, Generation and Control of Optimization Algorithms 1

Stream: Data Science meets Optimization
Invited session
Chair: Andrew J. Parkes
Chair: *Ender Özcan*

1 - Integrated optimization and machine learning: an application to predictive maintenance
Marie Bouilloud, Michel Nakhla

This paper examines how optimization and machine learning can be combined to improve predictive maintenance in wind farms.

Optimization integrated with machine learning creates powerful methods to solve complex problems by improving solution search strategies and enhancing decision-making processes, in contrast with the usual sequential approach. This synergy enables algorithms to learn from data and guide optimization procedures more effectively. In this proposal, we present an application of this combination for predictive maintenance, where a MIP schedules tasks to minimize downtime while maximizing system reliability and machine learning models, including random forrest and isolation forrest, anticipate equipment failures.

The model we propose mobilizes ensemble learning with a loop such that the performance of the corresponding tasks planning allows to adjust the threshold for aggregating the results of the different prediction models. The predictions are adjusted through iterations by the results of the optimization. The optimization then leads to a return to the ensemble learning, becoming similar to a layer of a learning algorithm.

Experimentations were carried out on industrial data.

2 - Data-Driven Constructive Metaheuristic for Combinatorial Problems
Mariusz Kaleta, Tomasz Sliwinski

We propose a general approach to solving combinatorial optimization problems by leveraging the fact that, in many practical cases, input data exhibit inherent regularities. For example, the parameters of packed items or scheduled tasks often follow specific patterns. Our new metaheuristic applies to problems where solutions can be constructed iteratively, such as sequentially packing items or dispatching operations to a partially built schedule.

At each iteration, a set of candidate decisions is considered and scored using a small-scale simple feed-forward neural network, selecting the decision with the highest score. The network's low complexity enables an evolutionary strategy for optimizing its parameters, treating the construction algorithm as a black-box optimization problem. In this strategy, the population of individuals represents a set of neural networks, effectively defining a population of constructive algorithms. The proposed approach is general ("meta-"), requiring the specification of a method for generating candidate decisions, a feature vector describing the current state and potential decisions, and a transformation function that updates the state.

We showcase results for a series of well-known combinatorial problems, including Strip Packing, Cutting Stock, and Flexible Job Shop, demonstrating the superiority of our approach over state-of-the-art constructive algorithms.

3 - Online Stochastic Generalized Assignment Problem with Delayed Demand Learning
Hao Wang, Zihao Li, Limeng Liu, Zhenzhen Yan

We study an online generalized assignment problem under a stochastic arrival model. Items arrive sequentially, following a known independent and identical distribution. Each arriving item has an associated demand, which is stochastic and drawn from an unknown type-specific distribution. However, a key challenge is that the actual demand is only revealed after a delay, occurring some time after the item has been successfully packed into an offline bin. Such delayed demand revelation is common in many real-world applications, such as food delivery, where actual order sizes or customer consumption patterns may only be observed post-allocation. Upon each item's arrival, an immediate decision must be made: either pack it into a bin, reducing its capacity, or reject it. The objective is to maximize the total reward of the packing scheme while adhering to capacity constraints. To tackle the uncertainty introduced by delayed demand revelation, we design an algorithm based on the exploration-exploitation principle, which simultaneously learns about the demand distribution and optimally allocates items. We provide a non-asymptotic parametric guarantee for discrete demand distributions supported on finite rational values and extend our analysis to arbitrary distributions. Finally, we conduct numerical experiments to evaluate the effectiveness of our algorithm across different demand distributions.

4 - Reinforcement learning-based iterated local search for the unrelated parallel machine scheduling problem
Arthur Kramer, Ruan Myller Magalhães de Oliveira, Thiago Alves de Queiroz

In this work, we propose an optimization method that combines Iterated Local Search (ILS), Variable Neighborhood Descent (VND) and Reinforcement Learning (RL) to solve the earliness and tardiness unrelated parallel machine scheduling problem with sequence and

machine-dependent setup times that arises in just-in-time manufacturing systems. In this problem, a set of non-identical parallel machines are available to process a given set of tasks. Each task has a due date, two penalty weights (earliness and tardiness) and requires a machine-dependent processing time to be completed. In addition, a setup operation is necessary between the operation of two consecutive jobs. The objective is to schedule all tasks so that each machine process at most a job at time and that minimizes the total weighted earliness and tardiness penalty. The state-of-the-art meta-heuristic method in the literature to solve this problem is a combination of ILS and a randomized VND where the neighborhoods inside the VND are explored in a random order. Thus, in this work we propose a RL-based method to define, at each iteration of the ILS, the exploration order of the neighborhood structures inside the VND instead of considering totally fixed or totally random orders. We model this decision problem as a Markov decision process and consider different policies and reward functions. Experimental tests show that the method is able to find solutions within 2% from the best-known solutions in the literature.

■ MA-41

Monday, 8:30-10:00 - Room: Newlyn GR.01

Theoretical and Methodological Developments in Problem Structuring

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Leroy White*
Chair: *Mike Yearworth*

1 - Participative Optimisation Modelling (PartiOpt): A Case Study in Mental Health Service Design
Maria Paola Scaparra, Sheema Noorain, Kathy Kotiadis

Mathematical optimisation models have the potential to support complex decision-making in healthcare but are often underutilised due to limited stakeholder engagement, difficulties in capturing real-world complexities, and challenges in translating model outputs into actionable insights. While facilitative modelling frameworks exist for simulation (e.g., PartiSim), no established framework currently supports the collaborative building of optimisation models with stakeholders. This talk presents PartiOpt, a participative framework designed to bridge this gap by actively engaging stakeholders in the development of optimisation models. PartiOpt combines problem structuring tools adapted from PartiSim with newly developed tools specifically tailored for optimisation. Through facilitated workshops, diverse stakeholders contribute to problem conceptualisation, formulation, and validation, ensuring that optimisation models are aligned with decision-maker needs and are effectively implemented in practice. We demonstrate PartiOpt through a case study on redesigning a Primary Care Mental Health service in Kent, UK. The talk also discusses the potential applicability of the proposed approach to other care settings and the benefits of using the PartiOpt framework to build realistic and usable optimisation models, thus reducing the gap between technical model development and real-world applications.

2 - Development of the Rich Notes Technique through an Action Research Programme
Chris Smith, Karthik Suresh, Giles Hindle

Rich Notes is an action focussed novel facilitator led diagrammatic modelling technique developed to be used online. The paper focusses on the development of Rich Notes through an action research programme spanning 8 years with data from over 300 real world applications. The development of Rich Notes is tracked across three distinct learning loops where each showed a step-change in the technique's development. The paper identified the catalysts for these changes and shows the theoretical, methodological and practical reasons for the change to the approach. For each learning loop the paper shows how the approach operationalised theory through the development of a methodology; how we understand action through real-world interventions; and, elaborate theory from this practice.

3 - Signed Digraph Modeling: a novel problem structuring method
Seyed Hamid Hashemi Petrudi

This study introduces Signed Digraph Modeling (SDM), a new Problem Structuring Method (PSM) designed to address limitations in traditional Interpretive Structural Modeling (ISM). While ISM is effective in structuring complex issues through expert consultation and hierarchical digraphs, it lacks the ability to indicate the intensity and sign of relationships. SDM enhances ISM by incorporating directional insights and stakeholder consensus measures, improving interpretability without requiring advanced mathematical knowledge. The SDM process consists of seven key steps: stakeholder identification, element identification through expert consultation, defining contextual relations with positive and negative signs, constructing an adjacency matrix, building the initial digraph, and refining the final digraph for clarity and consistency. The methodology emphasizes a heuristic approach to structuring complex problems, facilitating stakeholder engagement and providing actionable insights. The paper also proposes a new leveling method based on influence to dependence ratios to guide the hierarchical organization of elements. The method's practical applicability is demonstrated through a numerical example and a real case, illustrating its efficiency and usefulness in decision-making. The study contributes to the advancement of PSMs by offering a more intuitive and interpretable approach to analyzing systemic relationships in complex decision-making contexts.

■ MA-42

Monday, 8:30-10:00 - Room: Newlyn GR.02

Sustainable food supply chains

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: *Yu Shi*

1 - Logistical challenges in regional food supply for communal catering
Sandra Zajac, Heinrich Kuhn

With an increased focus on sustainability and strengthening the autonomy of a region, interest and demand for regionally produced food has grown in recent years. Customers can buy regionally produced food at farm markets, designated grocery stores and restaurants, or through regional food box delivery services. However, regional food is less frequently offered in out-of-home catering, especially in communal catering. This is due to significant additional costs associated with local food provision, which are not always matched by customers' willingness to pay. Furthermore, communal catering faces unique challenges, such as the need for large quantities, consistent quality, and cost efficiency. These challenges require an efficient logistic structure, including optimized transport routes, collaboration between producers, and digital tools to streamline supply chains. The talk deals with the logistical challenges in regional food supply for communal catering and illustrates the OR planning problems to be solved in this context. New types of optimization problems are defined, ranging from supply network planning, requirements planning for meal ingredients, and transport planning to menu planning. A supply chain planning matrix of communal catering with a regional sourcing strategy illustrates the relationship and interdependencies between the decision problems to be solved.

2 - Investigating Retailer-Food Bank Partnership: Decision Analysis on Supply Chain Efficiencies and Consumer Income Diversity
Yu Shi

Global food supply chains face rising challenges from food insecurity, increasing demand, and food loss and waste (FLW). This study examines how a retailer's partnership with a food bank—through charitable donations—compares to non-partnership strategies (fixed pricing and markdown pricing) in terms of profitability and supply chain efficiency. Supply chain efficiency is measured by total FLW and food accessibility rate, reflecting environmental and social sustainability respectively. A two-period decision model is developed, incorporating strategic consumer behaviour, income segmentation, and food quality depreciation. The findings reveal that while food bank partnership generally does not harm retailer profits, it can increase overall FLW and reduce food accessibility, especially when logistical losses occur. Such partnership is beneficial only when the valuation of surplus food exceeds low-income consumers' budgets and high-income consumers dominate the market. When donation rewards for the retailer are low, markdown pricing is more profitable than charitable donations, but the relative outcomes for supply chain efficiency remain unchanged. These insights help retailers optimise surplus-food strategies based on consumer income structures, and highlight the need for improved food bank logistics and carefully designed government policies to improve food redistribution efficiencies.

3 - How many is too many toasties? Optimising fresh food loading for inflight retail
Craig Poku, Paul Sharkey, Matthew Sawkins

From production to consumption, food is one of the world's biggest waste sources. Staggeringly, the UN estimates that one-fifth of food produced is thrown away. For airlines, fresh food sales are a crucial revenue stream for inflight retail, making it essential to strike the right balance between maximising profit, minimising food waste, and avoiding stockouts.

This talk presents the solution developed for a low-cost airline to optimise fresh food loading predictions. Previously, their business practices led to extreme overloading or underloading, resulting in missed profit opportunities and waste levels as high as 42%. Our solution consisted of two key elements: a forecaster that uses features such as past sales and flight characteristics to predict demand of a given food item; and a stock optimiser to find the optimal number of loadings that will maximise profit while constraining for both food waste and stockouts.

During offline evaluation, we observed a 5% profit uplift across the airline's network while decreasing food waste by 19% and stockouts by 9%. This and further live tests demonstrated that our model is competitive in terms of profit, while enhancing sustainable practices. Although our client initially told us to focus on just profit uplift, we showed that beyond financial gains, using demand forecasting improves sustainability by reducing food waste and improving supply chain efficiency.

■ MA-43

Monday, 8:30-10:00 - Room: Newlyn GR.07

Operations Research and the Common Good

Stream: OR and Ethics
Invited session
Chair: *Cathal MacSwiney Brugha*
Chair: *Ulrike Reisach*

1 - Advances in Optimization Algorithms for Municipal Flood Mitigation
Jan Boeckmann, Clemens Thielen

As a consequence of climate change, flash floods pose an increasing threat on mankind. Within the research project AKUT at TUM Campus Straubing, a software has beed developed that uses optimization algorithms to automatically elaborate high-quality flood mitigation concepts. This software has already been used in practice by municipalities all over Germany, and the project was awarded the EURO Prize for the Common Good 2024. In this talk, recent advances and the practical impact of the software are presented. Those reach from experiences of the go-live of the software's new, more powerful version over a genetic algorithm, which uses a convolutional neural network to evaluate damages, to an entirely new application of finding optimal locations for sandbags in the case of fluvial (river-caused) flash floods.

2 - Good enough for Government Work? Building and maintaining an analysis Quality Assurance (QA) system.
Ian Mitchell

The Department for Energy Security and Net Zero (DESNZ) Modelling Integrity Team reviews the design and operation of their network-based approach to the Quality Assurance (QA) of models, reflecting on over seven years' experience.

The presentation describes the working tools of the system, collaborative capacity building with the QA College programme and the importance of governance especially the support of senior sponsors.

It includes the assurance of code-based models and implications of Artificial Intelligence (AI) developments for analysis, particularly for validation and the utility of Problem Structuring Methods to complement developments in coding, suggesting that these offer competitive advantages for Operational Researchers.

3 - Digital Twins as Persuasive Technology for Transport Decarbonisation
Luciana Blaha

Digital twins (DTs) are emerging as powerful virtual representations of transport systems, offering potential as persuasive technologies to influence sustainable behaviors. This paper examines the intersection of DTs and persuasive technology in transport, highlighting four critical gaps: limited focus on persuasive potential, insufficient attention to user experience, unexplored social and ethical implications, and absence of specific design frameworks. While DTs can enhance decision-making, improve resource allocation, and influence transport choices to address climate challenges, they raise significant ethical concerns regarding data privacy, manipulation, and unintended consequences. The increasing adoption of DTs in transport operations presents opportunities to drive decarbonization efforts through behavioral change, but requires careful consideration of ethical boundaries and user-centered design. Transport DTs must balance operational efficiency with transparent stakeholder engagement to maintain trust while maximizing positive environmental impact. This paper touches on in-progress empirical research on human-DT interactions and calls for the development of ethical design frameworks specifically for transport DTs to guide their implementation as tools for sustainable transport transformation.

4 - DISCS: Using a decentralised approach to improve sustainable decision making processes
Dennis Dokter

This presentation explores the integration of Digital Twin technology into smart city innovation through the DISCS (Design and Integration of Smart City Solutions) framework. DISCS provides a structured approach to designing, testing, and deploying transformative urban solutions by combining Digital Twins with living lab principles and testbed environments. Central to this approach is the use of Digital Twins to enhance data-driven decision making by creating dynamic, real-time, and context-aware models of city systems. These Digital Twins allow stakeholders to evaluate policy impacts and optimise operations with a higher degree of accuracy and confidence. By integrating Digital Twins with testbeds and living labs, DISCS enables cities to prototype and refine solutions in realistic environments, reducing innovation risks and bridging the gap between concept and implementation. The presentation emphasises the need for well-defined system requirements and architectural frameworks to ensure interoperability and scalability. Practical examples in Energy Management, Sustainable Mobility, Water Resource Management, and Disaster Response illustrate how digital twins drive smarter, faster, and more resilient urban decisions.

■ MA-44

Monday, 8:30-10:00 - Room: Newlyn 1.01

Advancing Energy System Models

Stream: Energy Economics & Management
Invited session
Chair: Robert Gaugl

1 - Distribution Locational Marginal Pricing under Generation and Network Scarcity Conditions
ZeJun Ruan, Anthony Papavasiliou, Mehdi Madani

This work focuses on a computationally tractable formulation for reserve deliverability on meshed networks, which opens the path for integrating scarcity prices in distribution locational marginal prices. The problem of reserve deliverability is approximated as a problem of approximating a polyhedron of admissible reserve trades by an inscribed box of maximum volume. The equivalence of the model with an existing alternative model of reserve deliverability is proven for radial networks. The study analyzes the pricing patterns that arise from the proposed model and examines a realistic case study of coordination between the transmission and distribution systems. At last, the effect of alternative design choices on distribution network prices and incentives to invest are analyzed.

2 - Analyzing Techniques to Connect Representative Periods in Energy System Optimization Models
Felix Clemens Alexander Auer, Diego Tejada, Sonja Wogrin

In energy system optimization, time series aggregation using representative periods is a common technique to reduce computational complexity and solving times for large-scale models. However, accurately handling constraints at the edges of representative periods to model the transitions between them proves to be a challenge, since the overall deviations from the original problems (or rather their solutions) should be kept minimal.

Currently, three methods are mainly used to handle edges between representative periods: Not enforcing the constraints at the edges at all; fixing the variables at the edges; or, establishing cyclic constraints within each representative period. While easy to implement, each of those methods has its limitations with respect to accurately capturing the original, non-aggregated problem.

We introduce an innovative approach leveraging Markov chains to capture the stochastic transitions between periods. Importantly, the technique is not limited to constraints concerning continuous variables, but also applicable to those with binary variables.

We present a case study of a unit commitment model with ramping constraints, but the Markov chain method can also be extended to other types of constraints. Analyzing the differences in model size, solving time, objective function value and individual unit commitment, we show the potential of this method to improve energy system optimization models which are using representative periods.

3 - Decomposition Algorithms for Stochastic Capacity Expansion Planning with Endogenous Adequacy Targets
Marilena Zampara, Alexandros Visas, Daniel Avila, Anthony Papavasiliou

The scope of this work is to test alternative algorithmic schemes for addressing a large stochastic capacity expansion problem with specific constraints on expected energy not served. The challenge lies in decoupling scenario-specific variables, which are originally bundled by adequacy constraints, so that scenario-specific problems can be solved in parallel. The examined schemes include Benders' decomposition, the projected subgradient method, the level method, and Dantzig-Wolfe decomposition. Numerical experiments are conducted on a small-scale problem, for which we can compute the extended form solution and thus benchmark the effectiveness of the proposed decomposition algorithms.

4 - NetZero-Opt: Advancing Time Series Aggregation for Computational Efficiency in Net-Zero Power Systems Optimization
Luca Santosuosso, Sonja Wogrin

Our power grid stands as the most complex human-engineered infrastructure ever created. Decision-making within this intricate system relies heavily on optimization, with the key challenge being to balance modeling accuracy with computational efficiency. Time series aggregation (TSA) methods are employed to streamline the input data for aggregated optimization models, aiming to reduce complexity of full-scale optimization problems while retaining representativeness. However, current TSA methods either rely on a priori input data analysis, mistakenly assuming that minimizing clustering error reduces output error, or use heuristics without theoretical guarantees. The ERC-funded NetZero-Opt project addresses these challenges by advancing TSA. The project stems from the groundbreaking discovery of a new TSA method, leveraging simplex algorithm-based input data clustering. For the illustrative example of an economic dispatch problem, this approach reduces the input space from 8760 hours down to just 3 representative hours, while preserving solution accuracy exactly. These findings demonstrate tremendous potential for reducing complexity in optimization and raise key research questions: (1) Can this method be extended to nonconvex problems? (2) Can it establish a performance guarantee for exact TSA in optimization? This talk will explore the findings of NetZero-Opt and discuss ongoing strategies to address these research questions, as well as other future directions for the project.

■ MA-46

Monday, 8:30-10:00 - Room: Newlyn 1.07

Hydrogen Production Planning and Operation

Stream: Energy Economics & Management
Invited session
Chair: Pedro Sánchez-Martín

1 - Tackling uncertainty in electrolyser deployment: the role of degradation on expansion planning problems.
Juan F Gutierrez-Guerra, Jose Pabl Chaves avila, Andres Ramos

Uncertainties surrounding the long-run cost-benefit of hydrogen hybrid plants (i.e., dedicated renewable power, energy storage technologies, and grid connection) are challenging the widespread adoption of electrolysers, hindering the production of green hydrogen on a large scale. Both electrolysers and renewable generation systems require high capital investment. However, weighing only the initial expenditures can be misleading: the technology choices and system operation design have a direct impact on electrolyser efficiency, lifetime, and associated costs. This work presents a multi-period expansion and planning model that can simultaneously determine the investment and operation decisions of a hydrogen hybrid plant at minimum cost. The model is formulated as a mixed-integer linear programming (MILP) problem in hourly resolution and accounts for degradation effects in key system components, including battery storage, solar PV and wind power generation, and PEM electrolysis stacks. The case study, which covers a modelling horizon of 30 years, is based on a real Spanish facility producing hydrogen for use as industrial feedstock. We explicitly address the effects of PEM stack degradation and replacement, providing insights into its implications for investment strategies, operational performance, and the levelised cost of hydrogen.

2 - The Role of Low-Carbon Hydrogen in Optimising Hydrogen Production Costs and Electrolysis Plant Design
Santiago Serna, Timo Gerres, Rafael Cossent

Renewable hydrogen has gained significant attention in European regulations as a key element in decarbonising sectors where electrification is challenging. Several studies have analysed the production cost of RFNBO (Renewable Fuel of Non-Biological Origin) hydrogen and the impact of strict production conditions, particularly the temporal correlation between renewable electricity generation and electrolyser consumption (Delegated Act 2023/1184). In contrast, the role of electrolytic low-carbon hydrogen, as defined in the Directive EU 2024/1788, has received less attention. This Directive allows low-carbon hydrogen production using grid electricity, provided it meets emission reduction targets relative to a fossil fuel benchmark. Integrating RFNBO and low-carbon hydrogen offers investment and operational advantages. It minimizes inefficient start-stop cycles, increases annual operating hours, and reduces investment impact by spreading the costs over a greater output. However, the production of low-carbon hydrogen is uncertain as it depends on the emission intensity of the grid. This presents challenges in designing a system that ensures a reliable hydrogen supply while meeting regulatory constraints. This paper examines the role of low-carbon hydrogen in reducing production costs and its implications for plant design. We developed an optimisation model integrating investment decisions with operational planning under different grid-electricity emission profile scenarios.

3 - Optimized Self-Scheduling of a Hydrogen-Based Virtual Power Plant in the Day-Ahead Electricity Market
Erik Alvarez, Pedro Sánchez Martín, Andrés Ramos Galán

This study presents an optimisation model for the self-scheduling of a hydrogen-based virtual power plant (H2-VPP) in the day-ahead electricity market. The model strategically integrates renewable energy sources, battery storage, electrolysers and hydrogen storage to maximise operational efficiency and economic performance. By optimising the interaction between electricity and hydrogen networks, it enables better resource management and increased use of renewable energy. A case study evaluates different system configurations, highlighting the impact of battery storage and hydrogen tanks on cost reduction. The results show that excluding battery storage increases costs by up to 87%, while excluding hydrogen storage increases costs by up to 153%. These findings underline the critical role of storage technologies in increasing flexibility, minimising electricity purchases and improving market competitiveness. The proposed framework supports the development of hydrogen-based VPPs, contributing to a more efficient and resilient energy transition.

4 - Techno-economic analysis of offshore salt-cavern hydrogen storage
Gerardo Perez Valdes, Raquel Alonso-Pedrero

We present the application of the EMPIRE power system optimization model to assess the economic feasibility of offshore salt caverns for hydrogen storage in the Northern sea. The EMPIRE model integrates long-term investment decisions with short-term operational uncertainties. Our study focuses on the techno-economic analysis of utilizing offshore salt caverns for large-scale hydrogen storage, leveraging renewable energy sources such as wind and solar power. The seasonal aspect of both demand and renewable production gives an incentive to store large quantities of energy for long periods of time; green hydrogen can be a possibility.

Salt cavern storage is already used for hydrogen in pilot projects onshore; natural gas offshore storage is also a technical possibility with more studies behind it. The Hy4Get project, financed by the Norwegian Research Council, hopes to overcome challenges involving safety, geology, chemistry, and economy, supporting the transition to a low-carbon energy system.

In this work, we evaluate key techno-economic indicators, such as the Levelized Cost of Hydrogen (LCOH), initial investment requirements, and operational expenses. EMPIRE's hydrogen modelling has been expanded to account for hydrogen storage movement, new goal locations, and salt-cavern-related technicalities to allow for a better understanding of the large, long-term storage potential.

■ MA-48

Monday, 8:30-10:00 - Room: Parkinson B09

Location and Logistics

Stream: Locational Analysis
Invited session
Chair: *Serena Fugaro*

1 - Optimizing the Location and Size of Facilities on a Network to Maximize Total Expected Utility
Ken-ichi Tanaka

We consider the problem of determining the location and size of multiple facilities on a network, where all facilities are owned by a single decision-maker. The decision-maker has a discrete set of options for the facility sizes, with larger facilities incurring higher costs. Users' choice behavior in selecting facilities is modeled using a multinomial logit model, where the utility for each user is an increasing function of the facility size and a decreasing function of the distance to the facility. We aim to maximize the total expected utility for all users, subject to the total budget available for locating facilities. We present a nonlinear integer programming formulation of the problem, and propose a solution method based on a subproblem where the objective function is approximated by a set of upper-bound linear functions. The proposed method is applied to road network instances, and the results demonstrate that it generates high-quality solutions within a reasonable amount of time. We examine how the distance deterrence parameter in the multinomial logit model influences the location and size patterns of facilities in the optimal solutions.

2 - Integrated location and inventory decisions in healthcare logistics: model and preliminary results
Inez Puttemans, Kris Braekers, An Caris, Jean-Sébastien Tancrez

Healthcare institutions, including hospitals and retirement homes, face budget constraints and staffing shortages, driving the need to reduce costs and enhance healthcare logistics without compromising care quality. One key opportunity to improve healthcare logistics is inventory pooling, where inventory from individual warehouses is consolidated into care hubs across a network of institutions, leading to significant cost savings and improved healthcare logistics. Decision support for inventory pooling is facilitated by integrated decision-making on location and inventory management, known as the location-inventory problem (LIP).

To familiarize with the current state of LIP research, we conducted a comprehensive literature review across sectors including manufacturing, healthcare, and spare parts. Based on these insights, we developed a mathematical model tailored to the healthcare sector, aimed at minimizing total costs, including location, transportation, and inventory-related expenses, while considering specific constraints such as multiple product types and maximum allowable distance between care hubs and healthcare institutions.

This talk will present the key insights from our review, which incorporates 45 recent papers across various contexts. We will also discuss the developed mathematical model, including its objective and constraints. The mathematical model is currently being tested on various instances, and preliminary results will be presented.

3 - A systematic approach for selecting the optimal inventory control policy and supply chain network design
Juan Peralta, Francisco J. Tapia-Ubeda, Pablo A. Miranda, Elias Olivares-Benitez, Armin Lüer-Villagra

Supply chain management is a crucial aspect to ensure the organization's competitiveness. One of the main challenges in this field is supply chain network design, which refers to the planning of the physical infrastructure of the supply chain. Traditionally, decision-making for supply chain network design has been carried out in isolation and hierarchically. This traditional approach has been proven to be profoundly mechanistic and fails to address the synergy between the aspects considered. This research proposes a new approach based on holistic decision-making and how this can help to find optimal global solutions. Thus, a few decades ago, inventory location models were introduced, typically integrating tactical and strategic decisions. However, these models assume a priori a fixed and known inventory control policy. In this context, this research proposes a novel inventory location model that allows selecting the best inventory control policy while ensuring cost efficiency. Since it is a mixed-integer, non-linear, non-convex model, a Generalized Benders Decomposition-based approach is also presented. The implementation of the proposed solution approach has resulted in finding the optimal solution for the synthetic instances tested. The proposed scheme systematically ensures the best configuration for the network.

4 - Enhancing post-disaster relief operations: a bi-objective approach to temporary logistics hubs location
Serena Fugaro, Antonino Sgalambro

In post-disaster relief operations, temporary logistics hubs are essential facilities for deconsolidating, storing, consolidating, and transporting relief supplies between emergency relief providers (e.g., donors, government warehouses) and affected areas. In this work, we propose a novel Bi-Objective Capacitated Multiple Allocation Hub Location problem with Splittable Demand to address the hub-and-spoke network design problem associated with humanitarian logistics in post-disaster environments. The decisions to be made are: where to locate the temporary logistics hubs, and the amount of flow of each relief material that should traverse the available network links to ensure timely aid. Two objectives are considered to assess the performance of the designed network: minimising the average arrival time of the flows and minimising the latest arrival time. Indeed, whilst time is a crucial factor in post-disaster operations management, it has received limited attention in humanitarian logistics problems in terms of modelling tools explicitly employed to ensure its adequate representation. In order to fill this gap, in this work we make use of Flows over Time. Uncertainty is an inherent part of a humanitarian logistics system due to the different levels of accuracy of its parameters; to represent this aspect, we use ad hoc modelling tools. We also propose algorithmic approaches to mitigate the uncertainty while providing valuable decision support in post-disaster relief operations.

■ MA-49

Monday, 8:30-10:00 - Room: Parkinson B10

Sums-of-squares optimization

Stream: Conic and polynomial optimization
Invited session
Chair: David de Laat

1 - Computational complexity of sum-of-squares bounds for copositive programs
Marilena Palomba, Lucas Slot, Luis Felipe Vargas, Monaldo Palmo Mastrolilli

In recent years, copositive programming has received significant attention for its ability to model hard problems in both discrete and continuous optimization. Several relaxations of copositive programs based on semidefinite programming (SDP) have been proposed in the literature, meant to provide tractable bounds. However, while these SDP-based relaxations are amenable to the ellipsoid algorithm and interior point methods, it is not immediately obvious that they can be solved in polynomial time (even approximately). In this paper, we consider the sum-of-squares (SOS) hierarchies of relaxations for copositive programs introduced by Parrilo (2000), de Klerk & Pasechnik (2002) and Peña, Vera & Zuluaga (2006), which can be formulated as SDPs. We establish sufficient conditions that guarantee the polynomial-time computability (up to fixed precision) of these relaxations. These conditions are satisfied by copositive programs that represent standard quadratic programs and their reciprocals. As an application, we show that the SOS bounds for the (weighted) stability number of a graph can be computed efficiently. Additionally, we provide pathological examples of copositive programs (that do not satisfy the sufficient conditions) whose SOS relaxations admit only feasible solutions of doubly-exponential size.

2 - A low-degree sum-of-squares bound for the stable set problem: A copositive approach
Luis Felipe Vargas

The stability number of a graph (G), denoted by $alpha(G)$, represents the maximum size of a stable (or independent) set in (G). Building on the theta number introduced by Lovász, several semidefinite programming (SDP) approaches have been proposed to approximate $alpha(G)$, typically involving lift-and-project methods or sums of squares relaxations.

In this talk, we introduce a novel hierarchy of approximations based on structured sums of squares representations. We prove that this hierarchy converges to $alpha(G)$ and provide quantitative bounds on its convergence rate. Remarkably, we show that for several graph instances known to be hard for existing SDP-based methods, our hierarchy converges to $alpha(G)$ in just one step. We conclude with a discussion on the computability of and complexity implications of our approach.

This is based on my joint work with Juan Vera and Peter Dickinson.

3 - Second-Order Cone Programming in Measures using Polynomial Optimization
Jared Miller, Jie Wang, Matteo Tacchi

Second order cone programs (SOCPs) are a fundamental tool in convex optimization. Applications of finite-dimensional SOCPs include stochastic linear programming, spectrum allocation, and robust linear-quadratic model predictive control. This work studies infinite-dimensional SOCPs posed over nonnegative Borel measures. The SOCP in measures involves a linear objective over a (possibly infinite) set of finite-dimensional second-order-cone and linear constraints. SOCPs in measures are present in the setting of infinite-dimensional quadratic programs in which all kernels possess known and finite-dimensional feature maps. We demonstrate that the SOCPs obey strong duality under compactness and continuity assumptions, and prove that the moment-sum-of-squares hierarchy of semidefinite programs will converge to the true SOCP optima under assumptions of polynomial structure. We apply this methodology towards solving measure SOCPs arising in risk analysis, optimal control with non-local quadratic costs, and design of periodic distributions.

■ MA-51

Monday, 8:30-10:00 - Room: Parkinson B22

Recent advances in multiobjective optimization

Stream: Multiobjective and vector optimization
Invited session
Chair: Ozlem Karsu

1 - Warm-Starting Strategies in Scalarization Methods for Multi-Objective Optimization
Stephanie Riedmüller, Janina Zittel, Thorsten Koch

In this talk, we explore the integration of warm-starting techniques within scalarization methods for multi-objective optimization for mathematical programming problems. Particularly in applied settings, scalarization methods remain the most commonly employed classical optimization techniques for computing a subset of Pareto-optimal solutions, specifically the weighted sum and epsilon-constraint methods. Despite the availability of more involved and specialized algorithms (which often use scalarization methods as subroutines), these scalarization methods are favored due to their straightforward implementation and universal applicability to both linear and integer programs across an arbitrary number of objectives. Although warm-starting has been integrated into scalarization methods in previous studies, a detailed methodology and comprehensive analysis have yet to be provided. Therefore, we present a theoretical overview of its advantages and limitations. An effective warm-starting strategy for scalarization methods is primarily determined by the sequence in which subproblems are solved. However, optimizing the sequence of subproblems in terms of warm-starting can directly conflict with other desirable properties based on the order of subproblems, such as the early detection of infeasible subregions. We illustrate their impact by an extensive computational study.

2 - Discrete Representation of Nondominated Sets in Multi-objective Integer Programs
Banu Lokman, Ilgin Dogan, Murat Koksalan

Multi-objective Integer Programs (MOIPs) have a broad range of applications in diverse domains including logistics, healthcare and energy. These problems often involve conflicting objectives, and as a result, there is no single optimal solution. It becomes crucial to identify nondominated points, where improving any one objective is not possible without compromising another. However, the number of nondominated points increases exponentially with the size of the problem, making it difficult to find each one. Recognising the need to generate a representative subset of nondominated points with specific desirable properties, we examine the characteristics of nondominated sets in various MOIPs. We observe that the distribution of these points plays a key role in selecting representative ones. We develop an exact algorithm that generates a representative set guaranteeing a prespecified precision. Our experiments demonstrate that this approach is robust across a variety of MOIP types.

3 - On image space transformations in multiobjective optimization
Felix Neussel, Oliver Stein

It is well known that one can apply a strictly increasing function to the objective function of any standard single-objective optimization problem without altering the set of optimal points. This can be helpful in generating properties like smoothness or convexity of the objective.

As a generalization to multiobjective optimization, we consider monotone transformations of the objective space that leave the set of efficient points invariant. Under mild assumptions, for the standard ordering cone, we show that such transformations must be component-wise transformations, which means that a univariate strictly increasing function is applied to each of the objectives.

The same class of transformations also leaves the sets of weakly and of Geoffrion properly efficient points invariant. In addition, our approach allows us to specify trade-off bounds of properly efficient points after the transformation. We apply our results to prove some previously unknown properties of the compromise approach.

4 - Weight Space Decomposition given Extreme Supported Nondominated Points of a Multiobjective Optimization Problem
Firdevs Ulus, Ozlem Karsu

Weighted sum scalarization (WS) is one of the most well-known scalarization problem for solving multiobjective optimization problems (MOPs). It is possible to find any supported nondominated point by solving WS problem with the corresponding weight parameter from the weight set W. For an extreme supported nondominated point y, there is a set of weight vectors $W_y subseteq W$ supporting y. Computing W_y for each such y is referred to as weight space decomposition. We propose a methodology for that given the set of extreme supported nondominated points of a MOP using geometric duality results for linear multiobjective optimization. We prove some properties of the weight sets and provide numerical examples.

■ MA-53

Monday, 8:30-10:00 - Room: Liberty Moot Court

Algorithmic Game Theory and Its Applications

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Yukun Cheng*

1 - On the Efficiency of Fair and Truthful Trade Mechanisms
Yiding Feng

We consider the impact of fairness requirements on the social efficiency of truthful mechanisms for trade, focusing on Bayesian bilateral-trade settings. Unlike the full information case in which all gains-from-trade can be realized and equally split between the two parties, in the private information setting, equitability has devastating welfare implications (even if only required to hold ex-ante). We thus search for an alternative fairness notion and suggest requiring the mechanism to be KS-fair: it must ex-ante equalize the fraction of the ideal utilities of the two traders. We show that there is always a KS-fair (simple) truthful mechanism with expected gains-from-trade that are half the optimum, but always ensuring any better fraction is impossible (even when the seller value is zero). We then restrict our attention to trade settings with a zero-value seller and a buyer with value distribution that is Regular or MHR, proving that much better fractions can be obtained under these conditions.

2 - Popular Facility Location
Xujin Chen, Changjun Wamg, Chenhao Wang

Facility location problems address the strategic placement of k facilities to serve a geographically distributed set of customers. We introduce a novel "popularity" criterion for location selection: a solution (a set of k selected locations) is popular if no unselected location is preferred over any selected location by a majority of customers. For networks with continuous customer distribution, we develop efficient algorithms to compute popular solutions when k exceeds a certain threshold. We analyze the quality of popular solutions using the Price of Anarchy and Price of Stability, comparing their social cost to the optimal solution. Our analysis reveals that these price ratios are bounded by small constants and are notably lower than those of Nash equilibria in the facility location games. This suggests that popularity offers a compelling alternative to traditional solution concepts, providing both computational tractability and good-quality solutions.

3 - Fairness in Facility Location Games
Minming Li

We consider the fairness perspective of facility location games where agents report their information while the mechanism needs to output a facility location that is fair and strategyproof. Various recent works will be discussed along the fairness perspective.

4 - A Novel Class of Games with the Continuous-Time Fictitious Play Property via Geometrical Approach
Zhouming Wu, Yifen Mu, Xiaoguang Yang

Fictitious play (FP) is the earliest and most fundamental learning dynamics for computing Nash Equilibrium (NE) and it has been receiving significant research attention over the years. A central question in this field is identifying games in which FP converges, often referred to as games with Fictitious Play Property (FPP). In this work, we introduce a novel class of games with FPP: 3 by 3 games without Internal Indifferent Points (IIP). Our approach is based on a geometric analysis that leverages the locations of NEs and the partitioning of best-response

regions within the strategy simplex of the player, while the indifferent point is a novel geometric object of a game at which the actions of each player will yield the same "payoff". Specifically, we consider the continuous counterpart of FP, and develop a new projection mapping that reduces a high-dimensional dynamical system to a planar system. To address the non-smoothness inherent in the dynamical system, we propose a redefinition of the concepts of saddle NEs and sink NEs. These specific NEs are shown to exist and partition the projected space into two distinct regions thus can help us prove the convergence of dynamics. Additionally, we demonstrate that our projection technique can be generalized to higher-dimensional and degenerate games. By constructing a 3×3 game without IIP which is not quasi-supermodular, we show that this game class is indeed novel and different from the identified class in the literature.

■ MA-55

Monday, 8:30-10:00 - Room: Liberty 1.09

Network Optimization 1

Stream: Network Optimization
Invited session
Chair: Wissem Ahmed Zaid

1 - Agent Deployment Algorithms for Heterogeneous Wireless Sensor Networks in a Remote Monitoring Mission
Banu Kabakulak, E. Alper Yildirim

Wireless Sensor Network (WSN) is a system of spatially distributed, autonomous low power electronic devices, i.e., agents, that communicate wirelessly to collect the sensed data from a target region. This research aims to generate an optimal network topology for heterogeneous WSNs to continuously collect data from a remote agricultural land by deploying immobile multi-type agents, namely sensor nodes, actuators, routers, and gateways. We handle the Network Agent Deployment problem of a WSN in a real-time monitoring mission of large-scale agricultural lands. We propose mathematical formulations to generate a budget-efficient network topology for heterogeneous agents with limited capabilities of battery-power, bandwidth, coverage and communication ranges. We develop centralized and distributed scalable agent deployment algorithms with the energy-efficiency, connected coverage, and reliability concerns to establish a network layer with maximized estimated network lifetime.

Thanks to our cross-layer deployment approaches, the constructed network topology supports the implementation of energy-efficient, reliable, and fault tolerant data routing algorithms with low latency. We optimally deploy heterogeneous WSNs for remote monitoring of agricultural lands in this study, albeit our proposed algorithms are implementable in various applications such as forest fire monitoring in environmental sciences, or battlefield surveillance in military.

2 - Optimizing Air Pollution Sensor Networks: Integrating Stationary and Mobile Sensors Under Budget and Calibration Constraints
Mohammad Jafari, Bart van Arem, Serge Hoogendoorn, Maaike Snelder

Air pollution has become a significant global challenge, affecting public health, ecosystems, and economic stability. Accurate monitoring is essential for informed decision-making. While high-cost stationary sensors provide precise data, their limited deployment reduces overall coverage. Low-cost mobile sensors (LCSs) mounted on buses can complement stationary sensors, improving both spatial and temporal coverage. However, LCSs suffer from poor accuracy and require frequent calibration through single-hop (near a stationary sensor) or multi-hop (between two mobile sensors) methods. A gap exists in integrating sensor coverage and calibration in mixed stationary and mobile sensor networks under budget constraints. This study formulates a non-linear optimization model to select the optimal subset of buses and sensor station locations based on real-time bus location data and spatiotemporal grid weights. The objective is to maximize sensor network coverage while considering budget limitations and ensuring that all mobile sensors are calibrated frequently. The results of the model, applied to a Rotterdam case study, show that with 11 buses and 2 stationary sensors, 50% of the grids can be covered. The model output demonstrates that optimizing bus and sensor station selection enhances both calibration and coverage efficiency. Further studies can explore utilizing a mix of mobile platforms to enhance sensor network coverage and improve calibration efficiency.

3 - Optimization of Resilient Wireless Tactical Networks Using Tabu Search
Wissem Ahmed Zaid, Alain Hertz

This research focuses on optimizing wireless tactical networks using advanced heuristic methods, particularly Tabu Search. The objective is to design resilient communication infrastructures that ensure connectivity in environments where traditional telecommunications fail, such as disaster-stricken areas. These networks must adapt to unpredictable conditions while ensuring efficient data transmission and minimal latency. To tackle this problem, we adopt an integrated approach combining metaheuristics and graph theory-based techniques. The network topology is generated and optimized using Tabu Search, ensuring an adaptive and scalable structure. A geometric heuristic is then employed to configure antennas, maximizing signal strength and coverage while minimizing interference. Finally, the overall network configuration is refined through heuristics to enhance stability and efficiency. Results from synthetic tests demonstrate that our approach not only generates more effective network designs but also achieves this with a fast and efficient algorithm, significantly improving upon a previous solution. The study highlights the importance of heuristic-based approaches in addressing complex network design challenges and emphasizes the role of optimization techniques in ensuring efficient wireless communication, particularly in critical situations where connectivity is essential for emergency response and mission success.

■ MA-56

Monday, 8:30-10:00 - Room: Liberty 1.11

Computational Biology & Healthcare

Stream: Computational Biology, Bioinformatics and Medicine
Invited session
Chair: Piotr Lukasiak

1 - Applications of Graph and Network Methods in Biomedcine
Guiying Yan

Graph network[U+FF0C]as an effective model to describe the interaction of data, has become a more and more powerful tool in attacking some biomedical problems. The rise of network sciences[U+FF0C]such as network biology, network medicine, network neuroscience and network pharmacology, provides a new perspective for systematic and comprehensive research on biomedical problems.In this talk, I will introduce some applications of graph and network methods in several important biomedicine issues

2 - Efficient Multi-Objective Optimization for Large-Scale Conservation Planning
Aboozar Mohammadi, Jeffrey Hanson, Virgilio Hermoso, Silvia B. Carvalho

Protected areas are essential for preventing species extinction and keeping biodiversity. They must preserve populations with high nucleotide diversity and populations from different genetic lineages to maximize resilience, given limited conservation funds. Multi-objective optimization is well suited for finding solutions that can address multiple, often conflicting, goals. However, it has rarely been applied in conservation decision-making. This work presents a novel multi-objective

mixed-integer linear programming (MILP) model for conserving nucleotide diversity and genetic lineages for a set of species across available planning units in a cost-efficient manner. The constraints ensure the selected planning units satisfy the required targets while meeting a pre-defined budget. To navigate trade-offs between objectives, we introduce a new multi-objective optimization algorithm based on the epsilon-constraint method to approximate the complete Pareto front by computing a list of non-dominated solutions. As advantages, this algorithm is efficiently applicable to other multi-objective MILPs and capable of approximating the complete Pareto front rather than a single solution. Additionally, special attention was given to computational complexity to ensure that the model and algorithm are well-suited for large datasets. Numerical results will be presented to demonstrate the algorithm's efficiency in approximating Pareto frontiers using both simulated and empirical datasets.

3 - Applications of decision support systems in medicine
Piotr Lukasiak, Maciej Majchrzak

Decision support systems are playing an increasingly important role in medical data analysis, as the ability to analyse data and explore the rules governing the phenomena is becoming crucial in diagnosis and prevention. In this study, the focus was on two areas: liver analysis and head injury analysis. The liver plays a key role in maintaining overall health, and the implementation of appropriate dietary and lifestyle choices is of paramount importance to ensure its optimal functioning. Early recognition of hepatic steatosis and hepatic fibrosis is crucial for effective management and prevention of liver dysfunction.The aim of this study was to demonstrate that routine clinical tests, augmented with machine learning algorithms, are able to provide sufficient data to predict critical endpoints.The proposed FibrAIm tool facilitates the identification of patients who, despite the absence of abnormal laboratory results, may already have severe fibrosis. Another application of machine learning we have designed is the prediction of head injury types based on medical imaging data. The tool designed in this study, based on neural network models, enables efficient diagnosis of various head injuries, reducing the risk of complications and providing an effective and efficient decision support system in hospital emergency departments. In both cases, the effectiveness of the methodology implemented and designed was confirmed by the analyses and experiments carried out.

4 - Measuring and Optimizing Healthcare Accessibility and Equity for Medical Resources in an Aging Community
Jingshan Li, Qing Wang, Leqi Weng

Healthcare accessibility and equity are crucial in providing public medical services. Enabling fair and quick access to healthcare service is of critical importance to all populations, particularly for aging people in a developing economy during a large-scale urbanization process.

In this talk, healthcare accessibility and equity are discussed and an indicator index system to measure accessibility and equity is proposed. An improved two-step floating catchment area (2SFCA) method is then introduced to evaluate accessibility to health facilities, with the consideration of factors related to distance to the facilities and chronic diseases for elder patients. Then a mixed integer programming model is presented to optimally allocate regional medical resources for improvement on healthcare equity. Finally, a case study in an aging community in a metropolitan city in China is carried out to illustrate the applicability of the method.

■ MA-57

Monday, 8:30-10:00 - Room: Liberty 1.12

Public Transportation

Stream: Transportation
Invited session
Chair: *M. Grazia Speranza*

1 - Exploiting the flexibility of modular buses in an urban transit system
M. Grazia Speranza, Carlo Filippi, Gianfranco Guastaroba, Lorenzo Peirano

Urban transit systems usually operate according to fixed-route and fixed-schedule schemes by employing fixed-capacity vehicles, despite the mobility demand is unevenly spread out in both space and time. Modular buses are an emerging technology in which modules of relatively small capacity can be dynamically docked together to form greater capacity buses and can, therefore, make the transit system capable of adapting the capacity to the actual mobility demand. A module can be shifted from one line to another at pre-defined intersections and can be relocated when empty, if beneficial. We call these two operations sharing and rebalancing, respectively. Given a transport network comprising multiple bus lines and a mobility demand, we present an integer linear program to determine an optimal assignment of modules to lines, so that the mobility demand is met with a minimum total number of modules. We prove theoretically that there is no bound to the reduction of the number of modules deployed with respect to a setting without sharing and rebalancing. Computational experiments show that, by exploiting the flexibility of modular buses, the total capacity deployed can be reduced by 49% with respect to a conventional transit system, whereas the average occupancy ratio increases from 41.22% to 72.85%.

2 - Designing distance tariffs for public transport
Philine Schiewe, Anita Schöbel, Reena Urban

Setting the ticket prices is a crucial decision in public transport. Its basis is the underlying fare strategy which is relevant for all related questions, such as dynamic prices or prices for different passenger groups. Popular fare strategies are based on zones or on the traveled distance. Transitions from one fare strategy to another occur frequently, e.g., if two public transport operators are joined, or if structural decisions in a region have taken place. Here, we report practically relevant issues when a fare structure should be changed to a distance tariff. We present mixed-integer linear programs for finding the parameters of a distance tariff, analyze rounding properties, and reflect how the change in income for the operator and the number of highly affected passengers can be controlled. As special cases we discuss the transition from a flat tariff to a distance tariff, and the transition from a zone tariff to a distance tariff, which currently appears in the context of the Deutschlandticket. All introduced models are experimentally evaluated on benchmark data sets as well as realistic data.

3 - A dynamic optimization model for flexible modular buses in urban transit systems
Carlo Filippi, Gianfranco Guastaroba, Lorenzo Peirano, M. Grazia Speranza

Urban transit systems usually operate according to fixed-route and fixed-schedule schemes by employing fixed-capacity vehicles, even though mobility demand is unevenly spread out in both space and time. Modular buses are an emerging technology in which modules of relatively small capacity can be dynamically docked together to form greater capacity buses and can therefore make the transit system capable of adapting the capacity to the actual mobility demand. A module can be shifted from one line to another at pre-defined intersections and can be relocated when empty, if beneficial. We call these two operations sharing and rebalancing, respectively.

We develop a dynamic, time-indexed optimization model to manage modular buses in a network of bus lines. In a given time horizon, e.g. the rush hours in the morning, transport demand is modelled as a set of origin-destination pairs located at the stops of the bus network, associated with a number of riders and a time of departure. The model establishes the flow of modules along the lines that allow satisfying the demand for transport using a minimum number of modules, leveraging module sharing and rebalancing, and can be used in a rolling-horizon fashion.

Preliminary computational experiments conducted within a Kernel Search framework demonstrate the practical solvability of the proposed model and highlight its advantages compared to a static model previously developed.

■ MA-58

Monday, 8:30-10:00 - Room: Liberty 1.13

Location-Routing Problems

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Cagri Koc*

1 - A metaheuristic for the location-or-routing problem with simultaneous pickup and delivery
Cagri Koc, Busra Olgun, Okan Arslan, Fulya Altiparmak

This study addresses the simultaneous pickup and delivery location-or-routing problem, where a distribution network is designed to serve end customers with both pickup and delivery demands. The problem is tackled by optimizing facility locations and vehicle routes. A customer must either fall within the coverage area of a facility or be included in a vehicle route. If a customer is located within the coverage range of one or more facilities, the customer can be served directly or through vehicle-based service. The coverage range represents the customer's ability to travel to the facility independently. Conversely, customers outside the coverage area require vehicle-based service, where their pickup and delivery demands are met simultaneously by the same vehicles. The objective is to determine the optimal facility locations and vehicle routes that minimize total costs. We formulate the problem as a mixed-integer linear programming model and solve it using a commercial solver. We develop a metaheuristic based on adaptive large neighborhood search to effectively solve the problem. Extensive computational experiments are conducted on a set of generated instances, derived from multiple benchmark datasets in the literature, to analyze the problem's characteristics.

2 - An effective aggregation heuristic for Capacitated Facility Location Problems with many demand points
Sandjai Bhulai, Ruurd Buijs, Rob van der Mei

In location analysis, demand aggregation has been extensively studied, primarily in the context of p-median and p-center problems. However, relatively few studies address aggregation in the Capacitated Facility Location Problem (CFLP). This research explores the benefits of aggregation in CFLP scenarios where the number of demand points far exceeds the number of potential facility locations, making aggregation a valuable tool for reducing computational complexity. We propose methods for generating fixed-resolution aggregations that are likely to perform well for specific problem instances. These techniques form the basis of a broader algorithmic framework contributing to CFLP heuristics.

Our core approach applies k-means clustering in an m-dimensional space, where m represents the number of potential facilities. The clustering space is constructed by transforming the normalized distance matrix of the original CFLP to emphasize relevant distance variations while suppressing irrelevant ones. We evaluate our heuristic on large instances inspired by a real-world reverse logistics problem. Results indicate that our method outperforms an intuitive benchmark aggregation technique. Additionally, selecting appropriate hyperparameters and initializing the clustering process effectively enhances performance. These findings highlight the potential of demand aggregation to improve CFLP heuristics.

3 - Recycling Orange Peel: a Variant of the Two-Echelon Location-Routing
José-Fernando Camacho-Vallejo, Abiel Galindo, Juan-Carlos García-Vélez

We consider the problem faced by a recycling company that collects orange peel from both small producers and large orange juice companies. Pickup from small producers is limited by rural roads, where large trucks cannot traverse the streets. Hence, small vehicles are used to perform this task. An important feature is that small producers are willing to store orange peel residues until a large truck arrives to collect them, in exchange for economic incentives. Additionally, large trucks transport the consolidated orange peel from small producers and the residuals generated by large juice companies. The orange peel is then sent to a final customer, which, in this case, is a livestock farm, where it is mixed with grain feed. From a mathematical optimization perspective, this problem can be seen as a variant of the well-known two-echelon location-routing problem (2E-LRP). The classical version of the 2E-LRP does not include the pickup and delivery assumptions considered in our problem. Specifically, in the first echelon, small vehicles collect orange peel from small producers and determine which of them will serve as collection points. In the second echelon, large vehicles transport the consolidated orange peel from the collection points and large juice companies to deliver it to the growth farms. A mathematical formulation is proposed. A real-life scenario in the citrus region of Nuevo León, Mexico, is used to validate the applicability of the proposed study.

■ MA-59

Monday, 8:30-10:00 - Room: Liberty 1.14

Time tabling in public transportation

Stream: Transportation
Invited session
Chair: *Anita Schöbel*
Chair: *Léa Ricard*

1 - Bus Timetable Resynchronization Considering Passenger Demand and In-Vehicle Passenger Load
Ioannis Kampouris, Amalia Nikolopoulou, Konstantinos Gkiotsalitis

Public transportation networks play a crucial role in urban mobility by providing efficient, reliable, and sustainable transport options. One of the main challenges in bus network operations is minimizing passenger inconvenience by improving service connectivity and thus, minimizing waiting times. Timetable synchronization seeks to optimize the timing of bus arrivals at transfer nodes, ensuring minimal waiting times for passengers transferring between routes. This is particularly important in multi-modal transport networks, where seamless connections between different transport modes significantly influence passenger satisfaction. This study builds on the bus timetable resynchronization problem and expands it by introducing the concept of generalized passenger travel times, which reflects how increased in-vehicle passenger load leads to longer perceived passenger travel times. Given these considerations, this study introduces the bus timetable resynchronization problem (BTRP) with perceived travel times and models it as a non-linear programming problem. BTRP is then reformulated as a MILP through the use of linearizations, and is solved to global optimality using Branch-and-Cut. Computational experiments have been performed demonstrating the impact of the in-vehicle load on the perceived passenger travel times and the synchronization of services.

2 - Comparing macroscopic and microscopic modelling for railway timetable optimization
Inneke Van Hoeck, Carl Henrik Häll, Anders Peterson, Pieter Vansteenwegen

Different levels of detail can be used to model a railway network when optimizing the timetable. While microscopic models are required to accurately represent the train operations, they are often quite complex and require long computation times. Therefore, macroscopic models are often used instead. Microscopic simulation is then used in a later stage to determine if the timetable is conflict-free. We consider a macroscopic, mesoscopic and microscopic network representation to assess which level of detail is most useful in practice in terms of the quality of the solution and the computation time. Specifically, we formulate mathematical models to optimize the timetable robustness for each of the representations and apply them to two case studies with very different properties: a line on the Swedish network and a bottleneck area of the Belgian network. For both cases, optimizing directly

on the microscopic level leads to better solutions compared to optimizing with less details and solving the conflicts in a later stage. Regarding the computation times, the results show that, surprisingly, including more details does not always lead to longer computation times.

3 - Line planning and timetabling with limited station capacities
Michael Rihlmann, Anita Schöbel

Offering attractive public transport systems is a crucial aspect to reach a climate-neutral world. Many papers consider how to make them attractive for passengers but research mostly neglects to make them realizable in practice. In this talk we will cover model extensions to line planning and timetabling models from the literature to encounter the problem of limited station capacities. Many urban public transport systems have some main stations, where most of the existing lines stop regularly. The physical space at those stations can limit the number of platforms and therefore the maximal number of simultaneously arriving vehicles. Allowing two lines to stop at the main station at the same time creates a very convenient cross-platform connection for passengers, which is particularly reasonable if many passengers want to use this transfer. However, this is probably not possible to establish for all transfers at the main station if the number of platforms is limited. We will extend known line planning and timetabling models from the literature to include the aspect of stations with limited capacities. Additionally, we will present a new model for the case of one large main station which selects groups of lines to meet there minimizing the number of passengers transferring between the groups. Our findings are illustrated at the public transport bus system of Kaiserslautern, Germany.

4 - Railway Timetable Rescheduling at Scale
Léa Ricard, Michel Bierlaire

The timetable rescheduling problem addresses trains and passengers rerouting in disrupted railway networks, typically to minimize passenger inconvenience, operational costs, and deviations from the planned schedule. This study introduces a novel mathematical formulation based on a two-layered event-activity graph: a nearly microscopic graph for train operations and a macroscopic graph for passenger movements. The nearly microscopic graph models station tracks (i.e., tracks within stations, some equipped with platforms for passenger boarding and alighting) and section track occupations, accounting for potential track changes at bifurcations. Passengers are dynamically assigned to paths based on the disposition timetable adopted.

Recovery strategies include train cancellations, delays, rerouting, resequencing, emergency deployments, stop modifications, and short-turning. The proposed framework is tested on the Vaud railway network in Switzerland, which comprises 109 stations, 41 bifurcations, 262 section tracks, and 308 station tracks, under various disruption scenarios. Experimental results demonstrate that the framework can provide planners with several non-Pareto-dominated solutions within a three-minute computational time.

■ MA-61

Monday, 8:30-10:00 - Room: Maurice Keyworth G.31

Cognitive and situational factors in supported and unsupported processes

Stream: Behavioural OR
Invited session
Chair: L. Alberto Franco

1 - The impact of situational factors such as time pressure on the design and use of operational systems
Barbara Summers, John Maule

Operational systems are largely task centred, designed to help users optimise their decisions. However, system design has generally ignored the impact of situational factors that induce heightened emotional states which change information processing strategies and how decision makers interact with the system. Changes related to emotional state have implications for the design and usage of operational systems. We explore these issues, reporting results from two studies investigating how time pressure changes the decision processing strategies of experienced managers in the workplace. Our findings reveal six different strategies deployed by managers to cope with time pressure: Filtration (prioritising important information); Contest Deadline (contesting/renegotiating a deadline); Intuition (relying on gut reaction); Involving Others (delegating or getting advice from others); Working Longer (working beyond normal working hours); Acceleration (speeding up information processing). We show that how time is limited (e.g., deadline flexibility), characteristics of the task environment (e.g., how accountable the decision maker is for the outcome) and decision type (e.g. whether risk is a major feature of the decision situation) influence the strategy deployed. Importantly, we show strategy choice affects the quality of the decision outcome and discuss how different system design/implementation choices may, under time pressure, lead to the deployment of high or low quality strategies.

2 - Effects of intra-organizational gamification on performance
Mounir Derboghossian

Gamification is increasingly expanding beyond traditional domains such as education and healthcare to business applications. Initially applied in B2C contexts, gamification has recently gained traction in intra-organizational settings, aiming to enhance employee engagement, motivation, and productivity. But organizations risk incurring sunk costs, employee dissatisfaction, and increased turnover rates if an implementation fails. Despite its growing adoption, research on organizational gamification remains limited, and existing findings are inconclusive. Establishing a robust understanding of the conditions under which gamification succeeds is crucial for advancing this field and providing managers with evidence-based insights. To address this gap, we investigate the effects of gamification on productivity in comparison to and in combination with monetary rewards in a real-effort task setting. In our experimental study participants complete a tiresome task in a limited time under gamified, non-gamified conditions and with or without monetary incentives. Initial results show no significant effects of gamification on productivity compared to no or monetary rewards. Nevertheless, an increase in baseline enjoyment was observed compared to non-gamified conditions. In addition, higher enjoyment in gamified conditions lead to an increase in solution quality.

3 - Dynamics of decision making in optimal stopping: Diffusion decision model approach
Ly Tran, Ilkka Leppanen, Tianqi Hu

Researchers in Behavioural Operational Research (BOR) and related fields often acknowledge the need to study the cognitive processes underlying decision making. However, experimental research using cognitive process models to uncover the mechanisms driving decisions remains scarce. This paper introduces the Diffusion Decision Model (DDM), a cognitive process model that structurally captures how information in preferential choice is accumulated and integrated into relative decision values that determine choices. By applying the DDM to the Classical Secretary Problem, a sequential search task with rank-dependent payoffs where participants decide whether to accept or reject candidates based solely on their relative ranks, we demonstrate how cognitive process modelling can advance BOR, offering novel insights into decision dynamics that traditional behavioural studies often overlook. We use choice and response time data to estimate hierarchical DDMs and reveal how decision-making evolves throughout the search process. Our findings highlight that drift rates — the speed of evidence accumulation — decrease as relative ranks improve, signaling greater decision difficulty for high-quality candidates. By revealing not just what decisions are made but how and why suboptimal choices arise, cognitive process modelling provides actionable insights into the cognitive roots of decision biases. We conclude by advocating for the broader integration of cognitive process models within BOR.

4 - Intuition in decision making: Insights from drift diffusion modelling
Tianqi Hu, Ilkka Leppanen, L. Alberto Franco

Research on intuition often produces conflicting results and suffers from reliability issues due to the lack of tools that can conclusively evaluate a person's latent intuitive position. It has been recently proposed that a decision maker's intuitive position can be evaluated by estimating parameters with sequential sampling models (SSMs), which provide a biologically plausible framework to measure how intuition affects decisions. In two studies we use the Drift Diffusion Model (DDM), as a type of SSM, to investigate topics where intuition is difficult to evaluate. In Study 1, we examined how the Cognitive Reflection Test (CRT) scores relate to intuition in risky decision making. Our results challenge the conventional view that high CRT scores imply less reliance on intuition and that intuition is detrimental to decision performance. In Study 2, we examined the proposition that the preference for intuition is a stable disposition across decision domains. By comparing the preference for intuition between risky and social decisions, we provide evidence against the proposition. The evidence for this unstable preference has hitherto primarily resulted from self-reports, which have a questionable ability to assess the preference for intuition. In both studies, we demonstrate that the DDM can accurately simulate the decision outcome and decision time patterns that are affected by intuition, providing evidence for the usefulness of DDM analysis in the study of intuition.

Monday, 10:30-12:00

■ MB-01

Monday, 10:30-12:00 - Room: Great Hall

Thomas Spengler

Stream: Keynotes
Keynote session
Chair: Karsten Kieckhäfer

1 - Green Steel Production in Europe - Perspectives and Challenges
Thomas Spengler

Due to climate change, decarbonizing industrial processes is highly important. Regulatory instruments have been introduced to mitigate industrial greenhouse gas emissions, the most important of which is the EU Emissions Trading System. In Europe, the steel industry is responsible for around 20% of these emissions mainly resulting from coal-based production processes. Although technologies for low-carbon steel production exist, their integration into integrated steel mills requires high investments and leads to significant changes in material and energy demand and the resulting cash flows. In addition, the replacement of existing production facilities has an impact on the allocation and demand for emission allowances. Steel manufacturers are therefore faced with decisions regarding the transformation of their production infrastructure in a complex regulatory and economic environment. Such decision-making processes can be supported by methods of production management and Operations Research, whereby the design of advantageous transformation pathways using mathematical optimization is particularly important. The presentation will focus on the techno-economic modeling of strategic transformation pathways and the determination of prospective solutions based on the optimization of the resulting discounted cash flows.

■ MB-03

Monday, 10:30-12:00 - Room: Esther Simpson 1.01

EDDA 2

Stream: EURO Doctoral Dissertation Award
Award Competition session
Chair: Marjan van den Akker

1 - Pareto Front Reconstruction of Multi-Objective Optimization Problems
Pierluigi Mansueto

The thesis is concerned with multi-objective optimization (MOO) problems under various constraint types. In particular, we consider the unconstrained, the box constrained, the general convex constrained and the cardinality constrained settings. As a mathematical tool, MOO has received much attention over the years, being suitable both in operation research applications and in many real-world problems where contrasting goals have to be taken into account. In the dissertation, a general overview of the main MOO concepts is given, focusing on the notions typically employed in the gradient-based MOO approaches. In particular, we present a general formulation for the search direction problem and a general framework for single-point methodologies, i.e., approaches designed to generate a single solution to the problem at hand. The features of each of the two concepts are discussed and analyzed; finally, we show how they can be reduced to well-known schemes from the MOO literature. Then, we propose novel gradient-based methodologies aimed to reconstruct the Pareto front for the considered problem classes. In some of the mentioned settings it is the

first attempt to define this type of approaches generating multiple solutions rather than one, while in the others the topic has been almost unexplored yet. However, in the MOO context, returning an approximation of the Pareto front rather than a single solution can be much more useful for the final user, so as they can choose among multiple tradeoffs of the objectives the one that is the most suitable for themselves. For each methodology, detailed descriptions of the algorithmic scheme and characteristic features are reported; moreover, each methodology is theoretically analyzed and its convergence properties are stated and proved. Finally, the proposed methods are numerically tested with wide benchmarks of test problems, comparing each of them with state-of-the-art approaches from the MOO literature. The results show the efficiency and the effectiveness of the proposals w.r.t. the competitors in diverse experimental settings.

2 - Mixed-Integer Optimization Techniques for Robust Bilevel Problems with Here-and-Now Followers
Yasmine Beck

In bilevel optimization, some variables of an optimization problem have to be an optimal solution to another nested optimization problem. This structure makes bilevel optimization a powerful tool for modeling hierarchical decision-making processes, which arise in various real-world applications such as in critical infrastructure defense, transportation, or energy. However, due to their nature of combining two different decision-makers in one model, bilevel problems are inherently hard to solve. Further challenges arise if problems under uncertainty are considered. In this talk, we address different types of uncertainty in bilevel optimization using techniques from robust optimization. In particular, we highlight that the sources of uncertainty in bilevel optimization are much richer compared to single-level optimization since not only the problem data but also the (observation of the) decisions of the two players can be uncertain. To address data uncertainty in mixed-integer linear bilevel problems, we present exact branch-and-cut approaches with cuts tailored to the important class of monotone interdiction problems, which frequently arise in critical infrastructure defense and counterterrorism. Given their overall hardness, we also propose heuristics for these problems that do not require problem-specific tailoring. Finally, we study the problem of determining optimal tolls in a traffic network in which the network users hedge against uncertain travel costs in a robust way.

■ MB-04

Monday, 10:30-12:00 - Room: Rupert Beckett LT

Interpretable Optimization Methods and Applications

Stream: Data Science meets Optimization
Invited session
Chair: *Patrick De Causmaecker*
Chair: *Sureyya Ozogur-Akyuz*

1 - A SHAP-Driven Approach for Explainable Ensemble Pruning Using Semi-Infinite Programming
Melisa Caliskan-Demir, Volkan Bakır, Sureyya Ozogur-Akyuz

In this study, an ensemble Convolutional Neural Network (CNN) model was developed using different parameter configurations on the different datasets. The ensemble was pruned using Semi-Infinite Programming (SIP) to reduce model complexity while maintaining classification performance. Following this, SHapley Additive exPlanations (SHAP), an Explainable Artificial Intelligence (XAI) technique, was incorporated to enhance the interpretability of the model. SHAP values were used to analyze the contribution of different features to the decision-making process, and a second ensemble was formed based on this explainability-driven analysis. This new ensemble was then pruned again using SIP, and the results were compared with the initial pruning approach. Experimental findings demonstrate that SIP-based pruning effectively optimizes ensemble performance, while integrating SHAP enhances transparency by identifying key image regions influencing predictions. The comparative analysis of pruned ensembles, with and without SHAP integration, highlights the impact of explainability-driven pruning on deep learning model efficiency and decision reliability.

2 - Game-theoretic Tree Regression for Surrogate-based Optimisation of Active Pharmaceutical Ingredient Manufacturing
Artemis Tsochatzidi, Francesca Cenci, Magdalini Aroniada, Lazaros Papageorgiou

Modern industries rely on advanced modelling techniques to enhance process efficiency, yet the computational complexity of these models often limits their direct use in optimisation. Surrogate-based approaches provide an effective alternative, enabling efficient exploration of the solution space. In this work, we introduce a game-theoretic tree regression approach for surrogate-based optimisation, integrating a multi-target tree regression model to approximate complex process dynamics. The proposed approach formulates optimisation as a strategic decision-making problem, to reveal trade-offs between conflicting objectives such as yield and purity in Active Pharmaceutical Ingredient (API) manufacturing. By leveraging Pareto fronts and Nash equilibrium, the methodology provides a structured mechanism for navigating these competing goals and deriving optimal operational strategies. The proposed approach enhances interpretability, computational efficiency, and practical applicability, offering a powerful tool for decision-making in pharmaceutical manufacturing and beyond.

3 - Predictive performance and interpretability of machine learning algorithms compared to conventional mixed logit models in analyzing stated choice data
Christoph Herrmann, Katharina Friederike Sträter

Discrete choice experiments (DCEs) have become a popular tool to collect stated choice data. These structurally diverse data are traditionally analyzed using theory-based choice models to elicit the preferences behind a choice. In recent years, however, there have been several calls to also apply data-driven methods, such as machine learning algorithms. In this light, this paper investigates the added value of applying selected machine learning algorithms (random forest (RF), gradient boosting machine (GBM), neural network (NN), näive Bayes (NB)) to two structurally different examples of DCE-derived data, considering different types of data preparation. Thereby, special foci are on a) the predictive performance of the machine learning algorithms compared both to each other and a mixed multinomial logit (MMNL) model commonly used to analyze DCE-derived data, and b) whether it is possible to extract information about behavioral indicators from the machine learning algorithms' outcomes. The results indicate that the machine learning algorithms perform slightly better in terms of prediction when the data structure is rather simple. However, they provide only limited possibilities for interpretation, although variable importance (GBM and RF), SHAP-value (GBM and RF) and NB-specific conditional probabilities deliver important information that can help refine classical choice models. In addition, pitfalls that can arise due to DCE-specific data structures are discussed.

4 - Learn to Rank: Efficient Ranking and Visualisation of 4K Build Orientations for Surface Roughness Reduction in Additive Manufacturing
Peizhi Shi, Yuchu Qin, Fanlin Meng, Ming Luo, Sajid Siraj

Additive manufacturing is a promising manufacturing technique that is capable of building complex geometries and customised products. Due to its layer-by-layer printing nature, the build orientation of a part has important effect on the surface roughness of the part. In this research area, search algorithms are typically adopted to find optimal build orientations that could minimise the surface roughness. On the one hand, a search algorithm typically needs to explore a huge space. This time-consuming searching process often results in sub-optimal solutions. On the other hand, these heuristic search methods only cover a small

proportion of the search space and fail to provide visualisation for the whole space. To address these two problems, this paper proposes a novel ranking network that predicts the surface roughness ranking of 4,096 orientations based on a given solid model. By adopting this approach, the time-consuming O(N) search process could potentially be converted into one forward pass with O(1) complexity, which greatly increases the search efficiency. Additionally, surface roughness of 4K orientations could be visualised based on the ranking outcome. Experimental results show that the proposed learning paradigm with the new loss function produces superior results compared to search-, unsupervised learning-, and supervised learning-based approaches.

■ MB-07

Monday, 10:30-12:00 - Room: Clarendon GR.01

Advances in scheduling: From theory to practice

Stream: Scheduling and Project Management
Invited session
Chair: Erwin Pesch
Chair: *Alena Otto*
Chair: *David Müller*

1 - General load-balancing problems
Péter Györgyi, Tamas Kis, Evelin Szögi

We study a scheduling problem, where unit-time jobs require given quantities from a common resource throughout their execution. Each job has a set of time intervals, and a schedule is feasible if each job is scheduled within one of its time intervals. A special variant of the problem is when each job has a single time interval, i.e., when we have release dates and deadlines. The objective is to find a feasible schedule that minimizes a convex function of the load of the resource throughout the scheduling horizon.

Several variants of this problem have been studied under different names, e.g., the problem is a generalization of the load balancing problem, where each job requires a single unit from the resource. In the last decade, interest in the topic has increased as different energy management problems have become more important.

The presentation provides an overview on some recent results, mainly focusing on polynomial algorithms for various extensions of the problem. We have new results 1) for problems, where the jobs have more general processing times, 2) for problems, with more complex objective functions, 3) and for a problem, where the jobs need to be scheduled on parallel machines.

Acknowledgement: This research has been supported by the TKP2021-NKTA-01 NRDIO grant on "Research on cooperative production and logistics systems to support a competitive and sustainable economy".

2 - An algorithm selection approach for the flexible job shop scheduling problem: Choosing constraint programming solvers through machine learning
David Müller, Marcus G. Müller, Dominik Kress, Erwin Pesch

Constraint programming solvers are known to perform remarkably well for most scheduling problems. However, when comparing the performance of different available solvers, there is usually no clear winner over all relevant problem instances. This gives rise to the question of how to select a promising solver when knowing the concrete instance to be solved. We aim to provide insights into this question for the flexible job shop scheduling problem. First, we investigate relative performance differences among five constraint programming solvers on various problem instances. We find that two solvers, the IBM ILOG CPLEX CP Optimizer and Google's OR-Tools, outperform alternative solvers. Both solvers show complementary strengths regarding their ability to determine provably optimal solutions within practically reasonable time limits and their ability to quickly determine high quality feasible solutions across different test instances. Hence, we leverage the resulting performance complementarity by proposing algorithm selection approaches that predict the best solver for a given problem instance based on instance features. The approaches are based on two machine learning techniques, decision trees and deep neural networks, in various variants. In a computational study, we analyze the performance of the resulting algorithm selection models and show that our approaches outperform the use of a single solver and should be considered as a relevant tool by decision makers in practice.

3 - Fast bounds in Hexaly based on single-machine scheduling problems
Léa Petit-Jean Genat

Given a scheduling problem expressed in the Hexaly framework (a model and run mathematical optimisation solver based on various exact and heuristic methods), we aim to quickly compute a reasonable lower bound within a time that is negligible compared to the total solving time of the problem. Our approach employs classical scheduling algorithms with logarithmic-linear complexity on single-machine subproblems to address this challenge. We handle various objective functions, such as the (weighted) number of late jobs, weighted completion times, and maximum lateness, by leveraging well-known algorithms like Moore-Hodgson, Potts-Wassenhove, Smith, and Jackson. The main idea lies in detecting these expressions and exploiting the precedence constraints of the scheduling problem. The precedence constraints allow us to distribute due dates or weights across machines, enabling more tasks to be considered in the lower bound computation. This distribution allows us to compute lower bound values for each machine and ultimately select the most promising one. Experimental results on job-shop scheduling problems demonstrate significant improvements across different objective types. We achieved mean gap reductions of up to 31%, validating the effectiveness of our approach in quickly providing reasonable lower bounds.

4 - HLF optimality for scheduling a delayed precedence tree on m processors
Djamal Rebaine, Alain Quilliot

In a valid schedule of delayed precedence task graph, if there is an arc between task i and task j, then the start time of task j is at least d time apart from the completion time of task i. We consider n unit execution time tasks, linked by a delayed precedence intree, to schedule on m processors so as to minimize the makespan. It is known in the literature the Highest Level First rule is optimal for m=1. We prove in this study this rule remains optimal even if m is greater than 1.

■ MB-08

Monday, 10:30-12:00 - Room: Clarendon SR 2.08

Preference Learning 1

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Roman Slowinski
Chair: *Salvatore Greco*

1 - Dominance-Based Rough Set Approach and Seven-Valued Logic for Multicriteria Decision Aiding
Salvatore Greco, Roman Slowinski

The Dominance-based Rough Set Approach (DRSA) has proven to be a valuable tool in Multicriteria Decision Aiding (MCDA) due to its ability to represent decision maker preferences through "if..., then..." decision rules expressed in natural language. This feature makes DRSA particularly well-suited to address the increasing demands for

interpretability and explainability in decision-making processes. Here, we integrate DRSA with a recently proposed seven-valued logic for data analysis, which allows us to distinguish uncertainty due to imprecision from that caused by ambiguity arising from the granularity of information. This combined approach effectively addresses key MCDA challenges related to uncertainty, imprecision, and indeterminacy.

2 - Fast Estimation Process for Random Preference Model
Moha Ghaderi

Random Preference Model (RPM) is a nonparametric and flexible choice model capable of capturing a wide range of context-dependencies. In its most general case, it takes the population of permutations (complete rankings) over the set of choice options as the primitive and constructs: 1) a probability distribution over this set, and 2) a probability distribution over preference parameters (e.g., utility functions) that yield each specific permutation. Therefore the space of parameters grows exponentially with the size of choice options, making the estimation process intractable. Approximation algorithms rely restricting the RPM support, using partial instead of full rankings, or a combination of both. In all these case, however, RPM still requires sampling from the utility space to approximate the probability distribution over the preference parameters space, making it computationally expensive. I introduce an fast estimation process based on expectation-maximization algorithm that circumvents the need for a sampling and thus substantially reducing the estimation cost. I compare the proposed method with the sampling-based estimation using simulated choice data.

3 - Multinomial Decision Making (MNDM): A new Multi Criteria Decision Analysis based on random utility theory
David Palma, Richard Hodgett, Sajid Siraj, Romain Crastes dit Sourd

Common limitations in Multi Criteria Decision Analysis (MCDA) methods include (i) the need for direct definition of criteria weights, even though the literature on economics often favours indirect measures of preferences, e.g. in WSM, MAVT, TOPSIS and SMART; (ii) the often large number of pairwise comparisons required by methods like AHP or MACBETH; (iii) the need to normalise the value of criteria in methods like WSM, TOPSIS and SMART, introducing an additional source of variability when handling negative or minimising criteria; and (iv) the lack of flexibility dealing with uncertainty and interactions of criteria.

Multinomial Decision Making (MNDM) is a new method based on discrete choice modelling techniques and random utility theory. It requires the user to make a series of hypothetical simple choices (allowing for equal preference) among synthetic alternatives defined from subsets of criteria. From these choices, the weights of criteria are derived indirectly and a utility function constructed. The number of choices grows linearly with the number of criteria, avoiding overwhelming the user. Furthermore, it does not require normalising criteria values, allowing for the measurement of explicit trade-offs among criteria. A flexible definition of the utility function allows for interactions and non-linear effects of criteria (e.g. ideal point solutions). An explanation of the method and a software implementation will be presented at the conference.

4 - Eliciting additive preference models from heterogeneous preferences sources
Vincent Mousseau

Additive preference representation is standard in Multiple Criteria Decision Analysis, and learning such a preference model dates back from the UTA method [Jacquet-Lagrèze, Siskos, 1982]. In this seminal work, an additive piece-wise linear model is inferred from a learning set composed of pairwise comparisons. In this setting, the learning set is provided by a single Decision-Maker (DM), and an additive model is inferred to match the learning set. We extend this framework to the case where (i) multiple DMs with heterogeneous preferences provide part of the learning set, and (ii) the learning set is provided as a whole, without knowing which DM expressed each pairwise comparison. Hence, the problem amounts to inferring a preference model for each DM and simultaneously "discovering" the segmentation of the learning set. In this paper, we show that this problem is computationally difficult. We propose a mathematical programming based resolution approach to solve this Preference Learning and Segmentation problem (PLS), and also propose a heuristic to deal with large datasets. We study the performance of both algorithms through experiments using synthetic and real data. Moreover, we study the identifiability of the PLS problem, and propose, when two DMs are involved, a systematic elicitation procedure that enables to identify the two additive piecewise linear preference models.

■ MB-09

Monday, 10:30-12:00 - Room: Clarendon SR 2.01

Data Science in Insurance and Finance: New perspectives and Applications

Stream: OR in Finance and Insurance
Invited session
Chair: *Gabriella Piscopo*

1 - Integrated Crop and War Risk Insurance
Anna Nagurney, Ismael Pour, Borys Kormych

Conflicts and wars can significantly disrupt global agricultural supply chains, with severe impacts on food security worldwide. War risk insurance, on the other hand, can mitigate farmers' losses. In this paper, we use the theory of variational inequalities to construct a new multicommodity international trade network equilibrium model with exchange rates on general transportation networks joining supply markets with demand markets under different wartime scenarios. The model incorporates capacities on production and transportation, as well as potential commodity losses in transportation. We then propose formulae for integrated crop and cargo war risk insurance premiums that are supply market and commodity specific and incorporate them into the model, along with government subsidies for the premiums. A series of numerical examples, both illustrative and algorithmically solved, reveal the critical role of integrated war risk insurance and government support in sustaining agricultural commodity trade flows and supply market prices as well as protecting the revenue of farmers.

2 - Finding robust profiles of mental well-being across Europe
Irene Albarran

The aim of this work is to find robust profiles of older adults to better understand differing levels of emotional well-being across Europe. We use data from the Survey of Health, Ageing and Retirement in Europe, which was carried out in 26 countries and represents over 181 million aged individuals in Europe. In a first step, we use the information of around 80 variables in order to design composite indicators focused on quality of life in older age, loneliness, social integration and social connectedness. Next, we combine them with a collection of descriptive qualitative variables by computing pairwise robust generalized Gower distance for weighted data. Finally, we apply Fast k-medoids clustering algorithm to obtain the profiles. This new proposal can help to improve the identification of patterns and trends in insurance, for example in the development of more accurate predictive models to determine personalised premiums tailored to the specific needs of individuals. Pyhton packages PyDistances and FastKmedoids are used for the computations. Key words: Emotional well-being, elderly, Fast k-medoids, robust G-Gower, weighted mixed-type data

3 - Premium calculation using Parametric Quantile Regression for insurance count data
Fabio Baione, Davide Biancalana, Aurora Ferri

The measurement of the risk premium in insurance is a fundamental problem that is typically faced by evaluating separate models for frequency and severity and applying a safety loading to compensate for unexpected losses. In actuarial literature, recent studies have explored premium calculation using quantile-based principles, where quantile

regression is employed to compute conditional quantiles, typically using a continuous response variable to model severity. Our objective is to measure the safety loading using a premium principle based on the quantiles of the number of claims (frequency). However, applying quantile regression to count data presents both theoretical and practical challenges, which are usually addressed by artificially smoothing the discrete response variable through jittering. For these reasons, quantile regression has been rarely applied to count data in the actuarial field. In this paper, we employ parametric quantile regression for count data, as introduced by Frumento and Bottai, to derive a quantile-based premium. Estimation is performed by minimizing a "simultaneous" version of the loss function used in standard quantile regression. We provide an application to "daily disability benefit insurance." This type of insurance contract falls under non-life insurance policies, where the source of uncertainty lies exclusively in claim frequency, as the benefit amount per day (severity) is contractually fixed at the inception date.

4 - Implementing non-dominated sorting into asset preselection within portfolio problem
Tomáš Tichý, David Neděla, Sergio Ortobelli Lozza

By monitoring the financial markets, we can discover a huge number of potential investments, such as various stocks. Notwithstanding, it is very complicated and time-consuming to analyze all stocks and then use all of them in optimization according to the preferred portfolio strategy. Hence, for portfolio managers, it can be useful to focus on just a specific selection identified by a proper filtering process. This paper proposes an efficient approach for stock preselection based on the multidimensional nondominated sorting of selected statistics. In contrast to previous research, we design an innovative application based on statistics obtained from approximated return series using nonparametric regression and principal component analysis (PCA). Additionally, we study the impact on mean-variance and recently proposed complex mean-trend risk large-scale portfolio selection strategies. In particular, this process examines the efficient frontier of portfolios on the basis of various return and risk perspectives. In the empirical application to US stock market data, we present an ex-post and ex-ante analysis with results for 40 portfolio strategies. The results obtained strongly indicate that for most risk-averse investors, the mean-trend risk strategies with preselection outperform the same strategies without preselection, as well as the mean-variance strategies.

■ MB-10

Monday, 10:30-12:00 - Room: Clarendon SR 1.06

Integrated Healthcare Timetabling Competition I

Stream: Automated Timetabling
Invited session
Chair: Andrea Schaerf

1 - The Integrated Healthcare Timetabling Competition 2024 (IHTC-2024)
Andrea Schaerf, Roberto Maria Rosati, Sara Ceschia, Pieter Smet, Greet Vanden Berghe, Eugenia Zanazzo

We launched the Integrated Healthcare Timetabling Competition (IHTC-2024, https://ihtc2024.github.io/) to stimulate research on the specifics of integrated scheduling problems in healthcare. We introduced the Integrated Healthcare Timetabling Problem (IHTP), which brings together three critical problems in healthcare: surgical case planning, patient admission scheduling, and nurse-to-room assignment. In particular, it requires the following decisions: (i) the admission date for each patient (or admission postponement to the next scheduling period), (ii) the room for each admitted patient for the duration of their stay, (iii) the nurse for each room during each shift of the scheduling period, and (iv) the operating theatre for each admitted patient.

We provided a public dataset composed of 30 instances in JSON format, along with the solution checker (in C++) that certifies the quality of a given solution. The first stage of the competition is complete, and we received 32 submissions from teams across various European countries. Among all the participants, we selected five finalists, whose solution methods will be evaluated on the hidden dataset in the second stage.

In this talk, we will present the results of the competition, and the general insights that we gained about the problem and the solution methods.

2 - Operation STOR-i Time(tabling): Our entry to IHTC-2024
Matthew Davison, Graham Burgess, Rebecca Hamm, Ben Lowery, Adam Page

Nurse rostering is a highly complex optimisation problem where traditional exact methods become computationally infeasible for large instances. Our open-source hyper-heuristic solution for the IHTC-2024 employs a two-phase strategy to construct and refine schedules.

In the first phase, we generate feasible solutions using a greedy heuristic. Mandatory patients are prioritised and sequentially inserted into the schedule. If any remain, they are re-prioritised for the next pass, and the schedule is reset. This process continues until all patients are admitted or the algorithm times out. Nurses are then assigned to shifts in sequence to meet workload demands. The second phase refines the initial solution using a parallelized heuristic, applying diverse sequences of moves to improve schedule quality. Moves are selected according to either a simple random approach or one of two reinforcement learning approaches (Monte-Carlo or Q-learning). Solution acceptance follows either a record-to-record or simulated annealing scheme.

By experimenting with different methods, we gained insight into heuristic approaches for the IHTC-2024, leading to the results for competition submission. Our approach highlights the adaptability and capability of heuristic methods for addressing complex rostering challenges.

3 - Healthcare Predictive Timetabling: A predictive control solver for integrated healthcare timetabling
Daniele Giovanni Gioia, Lorenzo Mazza, Manuel Macis, Edoardo Fadda, Paolo Brandimarte

Given the importance of timetabling for healthcare applications, a two-phase solution approach for the Integrated Healthcare Timetabling Problem is proposed. It addresses the Surgical Case Planning (SCP), Patient Administration Scheduling (PAS), and Nursing Resource Allocation (NRA) via Mixed-Integer Linear Programming. In the first phase, SCP and PAS are combined in a single model (SCPPAS), recognizing that the feasibility of any timetable depends on the alignment of surgical cases with patient admissions. While NRA is solved separately, its cost implications are approximated in the SCPPAS objective to ensure realistic resource considerations. The second phase solves NRA exhaustively, leveraging the previous approximation to refine staffing allocations. Since SCPPAS can become prohibitively large for real-world instances, a model predictive control strategy is adopted. Specifically, both the planning horizon and spatial dimension are restricted at each iteration, and then rolled forward over time. Smaller, more tractable subproblems are solved iteratively. This rolling approach ensures that decisions remain in a neighborhood of the feasible space, maintaining an integrated perspective across all subproblems. Preliminary computational experiments demonstrate that our method yields feasible schedules with tunable time and computation requirements.

4 - Using Graph Transformation and Mixed Integer Linear Programming to solve the IHTC 2024
Maximilian Kratz, Steffen Zschaler, Jens Kosiol, Andy Schürr

In this talk, we present our solution to the International Healthcare Timetabling Competition (IHTC) 2024. In IHTC 2024, competitors must calculate a valid roster for patients, nurses, and surgeons as well as a room schedule while ensuring various constraints are satisfied. Our solution is based on GIPS, the "Graph-Based (M)ILP Problem Specification (GIPS) Tool", which combines Graph Transformation (GT) and Mixed Integer Linear Programming (MILP). GIPS aims to

allow users to easily and compactly specify optimization problems using graph-based modeling and a domain-specific language close to the respective problem domain. In contrast to other approaches, GIPS does not need a (hand-written) low-level representation of graph structures like arrays or matrices for handling graph-based models. For example, required or forbidden structural graph patterns can easily be specified using mechanisms like inheritance and typification. GIPS translates a given compact specification to a MILP problem, which it solves with off-the-shelf constraint solvers. One of the benefits of GIPS is that the high-level specification can be changed and adopted easily which can support a rapid prototyping workflow, easy incremental development of problem specifications, and adaptation to new contexts. This talk will focus on showing how GIPS allows for compactly specifying the IHTC 2024 problem with its domain-specific language, using an iterative approach adding constraints step by step.

■ MB-11

Monday, 10:30-12:00 - Room: Clarendon SR 1.03

Kidney diseases and exchange

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Rachael Colley*
Chair: *David Manlove*

1 - System dynamics facilitate complex decision-making for healthcare delivery: A case study of chronic kidney disease in Wales

Thomas Padgett, *Phil McEwan*

INTRODUCTION Global healthcare systems face rising costs and increasingly complex choices for decision-makers, making it crucial to fully understand treatment value. Here, a systems dynamics approach allowed the Welsh NHS to evaluate the overall burden of chronic kidney disease (CKD) and understand the short- and long-term impacts of current treatment guidelines on future prevalence, to ensure treatment capacity in the future.

METHODS An age- and CKD stage-stratified system dynamics model of Welsh CKD prevalence was developed, with age-dependent migration and mortality rates. It was calibrated against observed prevalence data from 2000 to 2020 and used to predict prevalence up to 2044.

RESULTS Welsh CKD prevalence is predicted to rise from 208,000 in 2024 to 234,000 by 2034. Prevalence of end-stage kidney disease (ESKD) is predicted to rise from 3,448 in 2024 to 4,002 by 2034. Treatment optimisation is predicted to further increase CKD prevalence whilst marginally reducing ESKD. This is explained by the interplay between slowing of CKD progression and reductions in mortality rates, meaning people have longer to progress to later CKD stages . Across Wales, existing dialysis centre capacity was found to be sufficient up to 2044.

CONCLUSION Using systems dynamics to model the Welsh CKD population revealed future interplay between optimised treatment implementation and prevalence of ESKD, allowing informed decision making on future treatment (dialysis) capacity.

2 - A hybrid modelling approach for investigating interventions in renal care

Lucy Morgan, *Sally Thompson*, *Jennifer Wood*

In this talk we present a combined study of Chronic Kidney Disease (CKD) progression and capacity planning for Kidney Replacement Therapy (KRT). We use a hybrid modelling approach using System Dynamics (SD) to model CKD progression and project the rate of incident KRT patients over time; and a Discrete Event Simulation (DES) model to take that incidence and consider the capacity required to treat the projected demand. The modelling allows interventions in both models to be investigated meaning the impact of primary care interventions can be considered in isolation or in combination with changes to renal treatment pathways.

This project was carried out with guidance and support from the Midlands Renal Network with input from other regional networks. A facilitated modelling approach was adopted. The feedback from the network on the construction and validation of the models was critical to the project success. In this talk we present the modelling approach and project outcomes followed by reflections and planned future work.

3 - Refined ILP models for the kidney exchange problem with stability

Mathijs Barkel, *Maxence Delorme*, *David Manlove*

Kidney exchange programs allow patients with willing but incompatible donors to exchange their donors to obtain a compatible kidney. The Kidney Exchange Optimization Problem (KE-Opt) involves finding a matching of maximum size, i.e., a set of kidney exchanges involving cycles and chains that maximises the total number of transplants.

We consider the setting where recipients have ordinal preferences over their potential donors and where the objective is to find a maximum size stable matching, in which no exchange exists where all involved recipients prefer the donor in that exchange over their assigned one (if any). This problem is NP-hard, motivating the need for advanced methods.

To this end, we propose novel ILP models for KE-Opt with stability, building upon existing ones. We consider four previously defined types of stability, namely strong and weak stability, as well as strong and weak local stability. Our models are based on existing cycle and chain models for KE-Opt, some of which had not been tested before in the setting with stability. Further contributions include preprocessing techniques, refined stability constraints and a constraint generation framework to effectively handle stability.

Additionally, we conduct extensive computational experiments on realistically generated instances to evaluate and compare the performance of our models against existing ones.

4 - Local stability of kidney exchanges with length-two cycles

Elise Vandomme, *Marie Baratto*, *Yves Crama*

Kidney Exchange Programs (KEP) address the challenge of optimally assigning compatible kidney donors to patients who have willing but incompatible donors. In a KEP, incompatible donor-recipient pairs can "swap" donors with other pairs to create compatible matches. The swaps can involve multiple pairs in cyclic exchanges. The goal is to maximize the number of matches under various constraints, e.g., an upper bound on the cycle length or a stability requirement. Here, we restrict our attention to cycles of length 2 and to the case where each recipient expresses preferences among its compatible donors. This is the setting of the classical Stable Roommates Problem (SRP). It gives rise to a graph model where vertices represent recipient-donor pairs and edges represent compatibilities. A matching M is called stable when it has no blocking pair, meaning a pair of vertices that would prefer to be matched together rather than to their current mates in M. Determining whether a stable matching exists for an instance of SRP, and producing one if it does, can be done in polynomial time. Baratto et al. (2024) recently introduced a new concept called local stability (or L-stability). A matching M is L-stable if no blocking pair intersects M. We present several structural results on L-stable matchings, as well as a strong property of such matchings with respect to stable partitions. From these results, we derive a polynomial-time algorithm for computing an L-stable matching of maximum size.

■ MB-12

Monday, 10:30-12:00 - Room: Clarendon SR 1.02

Scheduling models and algorithms

Stream: Scheduling and Project Management
Invited session
Chair: Alessandro Agnetis

1 - The Unreliable Job Selection and Sequencing Problem
Emmeline Perneel, Alessandro Agnetis, Roel Leus, Ilaria Salvadori

We introduce the Unreliable Job Selection and Sequencing Problem (UJSSP), in which a subset of a set of jobs is selected for processing on a single machine that is subject to failure. Each job incurs a cost if selected and yields a reward upon successful completion. A job is completed successfully only if the machine does not fail before or during its execution, with failure probabilities varying across jobs. The objective is to determine an optimal subset and sequence of jobs to maximize the expected net profit. We establish the computational complexity of UJSSP, proving its NP-hardness when job costs are not identical. Additionally, we present a compact MILP formulation and derive an efficiently computable upper bound for the optimal solution. To tackle large problem instances, we develop a novel exact solution method and evaluate its performance through extensive computational experiments.

2 - Multiprocessor job scheduling with increasing the number of machines
Tao Sun

A multiprocessor job is the job that requires simultaneously more than one machine for its processing. For the multiprocessor job scheduling problem with minimizing the makespan, the impact of increasing the number of machines on the makespan is analyzed, the best-case impact ratio for the optimal schedule and that for approximation schedules are proved, and the law that the makespan decreases and trends toward stabilization as the number of machines increases is revealed. Furthermore, increasing the number of machines results in a decrease in the makespan and an increase in the machine costs. The trade-off between the decrease in the makespan and increase in the machine costs is analyzed, and the number of machines is determined to minimize the weighted sum of the makespan and the machine costs. An approximation algorithm based on the first fit decreasing algorithm is designed to obtain the schedule. The worst-case performance ratio of the approximation algorithm is proven to be no greater than 2. The simulation results show the effectiveness of the best-case impact ratios for the approximation schedules and the worst-case performance ratio of the designed approximation algorithm.

3 - The single machine adversarial bilevel total tardiness problem with job selection
Elena Rener, Federico Della Croce, Andrea Grosso, Vincent T'kindt

Bilevel scheduling problems emerge in a variety of domains, including manufacturing and information systems. In these contexts, local schedulers interact with global decision centers in a system characterized by asymmetric information and self-interested behavior. Our study focuses on a particular case where a local scheduler aims to minimize total tardiness by assigning jobs to a single machine. The scheduler first submits the jobs to a dispatching center, which selects only a subset of them. Assuming that the selection criteria are unknown and do not take into account the scheduler's objective, we consider the adversarial analysis, which evaluates the worst-case situation for the local scheduler, i.e., the case where the minimum total tardiness is the maximum among all possible job selections. From a computational perspective, this setting poses significant challenges in developing tight bounds and identifying partial job selections that yield suboptimal solutions. This is because the final schedule heavily depends on the full job selection. Nonetheless, in instances where the partial job selection exhibits specific characteristics, it is possible to derive an upper bound. Moreover, powerful job dominance conditions can be applied during the search process, and properties of optimal solutions can be used to rapidly identify good solutions. We propose an exact algorithm, derived from these results, that efficiently solves instances with more than a hundred jobs.

■ MB-13

Monday, 10:30-12:00 - Room: Clarendon SR 1.01

Medical services and applications

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Edilson Arruda

1 - Towards personalised pathway management for acquired brain injury paediatric rehabilitation via Markov models
Bruno Salezze Vieira, Edilson Arruda

Acquired Brain Injury (ABI) is a leading cause of disability in pediatric patients, requiring personalized rehabilitation approaches. This study introduces a Markov model-based framework for managing ABI rehabilitation pathways, enabling dynamic, patient-specific predictions. Unlike traditional models, which assume static recovery trajectories, our approach adapts to new patient data over time, capturing inter- and intra-patient variability.

Using anonymized data from the Bristol Royal Hospital for Children (2016-2018), we analyzed 575 weekly rehabilitation records from 53 patients. Multinomial logistic regression was employed to estimate transition probabilities between Kings Outcome Scale for Child Head Injury (KOSCHI) states. The model achieved 93% accuracy and a log-likelihood of 0.84, demonstrating strong predictive performance.

By offering a probabilistic view of recovery, our approach supports clinicians in making informed decisions, adjusting treatment plans dynamically, and improving patient outcomes. This study advances personalized pathway management through data-driven, adaptive modeling.

2 - Modelling the Dynamics of Familial Hypercholesterolemia (FH) Screening and Treatment: Insights from Singapore's Emerging Genomic Testing Initiatives
Alec Morton, Len Malczynski, Jamaica Briones, Jing Lou, Hwee Lin Wee, David Matchar

Familial hypercholesterolemia (FH) is a genetic condition that raises cholesterol and increases cardiovascular risk. In Singapore, an estimated 25,000 people have FH, though fewer than 10% are diagnosed. Early screening and statin treatment can prevent severe complications, but a nationwide FH screening program faces significant challenges in capacity and resources. This study presents a dynamic simulation model to explore strategies for FH screening, diagnosis, and management, informed by stakeholder insights.

The model simulates FH screening and treatment dynamics in Singapore, identifying strategies to meet rising demand within limited healthcare capacity. Through Group Model Building (GMB), we engaged clinicians, administrators, and policymakers to pinpoint key factors affecting FH screening and capacity constraints. These elements were integrated into a system dynamics model, highlighting interactions between referral flows, screening limits, and workforce shortages.

Cascade testing, which screens family members, may overwhelm primary and specialty care without resource expansion. Triaging by LDL levels and expanding primary care roles in initial screenings could alleviate some pressure on specialty clinics. Decentralizing testing and increasing genetic counseling capacity are also crucial for scalability. This model provides a tool for policymakers to balance screening demand with healthcare capacity, supporting large-scale genomic testing initiatives.

3 - Improving the Equity and Efficiency of Cystic Fibrosis Screening
Hussein El Hajj, Ebru Bish, Douglas Bish

Newborn screening (NBS) plays a key role in detecting life-threatening genetic disorders, with cystic fibrosis (CF) being a prominent example. CF stems from pathogenic variants in the CFTR gene, detectable through genetic testing, and is often associated with elevated immunoreactive trypsinogen (IRT) enzyme levels. With over 700 known CF pathogenic variant types, CF genetic testing is expensive and capacity-constrained. Consequently, across all US states, CF NBS begins with an inexpensive biochemical IRT test; genetic testing is reserved for a small fraction of newborns with elevated IRT levels, based on an IRT threshold. However, challenges arise in setting an optimal IRT threshold that balances sensitivity with overall screening cost and genetic testing capacity, exacerbated by variations in IRT levels and CF prevalences among different racial groups. This paper introduces an innovative screening approach, integrating an inexpensive small-panel genetic test (DNA) with IRT test, to develop a strategy that can customize IRT thresholds for the newborns. This approach leads to novel optimization problems, involving variant selection for the small-panel DNA, and IRT threshold customization based on the number of variants detected by the small-panel DNA. We establish key structural properties of optimal IRT thresholds, and develop Pareto frontiers that inform the decision-maker of the efficiency versus equity trade-off.

4 - Technology Opportunity Discovery for Smart Healthcare
Yucheol Kim, Hyungsuk Lim, Geon Hyeok Chun, So Young Sohn

Smart healthcare is a rapidly expanding field with potential of providing personalized and cost-effective healthcare solutions. Despite the rising attention in smart healthcare, most previous studies that focus on identifying innovative opportunities in smart healthcare only offer fragmented approaches as they neglect the integration of biological and technological perspectives. In this study, we propose a novel framework that can predict future innovations in smart healthcare based on disease co-occurrence pattern in smart healthcare technologies. Our framework leverages time-dynamic link prediction within a multiplex disease co-occurrence network that incorporates diverse relationship between diseases. In the link prediction process, we compare various network embedding models and window strategies to optimize the performance of predicting disease co-occurrence patterns. Additionally, we utilize community detection to uncover potential technologies that are capable of effectively addressing previously unobserved combinations of diseases.

■ MB-15

Monday, 10:30-12:00 - Room: Esther Simpson 1.08

Location problems

Stream: Combinatorial Optimization
Invited session
Chair: *Paolo Toth*
Chair: *Silvano Martello*

1 - Multi-period planning for electric vehicle charging station location and sizing with station-pile compatibility constraints
Song Wu, Yang Wang, Wei-Neng Chen, Jin-Kao Hao

Electric vehicles (EVs) are essential for advancing clean transportation and achieving carbon neutrality, yet their widespread adoption is hindered by insufficient charging infrastructure. This study addresses this challenge by introducing a novel multi-period optimization problem for the strategic location and sizing of charging stations. Over the planning horizon, demand points emerge progressively, with both fast-charging and slow-charging demands increasing over time. The objective is to minimize the total costs of station construction and pile deployment. Specifically, we consider stations offering a combination of fast and slow charging services, utilizing multiple pile types with varying power levels to meet diverse demands. Charging stations are further classified into different scales based on the number of piles, with each scale supporting a subset of available pile types. Additionally, station service capacity is constrained by the surrounding power grid. To solve this complex problem, we develop a mixed-integer programming model and propose an iterative kernel search matheuristic algorithm. Extensive computational experiments on 40 instances reveal that the proposed algorithm outperforms the Gurobi solver in 90% of instances, delivering better solutions within shorter computation times. Furthermore, a real-world case study based on the location data of 1,000 parking lots in Guangzhou is conducted, generating an optimal five-year deployment plan.

2 - Optimal Pricing in a Bilevel Hub Location Problem
Nele Pommerening, Uwe Clausen, Christoph Buchheim, Maja Hügging

We study a bilevel variant of the hub location problem in which a logistic-service provider (the leader) builds a logistical network and offers several options of shipment service at different quality and at different prices. These shipment options can represent different delivery speed or features like real-time tracking. The shipment costs for the leader increase with the quality of the service. Based on their available budgets and the prices appointed by the leader, customers (the follower) then decide whether they order one of the shipment options. A customer will always order the 'best' shipment option they can afford.

Because of the reciprocal interference of the two decision-makers, the leader has to take into account the customers' reaction when maximizing the profit, i.e. the costs of transport via the established network subtracted from the generated revenue.

Due to the complexity of classical hub location problems, our bilevel problem is NP-hard. Our langrangian decomposition approach yields a tractable customers' decision problem and an NP-hard prize-collecting hub location problem. We specify lagrangian multipliers and prove their optimality, showing that they leave no duality gap. As a by-product, we obtain a polynomial-time reduction of our bilevel problem to the more compact (single-level) prize-collecting problem which may offer a significant advantage with respect to the required computational effort compared to standard single-level reformulations.

3 - A Benders Decomposition approach for the clustered hierarchical hub location problem
Yerlan Kuzbakov, Laurent Alfandari

The Clustered Hierarchical Hub Location Problem (CHHLP) aims to find the locations of two types of hubs in a transportation network: local and global, and directing traffic through these hubs between each pair of customers at minimum cost. A key feature of CHHLP is the clustering of nodes, where inter-cluster connectivity is exclusively provided by global hubs. A practical application of this problem can be observed in transatlantic transportation systems, where continents function as clusters and seaports serve as global hubs. In this study, we propose a mixed-integer linear programming (MILP) formulation to address the CHHLP. The problem becomes computationally challenging for large-scale instances. To tackle this, we employ a Branch-and-Cut method, where cuts are generated using Benders Decomposition to enhance computational efficiency. Additionally, we explore heuristic approaches to provide near-optimal solutions for larger instances, ensuring a balance between solution quality and computational tractability. We also explore the application of Branch-and-Price techniques to solve various instances of the CHHLP. The results aim to demonstrate the effectiveness and scalability of the proposed methods.

■ MB-16

Monday, 10:30-12:00 - Room: Esther Simpson 2.07

Food and Nutrition Security - Food Waste

Stream: Sustainable Food & Agroforestry
Invited session
Chair: Marleen Balvert

1 - Data-driven robust menu planning for food services: Reducing food waste by using leftovers
Marloes Remijnse, Marjolein Buisman, Ahmadreza Marandi, Sonja Rohmer, Tom van Woensel

With food waste levels of about 30%, mainly due to overproduction, reducing food waste is an important challenge for the food service sector. As food is prepared in advance rather than on demand and has a perishable nature, this increases the risk of meals remaining uneaten. Flexible meal planning can promote the reuse of these leftovers and reduce the sector's environmental impact. In this study, we propose a menu planning model that not only incorporates traditional meal planning decisions related to serving and purchasing, but also decisions related to storage and reuse. Demand uncertainty presents a main driver of waste in this context, as we prove in this paper. We address this uncertainty through a data-driven adjustable robust optimization approach and show how this can be solved efficiently. Our model minimizes environmental impact or cost while aligning with customer preferences. By applying this model to a real-life case study of a food service provider, we demonstrate that reusing leftovers is a viable strategy for reducing purchasing costs (by 4%) and reducing environmental impacts of waste (by 11-19%). Further analysis shows that increasing order frequency, and making early purchases enhance flexibility and reduce waste. These findings offer actionable insights into promoting a circular (bio)economy in industries managing perishable products under uncertain demand.

2 - Optimizing Recipe-Based Product Bundles to Minimize Supermarket Food Waste
Liana van der Hagen, Joris Wagenaar

There is a global commitment to reduce food waste, reflected in the United Nations Sustainable Development Goals, which include a target to significantly reduce food waste by 2030. Food waste occurs throughout the supply chain, from production to retail to household consumption, and requires different strategies to effectively tackle it. In supermarkets, waste is often caused by products that are close to their best-before date and remain unsold. One strategy to address this is to bundle such products in recipe-based boxes, providing customers with meal ideas that encourage them to buy products that are about to expire. This approach also provides a practical way for customers to use the food that is about to expire. In this study, we develop an optimization model to assemble these boxes by maximizing the use of expiring products while ensuring compatibility with recipes. The model considers the availability of both expiring and regular products in the supermarket, and accounts for the fact that ingredient requirements can be met using different items from the store's assortment. We explore how this approach can reduce food waste at the supermarket level while providing customers with a structured and convenient way to consume food.

3 - Transforming Food Waste Management: Insights from Mobile Application Adoption
Jiequan Hong, Nadine Kafa, Anicia Jaegler

Food waste is a critical global challenge impeding progress toward Sustainable Development Goal 2 (Zero Hunger). Food Waste Mobile Applications (FWMAs) have recently emerged as innovative platforms for redistributing surplus food by connecting food businesses with consumers. However, their adoption by food businesses faces barriers such as limited managerial support, perceived operational costs, technological challenges, and regulatory uncertainties, alongside distinct motivational drivers. This study explores these factors using a systematic PESTLE framework, categorizing determinants into political, economic, social, technological, legal, and environmental dimensions. Employing a two-phase Delphi-Voting Analytical Hierarchy Process (VAHP) approach, the research identifies economic factors, particularly cost optimization, as the most critical driver. Experts in FWMAs, as well as suppliers and operators, validate these factors through the Delphi method, while the VAHP prioritizes their relative importance, offering actionable insights. The study highlights the need for tailored policy interventions, advanced technological solutions, and financial incentives to boost FWMA adoption. By addressing these factors, FWMAs can play a pivotal role in building sustainable food systems, reducing waste, and enhancing resource efficiency. This research provides valuable guidance for policymakers and businesses to advance the global fight against food waste.

■ MB-17

Monday, 10:30-12:00 - Room: Esther Simpson 2.08

Combinatorial bilevel optimization 2

Stream: Combinatorial Optimization
Invited session
Chair: Ivana Ljubic

1 - Game-theoretic relaxations in bilevel optimization
Noah Weninger, Ricardo Fukasawa

We introduce a framework for relaxing Stackelberg zero-sum games with perfect information, with a focus on those arising from discrete bilevel optimization. The framework consists of operators which transform games while maintaining an approximation or bound on the optimal objective value. This simplifies and generalizes our two previous works on knapsack and matroid interdiction. It also generalizes well-known techniques including the high point relaxation and the derivation of bounds by restricting/relaxing the lower level problem. To further motivate this approach, we apply it to matching interdiction, in which the objective is to interdict (i.e., remove) edges from a graph so that the maximum matching weight is minimized, subject to a knapsack constraint on the set of interdicted edges. We present a branch-and-bound algorithm for this problem which uses a new lower bound derived using our framework.

2 - An Exact Method for Nonlinear Network Flow Interdiction Problems
Martin Schmidt, Johannes Thürauf

We study network flow interdiction problems with nonlinear and nonconvex flow models. The resulting model is a max-min bilevel optimization problem in which the follower's problem is nonlinear and nonconvex. In this game, the leader attacks a limited number of arcs with the goal to maximize the load shed and the follower aims at minimizing the load shed by solving a transport problem in the interdicted network. We develop an exact algorithm consisting of lower and upper bounding schemes that computes an optimal interdiction under the assumption that the interdicted network remains weakly connected. The main challenge consists of computing valid upper bounds for the maximal load shed, whereas lower bounds can directly be derived from the follower's problem. To compute an upper bound, we propose solving a specific bilevel problem, which is derived from restricting the flexibility of the follower when adjusting the load flow. This bilevel problem still has a nonlinear and nonconvex follower's problem, for which we then prove necessary and sufficient optimality conditions. Consequently, we obtain equivalent single-level reformulations of the specific bilevel model to compute upper bounds. Our numerical results show the applicability of this exact approach using the example of gas networks.

3 - Bilevel optimization with sustainability perspective: a survey on applications
Ivana Ljubic, Giulia Caselli, Manuel Iori

Bilevel optimization, a well-established field for modeling hierarchical decision-making problems, has recently intersected with sustainability studies and practices, resulting in a series of works focusing on bilevel optimization problems involving multiple decision makers with diverse economic, environmental, and social objectives. This survey offers a comprehensive overview of sustainable bilevel optimization applications. We review the most relevant works published in sustainable bilevel optimization, giving a classification based on the application domains and their association with well-known operations research problems, while briefly discussing the proposed solution methodologies. We survey applications on transportation and logistics, production planning and manufacturing, waste, material, and environment management, supply chains, and disaster prevention and response. We also outline a list of open questions and opportunities for future research in this domain.

■ MB-18

Monday, 10:30-12:00 - Room: Esther Simpson 2.09

OR for Sustainable Development II

Stream: OR for Sustainable Development
Invited session
Chair: *Jinal Parikh*

1 - The Impact of the Carbon Border Adjustment Mechanism on Employee Compensation: A Comparative Input-Output Analysis for the UK and Turkey

Oyku Yucel, Gizem Celik, Zafer Yilmaz

This research examines the impact of the Carbon Border Adjustment Mechanism (CBAM) on employee compensation in the UK and Turkey, utilizing a Multi-Regional Input-Output (MRIO) framework. The study develops various direct impact scenarios based on changes in exports to the EU, disaggregated by country and sector, with two key scenarios reflecting a 25% (Q1) and a 75% (Q3) change in export levels. These scenarios are designed to quantify how variations in export volumes to the EU influence labor compensation across different sectors in both economies. By analyzing the interplay between carbon pricing, trade flows, and sectoral characteristics, the research provides insights into how these factors collectively shape wages and compensation patterns in response to CBAM implementation. The findings suggest that CBAM generally exerts a negative effect on employee compensation, with notable variations between sectors. These disparities are primarily driven by each country's level of trade exposure to the EU, energy intensity, and industrial structure. Sectors heavily reliant on carbon-intensive production methods or those significantly impacted by changes in exports to the EU (especially under the Q3 scenario) experience larger reductions in employee compensation, whereas sectors with lower carbon exposure or those less dependent on EU exports show more limited impacts, particularly under the Q1 scenario. Additionally, the analysis reveals how sectoral differences in labor market flexibility or the ability to absorb carbon costs influence compensation outcomes. Industries with higher energy efficiency or better adaptation strategies may face smaller declines in compensation compared to others. This suggests that the impact of CBAM may not only be dependent on changes in export levels (as reflected in the Q1 and Q3 scenarios) or carbon exposure but also on the degree to which sectors can adjust to the evolving trade environment driven by carbon pricing mechanisms. The research contributes to the field of Operations Research by integrating MRIO models with environmental economics to address complex, real-world policy scenarios like CBAM. Additionally, the study highlights the need for OR techniques to inform policy design, particularly in identifying vulnerable sectors and recommending optimal interventions to mitigate adverse effects on labor markets. Ultimately, this research provides insights into the broader labor market implications of carbon pricing policies like CBAM, offering recommendations for policymakers to consider when designing strategies that support workers in the transition to a low-carbon economy.

2 - Selling to Luxury Fashion Customers: Pricing, Production, and Upcycling Decisions

Seyma Gozuyilmaz

Corporations are held accountable for the outcomes of their operations across the triple bottom line aspects containing social, environmental, and economic sustainability. The fashion industry, particularly luxury fashion, faces growing pressure to reduce its ecological footprint while maintaining brand exclusivity and profitability. A significant challenge in this regard is excess inventory management. Luxury fashion brands often incinerate or destroy unsold products, causing substantial environmental harm to protect exclusivity. Circular business models offer a sustainable alternative, with upcycling standing out due to its ability to enhance product value, extend lifespan, and minimize environmental impact. However, upcycling remains underexplored in operations management and is predominantly limited to small-scale applications rather than industrial adoption.

This research investigates the strategic role of upcycling as a promotional tool for liquidating excess inventory while improving financial and environmental outcomes. We develop an analytical model that captures a luxury fashion firm's decision-making process across two periods, where strategic, eco-conscious customers consider pricing and availability before purchasing. The firm determines the initial production quantity and first-period price, and after demand realization, it decides whether to upcycle unsold inventory instead of resorting to price reductions. We examine the potential of outsourcing upcycling to a third-party firm and analyze its impact on second-period demand, pricing, and overall sustainability.

Our study addresses key questions: (1) Can upcycling effectively serve as a promotional tool to manage excess inventory while balancing profitability and sustainability? (2) Under what conditions should a firm adopt upcycling, and what is the optimal proportion of inventory to upcycle through outsourcing? (3) How does strategic customer behavior influence upcycling decisions, pricing, and inventory management?

Our findings provide actionable insights for luxury fashion firms navigating sustainability challenges. By strategically leveraging upcycling, companies can reduce waste while maintaining exclusivity, turning excess inventory into a value-adding opportunity rather than a liability.

3 - Effect of aggregations on market equilibrium and emission control in agriculture

Pratik Samal, Sri Vanamalla Venkataraman

Smallholder farmers in emerging economies organise into formal or informal aggregations to improve their livelihoods. We develop an analytical model to study the market equilibrium when a group of farmers with differing production capacities compete with each other for two crops, with the possibility that a subset of these farmers can form an aggregation and realise cost reduction through economies of scale. Of the two crops the profitable variety is also emission intensive and the farmer can decide on the optimal emission control level, if he falls short of a mandated level of emission control he is penalised commensurately. We study the effect of various crop specific parameters on the equilibrium outcome. We find that the effect of aggregation is able to improve the abatement level of the aggregating farmer. The cropping decision, on the other hand, depends on the penalty imposed on the farmer. Furthermore, we find that the aggregation permits the aggregating farmers to produce more of the cost intensive crop. However, we see that it is not always in the interest of the farmers to aggregate. Even when the aggregation is feasible, the aggregating farmers do not earn higher payoffs under all circumstances. This is especially true when the farmer deals with a higher penalty. The aggregation has potential to cause an overall reduction in the emissions. We establish the theoretical conditions for all the results, and elicit managerial insights from our analysis.

■ MB-20

Monday, 10:30-12:00 - Room: Esther Simpson 2.11

Integer Programming and Combinatorial Optimization: Complexity Questions and Algorithms

Stream: Combinatorial Optimization
Invited session
Chair: *Sergei Chubanov*

1 - Highway Dimension: a Metric View
Andreas Feldmann

Realistic metric spaces (such as road/transportation networks) tend to be much more algorithmically tractable than general metrics. In an attempt to formalize this intuition, Abraham et al. (SODA 2010, JACM 2016) introduced the notion of highway dimension. A weighted graph G has highway dimension h if for every ball B of radius $\approx 4r$ there is a hitting set of size h hitting all the shortest paths of length $> r$ in B. Unfortunately, this definition fails to incorporate some very natural metric spaces such as the grid graph, and the Euclidean plane.

We relax the definition of highway dimension by demanding to hit only approximate shortest paths. In addition to generalizing the original definition, this new definition also incorporates all doubling spaces (in particular the grid graph and the Euclidean plane). We then construct a PTAS for TSP under this new definition (improving a QPTAS w.r.t. the original more restrictive definition of Feldmann et al. (SICOMP 2018)). Finally, we develop a basic metric toolkit for spaces with small highway dimension by constructing padded decompositions, sparse covers/partitions, and tree covers. An abundance of applications follow.

2 - Optimizing Integer Programming Problems using Branch-Line-and-Search Algorithm
Md Shahrukh Anjum, Jitamitra Desai

It is well recognized that finding a feasible solution to a mixed-integer program is a computationally difficult problem in practice. While there have been several attempts to improve the bound resulting from the relaxations at a given node within a branch-and-bound algorithm, there has been relatively scant attention paid to generating good quality feasible solutions relatively early in the branch-and-bound process. In this article, we develop a mechanism to quickly generate good quality feasible (incumbent) solutions by utilizing a line-search method to explore parts of the search space without relying on computationally intensive LP relaxations. The proposed algorithm, which we coin as the Branch-Line-and-Search (BLS) algorithm, is built on the principle of tracing collinear feasible integer points along the line segment formed by joining two (in)feasible integer solutions, possibly obtained at different nodes of the search tree. The BLS algorithm enhances the Branch and Bound method by integrating integer lattice properties to find improved integer feasible solutions. This novel approach reduces computational effort and leverages both feasible and infeasible points. In this work all the cases related to the position of the selected base integer points relative to the convex polytope and their impact on the solution complexity is studied.

3 - New Family of cutting planes for 0-1 polynomials programming problem: RTL-K to RLT-1 cutting planes
Ibrahim Dan Dije, Franklin Djeumou Fomeni, Leandro Coelho

The reformulation-linearization technique (RLT), due to Sherali and Adams, is a general framework for constructing hierarchies of linear programming (LP) relaxations of various optimization problems. It was first developed for 0-1 polynomial programs, but was soon adapted to continuous polynomial programs, and then extended to mixed 0-1 polynomial programs. Since then, it has been further extended and adapted, to cover a wide range of integer programming and global optimization problems. As one moves up the levels of the RLT hierarchy, the LP relaxations grow stronger, also the number of variables increases exponentially. In practice, therefore, one can hope to solve the relaxations only at very low levels of the hierarchy. In fact, even solving the relaxation at the level two can be challenging.

In this talk, we present a framework which generalizes quadratic space cutting planes from any given hierarchy level, by weakening the higher-level inequalities to quadratic space ones with a direct jump moving by using set subdivision. The estimators obtained from the weakening represent facets to the convex hull of the high-level multilinear monomials.

We test the generated cutting planes using instances of the quadratic knapsack problem, then we will present some computational results which show that these cutting planes improved the linear relaxation of the quadratic knapsack problem.

4 - On scaling methods for linear programming and convex optimization
Sergei Chubanov

The performance of certain methods for linear programming and convex optimization depends on the chosen coordinate system. Changing the coordinate system can either increase or decrease the running time of the respective algorithm for the same task. A systematic study of how scaling affects the behavior of exponential algorithms, such as the relaxation method for linear inequalities, leads to polynomial-time algorithms—meaning the complexity status of an algorithm can be improved by applying an appropriate scaling procedure. In this talk, we will discuss various scaling approaches of this kind. In particular, we will show that a suitable class of projective transformations results in a polynomial-time algorithm for positive semi-definite feasibility problems.

■ MB-21

Monday, 10:30-12:00 - Room: Esther Simpson 2.12

2D Cutting and Packing

Stream: Cutting and packing (ESICUP)
Invited session
Chair: *Célia Paquay*

1 - A large neighborhood search for the 2D bounded-sized cutting stock problem
Khadija Hadj Salem, Alexis Robbes

We introduce the two-dimensional bounded-sized cutting stock problem, referred to as (2D-BSCSP), which involves optimizing the cutting of small rectangular items from a set of larger rectangular plates, where the plates have bounded dimensions. In the (2D-BSCSP), the cutting patterns are restricted to non-exact two-stage guillotine cuts. The objective function is to minimize the total amount of raw material used, effectively reducing waste. This is a crucial concern in manufacturing industries, where material cost is a significant factor in overall production efficiency. To address this challenge, we propose a Mixed Integer Linear Programming (MILP) formulation based on strip types. In addition, we introduce a Large Neighborhood Search (LNS) algorithm to solve larger instances. To evaluate the performance of the proposed approaches, computational experiments are conducted on a set of randomly generated instances, as well as on adapted 2D cutting stock problem instances drawn from the existing literature, with the aim of providing insights into their practical applicability and efficiency in solving real-world cutting stock problems.

2 - A Deep Reinforcement Learning-based column generation for the 2D bounded-sized cutting stock problem
Alexis Robbes, Khadija Hadj Salem

In this work, we propose a Deep Reinforcement Learning-based column generation approach to solve the two-dimensional bounded-sized cutting stock problem (2D-BSCSP). The 2D-BSCSP is a variant of the 2D cutting stock problem in which the dimensions of the raw material plates are variables, constrained to fall within a specific range. This introduces additional complexity, as the dimensions of the plates are not fixed and must be considered when optimizing the cutting process. The cutting procedure involves two non-exact guillotine stages. We begin by introducing a new Mixed-Integer Linear Programming (MILP) formulation based on strip-based representations. Building on this, we present a column generation method that combines a Deep Q-Learning algorithm with a dynamic programming algorithm and MILP models. The Deep Q-Learning algorithm enables the method to learn the profit of the items over time, while dynamic programming is used to generate strips based on these profits. The proposed method is trained on a set of randomly generated instances, which serve as a diverse representation of possible problem scenarios. To assess its performance and generalizability, the method is validated on adapted 2D-Cutting Stock Problem (2D-CSP) instances from existing literature. These instances provide a benchmark to evaluate the effectiveness of our approach in solving real-world cutting stock problems. Finally, we compare the results of our DRL-based column generation method with those of an

3 - Mixed-integer linear programming formulation for a two-stage two-dimensional dual bin packing problem for wood reuse optimization
Pauline Bessemans, Célia Paquay, Morgane Dumont

The increasing demand for raw materials such as wood undoubtedly contributes to the depletion of natural resources and global warming. To curb this phenomenon, a more sustainable and circular management of wood could be developed through the intelligent management of wood waste. This wood waste can be in the form of beams or pallets and could be considered as wooden slats. They could be combined, assembled, and glued to build Cross-Laminated Timber (CLT) panels for the construction industry. We aim to develop optimization techniques to recycle raw wood waste to create two-dimensional CLT panels of variable dimensions. The input waste is in the form of slats with variable and heterogeneous lengths and widths but constant thickness. The algorithm provides the assembly schemes that maximize the amount of wood reused through the production of CLT panels. We conducted a literature review to identify our problem in the field of operations research and to name it accordingly. The present work addresses an exact case of the two-stage two-dimensional dual bin packing problem (E-2S-2D-DBPP) in the context of wood reuse optimization. We propose a description of the problem and a mathematical formulation with cuts. We also present the results of several numerical experiments based on realistic instances from the wood industry obtained by using Gurobi's B&B procedure. Finally, we identify the size limit of the instances for which the problem can still be solved in a reasonable time.

4 - Optimising Garment Remanufacturing: A Novel Approach to Two-Dimensional Irregular Multi-Bin Packing with Non-Fragmentation Constraints
Nesma ElShishtawy, Julia Bennell, Pammi Sinha

This study introduces a new variant of the cutting and packing problem: the Two-Dimensional Irregular Multi-Bin Packing with Non-Fragmentation Constraints (2D-IMBP-NFC). Motivated by upcycling and material reuse, the problem involves allocating and packing full garment clusters, non-fragmentable complete sets of pattern pieces, into irregularly shaped bins derived from disassembled deadstock garments. The methodology is structured into two integrated subproblems: (i) a Piece and Bin Selection Sub-problem, solved using a linear programming (LP) model to allocate cluster instances across multiple irregular bins and a fallback fabric strip, subject to capacity and demand constraints; and (ii) a Placement Sub-problem, where a geometry-informed heuristic generates the initial layout by leveraging the spatial characteristics of both bins and garment clusters to guide feasible placements. A column-wise post-optimisation phase refines layout compaction for each bin, then selectively reassigns clusters initially allocated to the fabric strip into the freed bin space. Evaluated on real-world garment data, the proposed integration of mathematical optimisation with domain-specific heuristics, demonstrates significant potential for reducing the reliance on virgin material in garment manufacturing. Additionally, it offers a robust framework that addresses key operational constraints integral to advancing garment remanufacturing in the fashion industry.

■ MB-26

Monday, 10:30-12:00 - Room: Maurice Keyworth 1.33

Speed Networking

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: *Susanne Heipcke*

1 - Speed Networking
Susanne Heipcke

Meet your peers in a friendly, informal way, through discussions in groups of 2-3 persons with pairings changing after a fixed time span of a few minutes. OR is a team business, and knowing people you can turn to for ideas, feedback and support makes all the difference. But it is not always easy building your network, especially if you are shy or feel that you are an outsider. This welcoming session is a way of overcoming the barriers to networking, and enjoying yourself while you do it.

If you cannot make it for the full duration of the session: discussion groups are reforming every couple of minutes, so joining the session after its start or leaving early will not be a problem. You may find it easier if you come with an idea of how you can introduce yourself to others in just two minutes (for example, you may wish to touch on your specific interests, any experiences you wish to share, or also any topics you particularly wish to hear about). But don't worry if you don't have time to prepare - you'll soon pick it up.

■ MB-27

Monday, 10:30-12:00 - Room: Maurice Keyworth G.02

Vehicle Routing under Uncertainty

Stream: Stochastic and Robust optimization
Invited session
Chair: *Francesca Vocaturo*
Chair: *Yossiri Adulyasak*

1 - The robust time-dependent vehicle routing problem with time windows and budget uncertainty
Igor Malheiros, Michael Poss, Vitor Nesello, Anand Subramanian

The Vehicle Routing Problem with Time Windows (VRPTW) is a classic problem with many applications. To develop more precise routing plans, academics and practitioners may consider travel time variations throughout the day, e.g., longer durations during rush hours. In the Time-Dependent VRPTW (TDVRPTW), travel time becomes a function of time. This work introduces a new variation of the TDVRPTW: the Robust TDVRPTW (RTDVRPTW) under uncertain travel times. Specifically, we assume all travel times belong to a known budget uncertainty set. The RTDVRPTW aims to provide precise planned routes designed in advance while remaining resistant to uncertainties, such as accidents or roadwork. First, we study the computability of the time-dependent travel time function in robust optimization under different assumptions. Second, we propose two approaches to solve our model: (i) an exact approach based on a compact formulation and (ii) a metaheuristic approach designed for large-scale instances. Finally,

we conduct experiments using different configurations of uncertainty sets and simulate them with real traffic data. The results show that our proposed model produces solutions with a better trade-off between robustness and cost than other models in the literature.

2 - Attention Model for Time Slot Management Vehicle Dispatching Problem
Sifanur Celik, Albert Schrotenboer, Layla Martin, Tom van Woensel

The rapid growth of e-commerce has raised customer expectations for faster and more reliable delivery services, making same-day delivery with selectable time slots a critical challenge. This study introduces a novel Transformer-based approach enhanced with attention mechanisms to optimize time slot offerings and delivery routing dynamically. To the best of our knowledge, Transformers have not yet been applied to time slot management. Our model integrates real-time customer demand and operational constraints to minimize transportation costs, maximize vehicle capacity utilization, and maintain high service levels. We structure the problem into two interconnected phases: (1) dynamically generating personalized time slot menus based on customer arrivals and (2) optimizing vehicle dispatching and routing while adhering to selected time windows. To solve the Vehicle Dispatching Problem (VDP) and the Vehicle Routing Problem with Time Windows (VRP-TW), we employ a Hybrid Genetic Search heuristic and a Maximum Delay Time heuristic, ensuring cost-efficient routing and timely dispatching. Our approach provides effective and fast solutions for balancing customer satisfaction with operational efficiency in last-mile logistics.

3 - Exploring right-hand side uncertainty for insular vehicle routing problems
Javier Maturana-Ross, Stefan Voss, Benjamin Peso

The Bi-Objective Insular Traveling Salesman Problem (BO-InTSP) is used to optimize freight logistics in island networks by minimizing maritime (MTC) and ground transportation costs (GTC). While exact formulations from literature are available, related deterministic assumptions ignore real-world uncertainties like fluctuating port capacities (weather, labor shortages). This study integrates right-hand-side (RHS) uncertainty into the BO-InTSP and attempts to solve it with inspiration from existing solution approaches from production scheduling and robust vehicle routing. That is, we propose a matheuristic framework combining exact methods (AUGMECON2) with metaheuristics (Variable Neighborhood Search, Fixed Set Search) to handle this complex problem. Stochastic port capacities are modeled via scenarios (e.g., 80%, 100%, 120% of a baseline), ensuring that solutions remain feasible under disruptions. Scenario generation aligns with robust optimization principles, retaining solutions that meet at least 90% of the feasibility thresholds. This hybrid approach balances rigorous Pareto-front generation with adaptive exploration, addressing a critical gap in island logistics research.

4 - Online vehicle routing with dynamic demand management
Yossiri Adulyasak, Linchuan Wei, Emma Frejinger

Motivated by a real-world application, we consider the integrated vehicle routing and dynamic booking management problem under uncertain time windows. In this context, the logistics provider offers each customer personalized time window options and accepts their delivery requests in an online fashion. The challenge of this problem lies in the trade-off between flexibility and operational costs. On the one hand, providing more options increases customer satisfaction and the likelihood of receiving a request. On the other hand, offering a large number of time window options to customers may result in inefficient vehicle routes and schedules, as too many customers may select high-demand time slots. To solve this problem, we incorporate customer choice models to capture customers' preferences for time windows in the vehicle routing problem. The primary decisions include the personalized time window options made available to each customer, the acceptance of booking requests, and vehicle dispatching plans, which are all made in an online and dynamic fashion. The problem is modeled using the dynamic programming framework, which is solved by a linear programming approximation and a column generation approach. We demonstrate the efficiency and effectiveness of the solutions using the data from our industrial partner.

■ MB-28

Monday, 10:30-12:00 - Room: Maurice Keyworth 1.03

Simulation and System Dynamics

Stream: Decision Support Systems
Invited session
Chair: *Uchitha Jayawickrama*
Chair: *Morgane Dumont*

1 - Sustainable Strategy for the Future with System Dynamics- Exemplified with a Cleaning Products Manufacturing Company in Taiwan
Yu-Tzu Chen

In recent decades, System Dynamics (SD) has proven very effective in simulating for sustainable development. To balance the concerns in long-term operation cost and environmental systems, the research focuses on two performance indicators, including Carbon Emission Reduction (CER) and Cost Reduction (CR) with internal and external factors. The internal factors include a cleaning products manufacturing company in Taiwan. The external factors include explore successful strategies from similar companies and current trends including 3 aspects in packaging, energy, and transportation. The simulation is set for 5 years (60 times) from Jan. 2023 to Jan. 2028 with one machine information in 2023. First, each factor is simulated individually with the basic company information and possible scenarios. Second, the optimized scenario in packaging, energy, and transportation will be compared to show the combination. The research is aiming to explore the potential savings in practicing the strategy without further exploring the initial investment cost and exemplified with only. The result shows that with the strategy of changing packaging to 100%PET, energy structure to 100% wind power, transportation to 100% electric vehicles, the CER is 1.92%, 42.47%, 54.49%, and CR is 18.57%, 52.85%, 21.48%. Combining the above-mentioned strategies, CER is 97.17% and CR is 49.3%. In conclusion, the prioritizing of the transition strategy is the energy structure, transportation and the packaging.

2 - Optimising Rolling Stock Maintenance: A Simulation-Driven Scheduling Approach
Cansu Kandemir

Rail depots manage crucial operations such as inspections, cleaning, refuelling, and maintenance. However, limited space and the unidirectional movement of rolling stock make efficient train sequencing essential to avoid delays and disruptions. Rolling stock maintenance further complicates operations, impacting railway safety and reliability. Increasing maintenance-related train delays, as shown in government reports and railway statistics, underscore the urgent need for optimised maintenance scheduling and depot train movement strategies. This study introduces an integrated framework that combines Discrete Event Simulation with a maintenance scheduling optimisation model, developed through an ontology-based virtual depot scheduling tool. By anticipating operational bottlenecks, predicting maintenance and movement conflicts, and dynamically adjusting schedules, this approach improves depot efficiency, reduces disruptions, and enhances system resilience. The framework enables proactive decision-making, ensuring smooth train movements while minimising delays and optimising resource allocation, thereby improving system reliability, passenger satisfaction, and cost efficiency. Its predictive capabilities make the railway system more adaptive, resilient, and capable of handling anticipated operational challenges, ensuring long-term efficiency and reliability.

3 - Microsimulation in Decision Support Systems: Advancing Demographic Forecasting
Morgane Dumont

The use of simulations and analytical frameworks as decision-support tools has demonstrated significant potential across various domains, including healthcare and transportation. This progress is increasingly facilitated by advancements in computational power and the growing availability of data. In many instances, assessing the impact of a decision requires projections for future years, making accurate forecasting essential. Macro simulations typically estimate aggregated counts without accounting for individual-level dynamics. However, when evaluating the effects of specific transportation policies or healthcare reforms, for example, it is crucial to incorporate detailed information on individuals' locations and household structures. Micro simulations address this need by modelling individuals separately, allowing for a more granular analysis. Several countries, such as Austria, have already integrated micro simulations into official demographic projections. In Belgium, we have developed a spatial micro simulation model that forecasts the complete Belgian population at the individual level until 2050. This model includes household structures and municipalities of residence, providing a comprehensive demographic projection framework. The Walloon region has adopted this framework for various projection purposes, such as estimating the future demand for retirement home beds until 2050, thereby enabling policymakers to adapt service accordingly.

■ MB-29

Monday, 10:30-12:00 - Room: Maurice Keyworth 1.04

Optimization in Mobility and on-demand services

Stream: Pricing and Revenue Management Innovations
Invited session
Chair: *Mesut Can Köseoğlu*

1 - Real-time pricing for a station-based one-way vehicle sharing system
Rose Sossou Edou, Frédéric Meunier

In this work, we consider a station-based one-way vehicle sharing system, whose rebalancing is exclusively performed by the users. This rebalancing is achieved by inciting the users to sometimes modify their destination stations, so as to reroute the flow of vehicles towards stations where demand is high. Dynamic prices attached to the stations are used for the incitation: the amount to pay for a ride is the price attached to the destination station. A user arriving at an origin station may not perform a ride only for two reasons: either there is no available vehicle at the station when the user arrives, or the current prices attached to the stations make the user prefer to walk.

Assuming that the prices can be updated in real-time, depending on the state of the system, we address the problem of maximizing the proportion of users eventually performing a ride with a vehicle. We propose two heuristics. The first one is a simple rule where the price depends only on the current state of the station. The second one relies on strong duality in the theory of optimal transport. The quality of these heuristics is assessed via simulation on synthetic data and also with respect to non-trivial upper bounds based on mixed integer linear programming. Experiments are currently conducted. In addition, special cases where exact optimal solutions can be determined are also identified.

2 - Dynamic Compensation Optimization for Occasional Driver Delivery
Kai Winheller, Matthias Soppert, Rouven Schur

Despite considerable scientific efforts and despite the substantial advancements made in the literature, the last-mile remains the supply chain's most costly component. In this context, the concept of crowd-engagement in last-mile delivery recently gained attention also for deliveries from brick-and-mortar stores. However, existing approaches assume that the store possesses detailed information on the crowd or that it possesses the control ability to assign delivery tasks to the crowd. In our work, we relax both of these two key assumptions. That is, on the one hand, we assume that the pool of potential drivers as well as their specific preference profiles are unknown to the store. On the other hand, the store's ability to engage the crowd is limited in the sense that compensations can be optimized dynamically but that a specific driver cannot be engaged with certainty. Thus, we consider occasional drivers in a narrower sense, where in-store customers may occasionally become drivers who deliver to online customers, depending on the compensations offered and the required detours. We formulate the problem as Markov decision process. Based on analytical analyses of the problem and the derivation of the exact solution for an important special case, we develop scalable heuristic solution approaches.

3 - A Bilevel Optimization Framework for Pricing and Trip Allocation in Shared Mobility Networks
Mesut Can Köseoğlu, Shadi Sharif Azadeh, Luce Brotcorne

In this study, we consider a joint pricing and trip allocation approach for a city public transportation operator (PTO) owning a bike sharing service (BSS). The aim is to invite travellers to adopt sustainable options and enhance multimodal integration by offering convenient trip options. We propose a framework comprise of a pre-processing stage to generate alternatives and a bilevel optimization model. Bilevel model links public transportation operator (PTO) decisions and the travellers' choices. In the upper-level problem, PTO seeks balance multimodal ridership growth and BSS profits by offering trip options and setting BSS prices. In the lower-level, homogeneous O-D travellers' mode choices are modelled via deterministic disutility minimization to reflect the decisions on offered options. The model is solved by reformulating it as a single-level bilinear and non-convex model by exploiting the optimality conditions of the lower-level problem, then converting to a relaxed convex mixed integer linear program (MILP) through McCormick Envelopes. The model is tested against randomly generated instances up to 241 nodes. Preliminary results show that all instances are solved to optimality with a commercial solver. Sensitivity analysis on price bounds indicates that lowering the upper bound improves approximation and lower bound allows strategic incentives to align with traveller needs. To validate performance and scalability, we are testing the model on an existing network.

■ MB-30

Monday, 10:30-12:00 - Room: Maurice Keyworth 1.05

Joint lot-sizing

Stream: Advanced Lot Sizing and Inventory Strategies
Invited session
Chair: *Sohrab Faramarzi-Oghani*

1 - Joint Ordering-Delivery Policies for Dual-Channel Distribution Network under Supply Disruption
Nishika Bhatia, Nalan Gulpinar

In a dual-channel network, a firm distributes its products through different channels mainly comprising of its own stores as well as third-party retailers. A disruption at any point of the dual-channel network impacts the overall operations of the firm. Thus, it is essential to consider disruption at both demand and supply of the network. To mitigate the disruption from supply side, the firm diversifies its sourcing strategy by ordering from a set of emergency suppliers along with their regular ones. In this research, we investigate the joint ordering and delivery policies of the dual-channel firm under disruption. At each decision-making stage, the firm decides how much to order from regular and emergency suppliers and how much to allocate inventories among its own stores and third party retailers. The joint decision-making problem of the firm is modelled as a stochastic dynamic program. The consideration of dual-retail channels and multiple decisions

massively expands state and action spaces. Thus, the underlying dynamic programming model is computationally difficult to solve by the standard solution methodology. We propose two decomposition methods where one of the methods utilises the structural properties of the dual-retail channel network while the other one considers its practical applications like the technological advances in inventory-tracking. An extensive numerical study is conducted to highlight different features of the models and to derive managerial insights.

2 - Joint economic lot sizing with simultaneous determination of the number of product-specific reusable transport items (RTIs)
Marion Lemke, Heinrich Kuhn

The increasing awareness for sustainability drives the establishment of circular supply chains. One approach to improve the triple bottom line involves the use of product-specific returnable transport items (RTI) rather than disposable packaging. However, little attention has yet been paid to decision support on joint optimisation of economic production and order lot sizes with simultaneous calculation of RTI fleet sizes considering different modes of ownership in a multilevel setting.

This research examines a three-echelon supply chain consisting of component supplier, manufacturer, and customer. The aim is to determine the joint economic production and order lot sizes with simultaneous determination of the required RTI fleet sizes for the supplier's and the manufacturer's products, taking into account different modes of RTI ownership (renting, purchasing, or a combination thereof) and return policies. Further, production, warehousing, and transportation capacity need to be respected. To achieve these objectives, a mathematical model is developed and solved. Numerical examples are provided to demonstrate the model's behaviour.

This work contributes to the existing body of literature by providing a decision support model for supply chain design to allow for optimized economic coordination of production lot sizes and order lot size in a three-echelon supply chain with two types of RTI, different ownership models and return policies within a deterministic context.

3 - Delivery Problem: Classification of Failed Deliveries and Future Research Opportunities
Sohrab Faramarzi-Oghani, Parisa Dolati Neghabadi

Delivery failure is a persistent challenge for stakeholders in last-mile logistics and a common experience for many customers. Motivated by the growing scale of parcel shipments and the detrimental outcomes of delivery failure, this article presents a new perspective through a detailed analysis of failed deliveries and explores how operations management (OM) can effectively contribute to addressing this critical issue. After highlighting the significance of the problem, we propose an extensive classification of failed deliveries across eight categories. We then identify several research opportunities by examining the delivery process, parcel journey, and emerging trends in the field, discussing them under two major streams: (i) proactive and preventive measures to reduce delivery failures, and (ii) corrective and mitigation strategies to address failed deliveries.

■ MB-31

Monday, 10:30-12:00 - Room: Maurice Keyworth 1.06

Machine Learning for Optimization under uncertainty 1

Stream: Stochastic and Robust optimization
Invited session
Chair: *Milos Kopa*

1 - Reinforcement Learning Methods for Risk-Sensitive Investment Management
Sebastien Lleo, Wolfgang Runggaldier

We investigate the benefits of relating reinforcement learning (RL) with risk-sensitive control. Our starting point is the duality between free energy and relative entropy, which establishes an equivalence between risk-sensitive control and standard stochastic control problems with an entropy regularization term; see, e.g., Dai Pra et al. (1996). A major advantage of this approach is that it rewrites the initial linear-exponential-of-quadratic-Gaussian problem as an equivalent (penalized) linear-quadratic-Gaussian problem. In so doing, it does not require a preliminary change of measure as is being done in the seminal work of Kuroda & Nagai (2002). Adapting the policy gradient method proposed by Jia & Zhou (2022b), we examine four distinct cases, categorized by the level of parameter knowledge (known or unknown) and state process observability (observable or not). Cases with known parameters connect directly to the existing literature on risk-sensitive investment management (Kuroda & Nagai, 2002; Davis & Lleo, 2008, 2020, 2021b) and can be solved analytically. Cases with unknown parameters showcase the advantages of reinforcement learning methods.

2 - Data-Driven Approach to Robust Portfolio Optimization Using Deep Neural Networks
Divyanee Garg, Aparna Mehra

The construction of optimal portfolios under uncertainty, stemming from data imperfections and market volatility, has received significant attention from scholars and practitioners. Traditional portfolio optimization (PO) models inadequately account for these uncertainties and often produce suboptimal solutions. This study integrates deep learning techniques with robust optimization to enhance portfolio performance and improve decision-making under uncertainty. We propose a robust PO model with deviation expectile value at risk (DEVaR) considering the uncertainty in expected asset returns. DEVaR is selected as the risk measure due to its growing prominence in recent literature. It is attributed to its theoretical strengths of coherence and elicitability and its computational efficiency enabled by its linear formulation. This article uses a deep neural network to learn hidden structures from data, leading to a non-convex uncertainty set. The trained neural network is integrated into a robust PO model by formulating the adversarial problem as a mixed integer linear program. We find the robust portfolio through the iterative constraint generalization algorithm. The effectiveness of the proposed model is demonstrated by constructing optimal portfolios on eight global stock indices. The out-of-sample statistics obtained from the proposed model are compared with techniques available in the literature. The proposed model outperforms all other models across most datasets.

3 - Consensus, upgrade and skeleton clustering for stochastic programming
Janosch Ortmann, Samah Abdalrhaman, Walter Rei

In this talk I will discuss two applications from freight transportation and logistics: a collective food network and a stochastic network design problem.

These problems can be modelled as two-stage stochastic optimisation problems, but the number of scenarios required to realistically model the uncertainty typically makes the optimization problem numerically intractable. I will show how to use problem-based clustering to extract information about the stochastic program from the single-scenario solutions.

We introduce new distance matrices on the scenario set that are based on the idea of giving the decision maker some flexibility to change the first-stage decisions after the uncertainty has been revealed. In particular, we integrate the ideas of upgrade and skeleton solutions.

We then apply clustering on the scenario set equipped with these distances. Preliminary result indicate promising bounds and reveal interesting new structures on the scenario set.

4 - Integration of Neural Network Surrogates in Two-Stage Stochastic Programming Problems
Enza Messina, Xiaochen Chou, Ludovica Di Marco, Iman Seyedi

Decision-making under uncertainty addresses real-world problems that are often hard to solve. Stochastic programming is a practical approach in which decisions are determined prior to the realization of uncertain variables, with subsequent adjustments made through recourse mechanisms once the uncertainties are revealed. An optimal solution must ensure robustness and adaptability across a range of potential future scenarios. Traditional solving methods rely on scenario-based approximations, where incorporating additional scenarios may improve accuracy but simultaneously escalates computational complexity, often making large-scale problems infeasible. With advancements in machine learning, this study aims to address these challenges by training neural networks as surrogate models for the recourse problems. These models estimate solution quality across diverse scenarios, thereby reducing the computational burden when integrated into the optimization framework. Empirical evaluations have been conducted on two-stage single-source capacitated Facility Location Problem, a stochastic variation of the multi-path Traveling Salesman Problem, and closed-loop Supply Chain Problem. Preliminary results demonstrate the effectiveness of this approach in balancing efficiency and accuracy taking advantage of the generalization capability of the neural network model. Future research will focus on extending its application to multi-stage stochastic programming problems.

■ MB-32

Monday, 10:30-12:00 - Room: Maurice Keyworth 1.09

Seaside Planning-2

Stream: Maritime and Port Logistics
Invited session

Chair: *Frank Meisel*
Chair: *Rosa G. González-Ramírez*
Chair: *Eduardo Lalla-Ruiz*

1 - The Strategic Berth Template Problem with Uncertain Arrival Times

Manuel Munoz-Marquez

The Berth Allocation Problem (BAP) involves assigning berthing positions and service times to ships arriving at container terminals. Various BAP models exist, considering berth types and ship arrival uncertainties. Ship calls may exceed port service capacity, making it unfeasible to serve all requests. The Strategic Berth Template Problem (SBTP) addresses this by determining which ships should be served and when/where, applying a cyclic template for recurring arrivals. Additionally, service decisions may link certain ships, requiring them to be served or rejected as a group.

A major challenge in berth allocation is uncertainty in ship arrival times, often unknown at the planning stage. This study extends SBTP by incorporating stochastic elements, creating the Stochastic Berth Template Problem (SSBTP). Initially, a worst-case analysis approach is applied, yielding highly conservative solutions. To improve flexibility, budget uncertainty analysis is introduced, limiting total uncertainty without losing the feasibility, resulting in a worst-case scenario.

To refine the model, a customized budget uncertainty approach is developed. It introduces valid inequalities and an embedded subproblem, which is integrated using dualization techniques. Extensive numerical experiments demonstrate the model's effectiveness. The impact of uncertainty inclusion is analyzed, particularly the relationship between the budget uncertainty parameter and waiting times.

2 - A Self-Adaptive Monte Carlo Tree Search Algorithm for Generalized Quay Crane Scheduling Problem

Chenhao Zhou, Lei Hai, Li Xue

Efficient quay crane (QC) handling is crucial for enhancing service levels and competitiveness in container terminals, particularly with the advent of ultra-large vessels necessitating rapid container turnover. As the complexity of terminal operations escalates, this paper addresses the generalized quay crane scheduling problem (GQCSP) aiming to minimize makespan for discharging and loading operations, where QCs operate bi-directionally under safety distance and non-crossing constraints, emphasizing the solution approach that delivers swift, feasible solutions over protracted optimal ones, essential for adapting to last-minute operational changes. The problem is formulated as a Markov decision process model, and a self-adaptive Monte Carlo tree search algorithm (MCTS) is proposed that can handle up to 10 QCs and 280 container groups. To expedite the MCTS, problem-specific methods are developed, achieving an improvement of approximately 1.2% of the objective values and a reduction of two-thirds of the computation time. Specifically, an adaptive lower bound is introduced for node selection and subtree pruning, accompanied by a lower bound-based reward function to facilitate backpropagation. This research showcases the MCTS algorithm's capability to significantly outperform existing heuristics, improving operational efficiency by an average of 20.92% to 72.88% across various scenarios, and achieving near-optimal solutions with remarkable speed.

3 - Dynamic Pricing Model for Tidal Ports

Deepankar Sinha

Seaports face stiff competition, especially those in close proximity. The service improvement strategies taken by the ports are often negated by counter strategies by the competing units. Besides service improvements and value additions, dynamic pricing of port services is one of the means to retain port attractiveness. Studies have focused primarily on demand patterns, congestion levels, and environmental factors. In many tidal ports, ships can call only during the high tide, and the quantum of cargo it can carry varies with the tidal range and the vessel's speed. Thus, ports must attract ships of the right size and speed at different times of the year. There are few references on attracting ships and cargo incentivising to leverage on tidal factors. The shipping lines have challenges maintaining varied fleet types and may incur costs while switching from larger to smaller vessels or vice versa while transiting from high tide to low tide seasons. Hence, given the size of the ship, their earnings vary with the navigable draft, which deters shipping lines from ports with high draft variability. Ports can reduce vessel and cargo handling charges to compensate for shipping line charges but must ensure full utilisation of draft to gain from cargo handling charges. This paper proposes a dynamic pricing framework based on varying drafts, using maximum likelihood estimations for parameter estimation, price-demand elasticity to assess changes in revenue, and a dynamic program method.

4 - Quantum Computing Optimisation for Maritime Logistics - Case Studies

Anisa Rizvanolli, Valeria Bartsch, Joshua Dibbern, Oliver Szal, Ole John

Over the past few decades, Fraunhofer CML has gained valuable insights from the maritime industry. Currently, critical business processes such as route planning, crew scheduling, cargo loading, yard management, and berth scheduling are often managed manually and based on experience. Given the complexity and operational significance of these tasks, there is a growing demand for decision support systems that can quickly deliver effective solutions. Quantum computing is expected to enhance optimization by improving both the quality and speed of of exploring large solution spaces inherent to logistics problems. By reducing computation time quantum computers will enable real time calculations of complex problems with conflicting objectives and increase the resilience and efficiency in logistics. Therefore, it is important to investigate the opportunities of this emerging technology for solving combinatorial optimization problems. Many works in operation research present mathematical models and solutions algorithms for combinatorial problem in maritime logistics like network planning in liner shipping, maritime inventory routing, berth allocation and quay crane optimization. But only a few of them address real-world use cases and present hybrid (combination of exact solution and heuristics) or pure-heuristics methods to solve them. In our presentation, we will explore relevant use cases in maritime logistics and examine advanced methods beyond QUBOs.

■ MB-33

Monday, 10:30-12:00 - Room: Maurice Keyworth 1.31

Scenarios and Stochastic Dominance

Stream: Decision Analysis
Invited session
Chair: Eeva Vilkkumaa

1 - Value-Driven Social Welfare Analysis based on Multidimensional Stochastic Dominance: Theory and Application to Comparisons of European Populations
Nikolaos Argyris, Lars Østerdal, M. Azhar Hussain

Recent decades have seen an increased acceptance, globally, that the measurement of social welfare must encompass more than material economic standards, and include dimensions such as health, education, social relationships etc. At the heart of this problem is the question how to compare population distributions over a multi-dimensional space. Here we introduce the theoretical framework for such multidimensional comparisons and apply this to a specific dataset. We present new results that characterise two multidimensional stochastic orders and permit the practical comparison of discrete multidimensional distributions. These form the basis for a new framework for welfare evaluation, which accommodates multiple dimensions of individual welfare and enables robust social welfare comparisons. Our framework allows incorporating concerns about distributional inequality in social welfare evaluation. Additionally, it can incorporate value-judgements, which allow for capturing specific policy or ethical considerations in the social evaluation exercise and have the potential to significantly sharpen the dominance relations. The framework also incorporates a welfare measurement scale. This facilitates a richer form of analysis, compared to other dominance-based methods, from which we can gauge the overall level of social welfare in different populations. We illustrate the application of our framework with a case study investigating social welfare across 31 European countries.

2 - Scenario-based decision analysis when scenarios are not mutually exclusive: axiomatic foundations and implications to decision support
Juuso Liesiö, Eeva Vilkkumaa

Scenario-based decision analysis (SDA) relies on (i) characterizing possible futures with a set of scenarios, (ii) evaluating how decision alternatives perform in each scenario, and (iii) harnessing expected (multi-attribute) utility to generate decision recommendations on which alternative to select. Although SDA has been successfully applied in real-world decision support, it is commonly criticized for (implicitly) assuming that the scenarios are mutually exclusive. This paper establishes an axiomatic foundation for SDA using subjective expected utility theory and shows how relaxing the assumption of mutually exclusive scenarios results in a set of feasible probability measures for the possible futures, which can be reduced by eliciting (incomplete) probability statements from the decision makers. We develop dominance and ranking concepts to analyze how sensitive the decision recommendations are to violations of the mutually exclusivity assumptions as well as optimization models that enable the use of these concepts in practical applications. Finally, we demonstrate the approach by applying the developed models to real-world data.

3 - Stochastic dominance intensity
Gaston Yalonetzky

Stochastic dominance conditions have long been used in myriad areas of finance, operations research and welfare economics to test the robustness of distributional comparisons to alternative evaluation functions satisfying a common set of axioms. Besides being commonly unable to rank all distributions, dominance conditions are deemed uninformative regarding the intensity of a preference relation between distributions. However, for a broad array of dominance conditions for ordinal variables known as cone orderings, we demonstrate that from the set of distributions ordered by a given dominance criterion we can derive a set of ordered pairs ranked by the intensity of the same dominance condition. For that purpose, we derive results describing the conditions whose fulfillment ensures that the preference difference favouring distribution p over q is greater than that favouring r over s for all evaluation functions consistent with the same dominance criterion. The results apply to well-known partial ordering criteria for ordinal variables including first-order dominance, Hammond welfare, Hammond inequality, median-preserving spreads and bipolarisation, among others.

4 - Optimizing the Finnish Colorectal Cancer Population Screening Program with Decision Programming
Eeva Vilkkumaa, Lauri Neuvonen, Mary Dillon, Ahti Salo

In Finland, colorectal cancer (CRC) incidence rates have steadily increased over the last decades and as of 2020, CRC is the second most common cancer in both males and females. CRC is a crucial concern for the public health of Finland, highlighted by the recent implementation of a national population screening program. We optimize the screening test positivity cut-off levels and potential incentive use for stratified populations with regard to the minimization of cancer prevalence with Decision Programming; a novel approach to solving discrete multi-stage decision problems under uncertainty. The results present optimal cut-off levels and incentive use for Finnish target groups with different colonoscopy capacity constraints. We also present estimated outcomes for the optimized strategies, including the expected CRC prevalences, expected numbers of required colonoscopies expected third-party costs, and measures describing different equality perspectives.

■ MB-35

Monday, 10:30-12:00 - Room: Michael Sadler LG15

Nonlinear Optimization Algorithms and Applications: 1

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: Ya-xiang Yuan
Chair: Xin Liu
Chair: Cong Sun
Chair: Zaikun Zhang

1 - A derivative-free regularization algorithm for equality constrained nonlinear least squares problems
Jinyan Fan

In this talk, we present a derivative-free regularization algorithm for the equality constrained nonlinear least squares problem, where the Jacobian matrices of the objective function and constraints are unavailable or expensive to compute. We approximate the Jacobian matrices via orthogonal spherical smoothing. At each iteration, a regularized augmented Lagrangian subproblem is solved to obtain a Newton-like step. If a sufficient decrease in the merit function of the approximate KKT system is achieved, the step is accepted, otherwise a derivative-free LM algorithm is applied to get another step to satisfy the sufficient decrease condition. It is shown that the algorithm either finds an approximate KKT point with arbitrary high probability or converges to a stationary point of constraints violation almost surely.

2 - Barzilai-Borwein methods for nonlinear composite optimization
Hongchao Zhang

This talk introduces new gradient methods to solve nonlinear composite optimization using Barzilai-Borwein stepsizes as frequently as possible. When the objective function is convex, the method proposes new step size rules without using line search. For nonconvex objective

function, novel line search rules are designed based on natural generalizations of the step size rules derived from the convex case. Global convergence and convergence rate will be discussed for the proposed methods. Very promising preliminary numerical results will also be presented in the talk.

3 - Solving 10,000-Dimensional Optimization Problems Using Inaccurate Function Values: An Old Algorithm
Zaikun Zhang

We re-introduce a derivative-free subspace optimization framework originating from Chapter 5 the thesis [Z. Zhang, On Derivative-Free Optimization Methods, PhD thesis, Chinese Academy of Sciences, Beijing, 2012] of the author under the supervision of Ya-xiang Yuan. At each iteration, the framework defines a (low-dimensional) subspace based on an approximate gradient, and then solves a subproblem in this subspace to generate a new iterate. We sketch the global convergence and worst-case complexity analysis of the framework, elaborate on its implementation, and present some numerical results on solving problems with dimension as high as 10,000. The same framework was presented during ICCOPT 2013 in Lisbon under the title "A Derivative-Free Optimization Algorithm with Low-Dimensional Subspace Techniques for Large-Scale Problems", although it remains nearly unknown to the community until very recently. An algorithms following this framework named NEWUOAs was implemented by Zhang in MATLAB in 2011 (https://github.com/newuoas/newuoas), ported to Module-3 by Nystroem (Intel) in 2017, and included in cm3 in 2019 (https: //github.com/modula3/cm3/blob/master/caltech-other/newuoa/src/NewUOAs.m3).

4 - An acceleration strategy for gradient methods in convex quadratic programming
Gerardo Toraldo, Serena Crisci, Anna De Magistris, Valentina De Simone

It is well known that the Cauchy steepest descent (SD) algorithm performs very badly, even for mild conditioned problems, since the worst case predicted by the theory is likely to happen. Barzilai Borwein related rules shown to be much more efficient than SD with surprisingly computational results even when generalized to nonquadratic and constrained problems. The design of effective steplength rules is the common ground on which all new gradient methods are based on. In this work we propose a different approach to accelerate the convergence of gradient methods, based on the idea of performing, in selected iterations, acceleration steps which are not gradient related.

■ MB-38

Monday, 10:30-12:00 - Room: Michael Sadler LG19

Optimization in contexts with multi-media signals or data security

Stream: Data Science meets Optimization
Invited session
Chair: *Dimitri Papadimitriou*
Chair: *Chien Chu Lu*

1 - Forecast demand and scenarize energy production in district heating networks
Slawomir Pietrasz, Marinette Loisy

Imagine you operate a district heating and cooling (DHC) network. Your goal is to constantly improve its global performance. What asset would you run to produce the daily required energy: gas boilers, cogeneration plants, geothermal heat pumps or biomass boilers? External temperature variations and network extensions significantly influence fuel supply to DHC networks. The challenge is threefold: satisfy the customers' heat demand, keep low operating costs and contribute to the ENGIE Group's Net Zero Carbon ambition. The networks have been equipped with sensors that collect more than 500 million pieces of data every day. A decision supporting platform "Predity for Asset" uses this data as an input for Artificial Intelligence and Operation Research tools. "Predi Demand", forecasts thermal demand over the next 15 days, based on the energy consumed on the network over the past year, and a forecast of outdoor temperature for the coming period. It is based on a parametric multiple linear regression model. "Predi Scenario", relies on the forecast computed by "Predi Demand" to determine the optimal heat production plan including heat recovered from the combustion of municipal solid waste. Boiler plants are thus supplied with the best available local and renewable energy. The platform is currently operational in France and is being deployed overseas. It will help reduce CO2 emissions by 45 million tons per year by 2030, with annual savings of 500 K EUR throughout France.

2 - Integrating Machine-Learning in District Heating Networks
Benjamin Dosse, Jérôme De Boeck, Bernard Fortz

The unit commitment (UC) problem consists in scheduling power generators in order to minimize their operating cost. Power generators may include thermal generation units, as well as renewable energy generation units, the latter introducing uncertainty regarding their production level when solving UC problems.

The UC problem must be solved several times a day in short time frames. Therefore, machine learning (ML) models can be used at different stages to speed up computation time, e.g. by finding first approximate solutions, or to alleviate errors due to uncertainty, e.g. by forecasting the network load.

Parallels can be drawn from UC with district heating networks (DHN) problems. In a DHN, an operator seeks to supply customers with heated water. To heat the water, thermal units are employed, such as gas boilers or heat pumps (HP). In combined UC and DHN, combined heat and power (CHP) units are considered.

To reduce greenhouse gas (GHG) emission of the energy sector, UC/DHN models can consider emission constraints, and multi-objective formulations both minimizing exploitation cost and emissions are developed.

In this talk, we present the contribution of ML models to solve UC/DHN and UC/DHN+GHG problems.

3 - Using financial and network analytics to elucidate firm performance in the pharmaceutical industry
Penina Orenstein, Rongrong Zhang

We explore the effect of network measures on firm performance using Tobin's Q and ROA and examine their impact on specific network structural metrics (e.g. average degree, eigenvector centrality), focusing on the pharmaceutical industry. Using a data visualization approach combined with a regression analysis, we verify that suppliers' network structures significantly impact their customers' performance in the pharmaceutical industry.

We expand the analysis to include the cash conversion cycle (CCC) and demonstrate how CCC appears as a potential channel through which network structure affects firm performance. CCC provides the number of days that a firm's cash is tied up during the operating activities of a firm. It is commonly used to measure a firm's operational efficiency.

Prior literature generally finds a negative relationship between CCC and firm performance. In the pharmaceutical setting, we expand the baseline firm performance regression model by adding CCC and the interaction term between CCC and the multiple network structural metrics. First, we document a negative and significant relation between CCC and Tobin's Q, in line with our position that operational inefficiency (i.e., high CCC) detracts from firm performance. Additionally, we document several other significant relationships between CCC and network structural variables. We then explain the implications of these findings for this industry.

4 - Evaluating the optimal blockchain system of DRTS in eastern Taiwan
Chien Chu Lu, Cheng-Chieg (Frank) Chen

In eastern Taiwan, the slow transition to digital currency can offer numerous benefits for both consumers and operators. The Hualien and Taitung region are situated to the east of the Central Mountain Range. Roadways are the primary mode of transportation to external destinations. But, the last mile was very inconvenient. Therefore, the Demand Responsive Transportation System (DRTS) was established. The problems of DRTS are (1) users must verify their identity before receiving subsidies; (2) operating units face delays for DRTS subsidies and complex verification processes. (3) management units are tasked with overseeing several operational units concurrently; (4) the distance between supervisory and frontline units hinders real-time oversight. The objective of this research is to address the challenges encountered by stakeholders and enhance the overall environment of the DRTS within the public transportation framework. This investigation focuses on the implementation of digital currency in the Hualien and Taitung regions, incorporating the principles of Ethereum blockchain technology. In order to optimize total operating expenses. This research employs advanced blockchain technology to enhance the transportation system of the Happiness Bus and address the challenges encountered by the broader DRTS, including data transparency, decentralized data management, and resistance to tampering.

■ MB-41

Monday, 10:30-12:00 - Room: Newlyn GR.01

OR Innovations in Policy Making - I

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Ine Steenmans*
Chair: *Irene Pluchinotta*

1 - Surfacing Anticipatory Assumptions to Improve Policy Problem Structuring
Ales Cap

Anticipatory Assumptions (AAs) shape how policy makers frame and engage with complex problems. They are the building blocks of our images of the future, influencing how we sense, perceive, and act in the present (Bergheim, 2023). AAs are a small but crucial part of Futures Literacy (FL) Labs (Miller, 2018), yet they remain theoretically and empirically underdeveloped. In a rapidly changing and uncertain world, where unexamined assumptions about the future can lead to strategic errors, understanding and surfacing AAs is critical for improving problem structuring and strategic foresight.

This presentation explores how AAs frame policy problems and how they might be elicited through structured methods. We will present our work on defining the boundaries of what AAs are, distinguishing them from related constructs like cognitive mapping (Downs & Stea, 1973). We will introduce emerging methods for surfacing AAs, aiming to provide policy makers with practical tools to identify and interrogate the assumptions shaping their decisions. We will also share thoughts on how AI-driven techniques could enhance the identification and analysis of AAs, uncovering hidden biases and broadening the range of possible solutions.

This work contributes to the broader field of Problem Structuring Methods (PSMs) by integrating insights from Futures Studies, cognitive science, and Behavioural OR, offering a new lens for understanding and improving decision-making in public policy contexts.

2 - Generating alternatives for policy design
Halil Berkay Tosunlu, Joseph Guillaume, Irene Pluchinotta, Alexis Tsoukias

In this talk, we present a complete procedure enabling decision analysts to support the policy design process with innovative "out-of-the-box" alternatives. The procedure combines problem structuring tools (cognitive maps and value trees) and formal design theory, extending the well-known C-K approach. More precisely, we show how to construct a concept tree out of a value tree and how to exploit that for innovative policy design.

3 - An activity theory-based framework for micro-level analysis of collaboration in facilitated modelling
Yuhong Wang, Pepe Puchol-Salort, Nici Zimmermann

Facilitated modelling, a participatory approach to problem structuring and collaborative decision-making, heavily relies on facilitators' roles and teamwork. While there exist guidelines for facilitated modelling, such as participatory system dynamics scripts, and while there is evidence that they influence communication and insight, there remains a gap in understanding the micro-dynamics in facilitated modelling. To bridge this gap, this paper presents an analytical framework rooted in the Activity Theory (AT) concept to examine collaboration within participatory system dynamics workshops, specifically Group Model Building (GMB). Through a proof-of-concept application of this framework, this study analyses group model building activities focused on the quality of public spaces in Thamesmead, London, UK. This framework offers a new perspective to understand the relationships among participating subjects, tools used, facilitators' division of labour, and the studied object (i.e., the GMB workshops). The findings from this study inform about stakeholders' experiential learning process in acquiring system dynamics techniques and languages. Additionally, the paper illustrates how facilitators can adopt various roles within their division of labour. Ultimately, this analysis framework has the potential to substantially advance our understanding of micro-collaboration dynamics within facilitated modelling activities.

4 - Augmented or Diminished? How AI Transforms Systems Thinking Capabilities in Policy Analysis
Ine Steenmans

Systems thinking is foundational for policy analysis, yet remains conceptually ambiguous in practice. As governments simultaneously invest in systems approaches and adopt AI analytical tools, I argue we must urgently examine how these technologies affect systems thinking competencies in public servants.

This research examines five key contexts where systems thinking manifests in policy practice. I develop an anticipatory framework to explore ex-ante how emerging AI technologies could transform capabilities like system boundary identification, relationship mapping, and multiple perspective integration.

Early findings from ongoing analysis reveal a paradox of affordances: AI tools can simultaneously enhance and diminish systems thinking. While they could boost cognitive capacity for complex visualisation and pattern recognition, they could also undermine critical capabilities by narrowing problem framing and reducing collaborative sensemaking - and often within the same analytical task.

This research contributes to OR research and practice by defining AI-relevant systems thinking competencies and identifying critical uncertainties in our assumptions about AI-augmentation of analytical capabilities. I conclude with a proposed research agenda for the OR community to develop measurement frameworks and intervention designs that ensure AI augments rather than diminishes systemic analytical capacity in government.

■ MB-42

Monday, 10:30-12:00 - Room: Newlyn GR.02

Game theory for the circular economy

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: *Enis Kayis*

1 - Evaluating the evolutionary impact of sustainability initiatives on customer behavior: A case of vaccine supply chain
Nazanin Nami, Cátia da Silva, Ana Barbosa-Povoa, Grigory Pishchulov, Joao Quariguasi Frota Neto

Sustainable supply chain management is crucial for addressing today's pressing environmental, social, and economic challenges. Despite growing awareness, many supply chain managers still struggle to integrate sustainability effectively. To ensure the efficiency and effectiveness of sustainable practices in the long run, accurate estimations of the impact of sustainability efforts and understanding the dynamic response of the customers to such practices are crucial. This paper addresses these issues by utilizing the evolutionary game theory along with an innovative decision support tool to create an effective and adaptive framework for managing dynamic sustainability initiatives in supply chains. Our approach shows how businesses can align sustainability goals with customer behavior, optimizing both economic and environmental outcomes. Through a case study based on an international meningococcal meningitis vaccine manufacturer, we demonstrate significant improvements in operational efficiency and sustainable performance of the supply chain, along with enhanced customer engagement in waste reduction. These results offer valuable insights for businesses and policymakers aiming to enhance sustainability in supply chains, providing a comprehensive solution that bridges the gap between theory and practice.

2 - Legitimacy of buyers' supply chain transparency disclosure under limited supplier visibility and state-imposed constraints?
Karthik Ramaswamy, Rajeev Ranjan Tripathi

Global companies outsource production to developing economies for lower costs and cheap labor, but this often leads to social issues like child and forced labor. In response, developed nations have enforced laws requiring companies to ensure their supply chains free of such practices. To comply, firms disclose their suppliers' details and rate them based on their social responsibility (SR) practices. However, these ratings are often unreliable due to buyers' limited visibility into their suppliers' operations due to various constraints. One such constraint is when governments in developing countries restrict supplier audits. We identify conditions under which buyer's disclosures regarding their supplier's SR practices are legitimate by considering two types of risk-sharing contracts between buyer and supplier (wholesale price contract and buyback contract) and state-imposed visibility constraints. We model the strategic interaction between the buyer and the supplier (rated low or high in SR practices) as a signaling game, where the supplier signals transparency or non-transparency, and the buyer updates his belief accordingly. Our analysis reveals that, regardless of the contract type, 1. Without state-imposed constraints and minimal supplier monitoring, low-SR suppliers opt for non-transparency, while high-SR suppliers opt transparency. 2. When state-imposed constraints are high, all suppliers choose transparency regardless of their SR type or external monitoring

3 - An options contract for WEEE reverse supply chains
Jenny Andris, Christoph Schwindt

The increasing number of electrical appliances on the market is contributing to a growing amount of waste from electrical and electronic equipment (WEEE). The European Union's WEEE directive stipulates that manufacturers are responsible for proper WEEE collection and disposal. In this talk, we focus on long-term contracting between a manufacturer and a collector in a reverse supply chain for WEEE. We propose a wholesale contract that serves as a benchmark for our research. Starting from a previously designed options contract with a collector as the Stackelberg leader and a manufacturer as the follower, we swap the roles of leader and follower and consider a new Stackelberg game. The options contract protects the collector's investment in capacity extension against the risk incurred by uncertain future order volumes. On the other hand, the financial risk of the manufacturer associated with the options investment can be limited to a given value at risk. We show that the wholesale contract inevitably fails to coordinate the supply chain, whereas the new options contract is proved to minimize the total supply chain cost under economically plausible conditions. In a computational experiment we compare the performance of the manufacturer's optimal options contract with the results obtained by using a wholesale contract.

4 - Supplier Selection under Carbon Border Adjustment Mechanism
Enis Kayis, Serkan Ürkmez

Emission Trading Systems (ETS) and the Carbon Border Adjustment Mechanism (CBAM) are pivotal carbon pricing mechanisms in the global effort to combat climate change. These strategies aim to reduce carbon emissions and promote green technology investments and sustainability practices across industries. Complementary to ETS, CBAM addresses the risk of carbon leakage by imposing a carbon price on specific imported goods, ensuring they meet similar carbon emission standards as domestically produced items. In this work, we explore the efficacy of CBAM in addressing carbon leakage and stimulating green technology investment for decarbonization. We focus on dual suppliers: one operating within a regulatory ETS region and the other in a non-ETS region subject to CBAM. Both suppliers provide materials to a manufacturer located in an ETS region, although the products themselves are not subject to ETS content regulations. We derive the equilibrium quantities regarding pricing and quantity decisions of the firms, and derive business insights on supplier selection and overall strategies for reducing carbon emissions.

■ MB-43

Monday, 10:30-12:00 - Room: Newlyn GR.07

Ethics and OR, Public Service and Societal Complexity

Stream: OR and Ethics
Invited session
Chair: Dorien DeTombe
Chair: *Cathal MacSwiney Brugha*

1 - Indices and models for monitoring the spread of information, communication and digital technologies - an overview
Nikolina Žajdela Hrustek, Nenad Perši

In times of great social and economic crises, one of the primary focuses should be strategies that contribute to greater implementation and use of ICT and digital technologies in all spheres, economic and social, as well as the allocation and optimization of limited resources to achieve the best possible effects for the purpose of sustainable development. Worldwide opportunities to access and use ICT and digital technologies vary dramatically. The consequences of digital exclusion are most often reflected in social exclusion when an individual belongs to a "vulnerable" group of the population, because almost all information, as well as great opportunities that significantly affect the life quality of individuals, are provided through ICT and digital technologies. Thus, monitoring movements of expansion and use of ICT and digital technologies by a "vulnerable" group of people, according to which the aims of new strategies should be defined and implemented, has become very significant for the bearers of economic and social policies in all countries. As the authors did not find an adequate model/index for monitoring the availability and use of ICT and digital technologies by "vulnerable groups" through the literature review, this research focuses on the review of available models and composite indices for the purpose of identification of key components, indicators, and influencing variables, as well as the methodologies used for its construction and validation.

2 - Ethical components of the Gaza war
Cathal MacSwiney Brugha

In 1917 Arthur Balfour, formerly Governor of Ireland, conceived of Britain's last colony: "forming for England a little loyal Jewish Ulster in a sea of potentially hostile Arabism", and inviting the Jewish diaspora from around the world to settle in Palestine. With the potential for a new Gaza Canal under Israeli control to rival Egypt's Suez Canal's access to the Mediterranean, and to be able to make sole claim over the recently discovered Gaza Marine Gas fields, colonising Gaza could provide hugely lucrative gain for Israel, its allies, and us in Europe. We in Europe, especially, are ethically and morally wrong and complicit, in not opposing Israel's colonisation, for being part of initiating, funding, arming, provoking, and extending the genocide of Palestinians in Gaza, because we could prevent it. It is to our shame, as Europeans, that we do not stand, and prevent this evil, when we could, and should. The pain of imprisoning Palestinian women and children without trial for years was used to trick Hamas to take the blame for starting the war, because they were led to believe that capturing Israeli soldiers could lead to a refugee swap. It would be good if Europe, through the United Nations, acted to protect and defend everyone affected, the victims on all sides, the doctors, nurses, women, children, journalists, the care givers, the peace protectors, and the generations to come of Palestinians and Israelis who are being forced into this unethical war.

3 - Pollution a complex societal problem
Dorien DeTombe

Pollution seems to be everywhere in the world. More and more people become aware about the danger of pollution for the health of species. There are almost daily announcements of new pollution scandals in the media. Much more items are threatening the health of humans, animals, plants and insects, then was known before. In a democracy the government has the task, among other things, to take care of the health of the people by providing hospitals, and institutes for healthcare, educating doctors and nurses and by giving rules for safety. However, these regulations do not cover all health threats, or if they do, the regulations are often not maintained. In many countries polluting industry is allowed or tolerated. Such as CO2 from agricultural industry and cancers stimulating waste from the large industries like Tata steel, and Chemours (PFAS). Although already widely known by the scientists and discussed with the politicians, these industries are still allowed to put their deadly waste into the air, ground and water and by doing this, threatening the health of species. Pollution is a complex societal problem. Changing the world to a saver environment need the support of the field of Methodology of Societal Complexity and the Compram methodology.

4 - A System Dynamics Analysis of Maternal Leave Policies and Their Sociopsychological Impacts
R. M. Kazakov, Penka Petrova, Yavora Rosenova

The decision of when mothers return to work after childbirth profoundly affects family well-being, child development, and societal stability. Short maternity leave disrupts parent-child attachment, increasing risks of behavioural issues, lower academic achievement, and future social instability. Women experience postpartum depression, hormonal shifts, and physiological stress for an extended period after childbirth, regardless of employment status, making early return to work an added strain. Parental stress also reduces work efficiency and necessitates costly childcare solutions. This study applies a System Dynamics (SD) approach to examine these trade-offs and their long-term consequences. Aligned with the United Nations Sustainable Development Goals (SDGs), this research addresses: SDG 3 (Good Health & Well-being): Psychological and physiological effects on parents and children. SDG 5 (Gender Equality): Reinforcing workplace inequalities and disproportionate burdens on women. SDG 8 (Decent Work & Economic Growth): Labor market stability and workforce productivity. Through scenario simulations, this study informs policy and labour strategies that balance economic demands with parental and child welfare, advocating for sustainable parental leave frameworks that promote mental health, gender equity, and social resilience.

■ MB-44

Monday, 10:30-12:00 - Room: Newlyn 1.01

Inverse Design Modelling of Energy Systems

Stream: Energy Economics & Management
Invited session
Chair: Katharina Esser

1 - Inverse multi-objective energy modelling for the optimisation of technical parameters of emerging technologies
Katharina Esser, Jonas Finke, Valentin Bertsch

The transition to a climate-neutral energy sector depends on integrating renewable energy sources alongside flexible and innovative technologies. However, modelling low technology readiness level (TRL) technologies remains challenging due to high uncertainty in input parameters like technology costs and efficiencies. To address this issue, we propose an inverted energy system modelling approach that turns conventional input parameters into decision variables and objectives of the optimisation. Multi-objective optimisation then enables trade-off analyses between total system costs and technology development requirements, e.g the minimum requirements that would still allow a technology to be used in a cost-efficient system. Applied to Central Western Europe's power system expansion planning—with Carnot Batteries (CBs) as low-TRL storage—preliminary results reveal trade-offs between technical properties and system costs. We find that with worsening technical properties requirements for CBs to compete in the market become stricter. Improving energy-to-power ratios achieves higher tolerable capital expenditures and lower system costs more effectively than enhancing roundtrip efficiencies. However, analyses of maximum annualised investment costs uncover conflicts between economic viability and product development goals in single trade-off solutions. These solutions need to be identified and further considered to guide early-stage product development and system design.

2 - Unlocking the Potential of Carnot Batteries in Industrial Energy Systems: A Target Cost Analysis Approach
Jonas Thomsen

In the transition to a decarbonised energy system, the need for medium- and long-term electrical energy storage solutions increases. While Power-to-H2-to-Power is projected to be dominant for seasonal storage and lithium-ion batteries (LIB) for short-term balancing, Carnot batteries (CB) offer a scalable alternative for storage over days and weeks. CBs also offer advantages compared to pumped hydro or compressed air storage, as they can be located independently from geographical requirements. However, due to their low technology readiness level there is a lack of reliable data regarding their potential costs and the corresponding achievable efficiencies. While most studies find CBs to be economically unfeasible for grid applications, they could be a viable option for behind-the-meter solutions, depending on factors such as load profile and on-site energy sources. To assess their potential, we use an inverse optimization approach to determine the maximum target costs for CBs. In a case study for three industrial sectors at two locations in Germany (wind- vs. solar-dominated) for the year 2046 we demonstrate that CBs are particularly attractive in wind-heavy regions and for industries with weekly load shifting potential. In solar-dominated scenarios, CBs primarily serve daily balancing and face stronger competition from LIBs. The inverse approach can help to identify suitable markets for CBs and define economic and technical development targets, such as cost and efficiency.

3 - Optimizing Revenue Potential of Mid-Term Storage Technologies in Sequential Electricity Markets
Jonathan Stelzer

Due to increasing share of volatile renewable energies, storage systems are essential for bridging longer periods with limited wind and solar energy. These phases, lasting several days or weeks, cannot be addressed by short-term storage. Mid-term storage systems, with

discharge times ranging from several hours to weeks, open up new revenue potentials. Unlike lithium-ion batteries, they provide cost-effective scalability for longer durations and larger capacities. Their economic viability can be enhanced by leveraging opportunities across sequential electricity markets. This study investigates the revenue potential of mid-term electricity storage systems by optimizing the storage dispatch over three sequential electricity markets. Using time series data from Germany's balancing energy market for automatic frequency restoration reserve, the day-ahead market and intraday market, a multi-stage optimization problem is formulated to determine the optimal market-driven operation strategy. By considering various efficiencies and discharge durations, the method enables the inverse determination of optimal technical configuration of mid-term storage technologies. The expected results assess whether expanding participation across the three sequential markets, rather than relying solely on the day-ahead market, can lead to increased revenues. Furthermore, it offers clarity on whether longer discharge times contribute to higher revenues and how efficiency impacts overall revenue.

4 - Empirical Parameter Estimation for Power Plants using Open Data
Jie Xu, Philipp Castro, Maike Spilger, Christoph Weber, Jonathan Berrisch, Florian Ziel

Dispatchable power plants offer the flexibility needed to accommodate intermittent renewable generation and variations in demand. Energy system models typically make use of generic engineering estimates of the key power plant parameters. In our research we make use of publicly available data, like hourly unit-level generation time series from the ENTSO-E Transparency Platform, to obtain empirically validated estimates for the parameters that describe the efficiency and flexibility of thermal power plants to respond to residual load variations.

The proposed method complements the generation data with market data, notably day-ahead prices, to identify the economic incentives and operational strategies of power plant operators and the underlying power plant parameters. We focus on the minimum stable operation limit as well as the efficiency at both this lower operation limit and the nameplate capacity. Both are key parameters in typical unit commitment and dispatch models for power plant operation. To identify the operational status, we make use of clustering techniques. We furthermore consider the complications arising from temperature-dependency of parameters, provision of ancillary services, CHP and retrofits. The empirical application focuses on gas-fired power plants in Germany and the Netherlands.

The developed methods can be extended to further parameters including start-up costs and ramping rates and may be embedded in a general inverse optimization approach.

■ MB-46

Monday, 10:30-12:00 - Room: Newlyn 1.07

Development and use of renewable fuels

Stream: Energy Economics & Management
Invited session
Chair: *Ali Ebadi Torkayesh*

1 - Impacts of incentives on development of power-to-liquid fuels in Europe
Ali Ebadi Torkayesh, Mina Farajiamiri, Grit Walther, Sandra Venghaus

Power-to-Liquid (PtL) fuels, synthesized from renewable electricity, water, and CO_2, offer a promising solution for defossilizing the transport sector, aligned with the EU Green Deal and Fit for 55 package. Especially in aviation and maritime transport—where electrification faces technical limitations—PtL fuels are expected to play a crucial role in achieving climate neutrality. Given the significant costs associated with developing these fuels, stakeholders, including investors across various stages of the value chain, need to explore potential financial support, such as subsidies and grants, to facilitate value chain implementation. Therefore, we developed a mixed integer programming model for value chain optimization of PtL fuels, including green hydrogen, ammonia, Fischer-Tropsch fuels, and e-methanol (MeOH) based on total cost minimization. We examined the effects of various direct monetary incentives - covering for resources (biomass, carbon, and electricity), production and storage technologies, operation & maintenance costs and imports - on optimizing value chain design. As renewable electricity and import costs represent the primary burdens of the value chain, extensive scenario analyses were conducted to assess the model's behavior under different incentive programs. Scenario analysis was also extended to include real-world incentive programs, e.g., Innovation Fund.

2 - Distributed e-Fuel Hubs (DEFH): A case study of a Belgian Fischer-Tropsch liquids hub
Samy Mokeddem

This paper introduces the concept of distributed e-fuel hubs (DEFHs), which consist of power-to-x facilities strategically located near e-fuel demand centers. "Distributed" refers to rather small units scattered across a country close to efuel demand centers (EDCs). DEFHs valorize the local industry's waste outputs to convert them into e-fuel, and the e-fuel synthesis by-products. The EDCs can be airports for plane refueling, ports for ship refueling, or heavy industries that require e-fuels for high-temperature processes.

This work explores the potential of DEFHs through a case study of a DEFH in Belgium synthesizing Fischer-Tropsh (FT) products (i.e. e-kerosene, e-diesel, e-naphtha) with a lime plant as the source of CO2. In this case study CO2 is captured from the plant's flue gases using post-combustion carbon capture (PCCC). The waste heat generated during e-kerosene synthesis is valorized in a district heating network. The other e-fuel by-product considered is oxygen which is valorized on market price. Using this case study, we illustrate the appeal of our approach in terms of production cost reduction. This problem is tackled as a linear program where we optimize the asset's capacities and operations.

3 - Life cycle assessment (LCA) of ethanol from sugarcane in India: A Comparative Analysis
Dushyanth Kumar Reddy Gangireddy

India relies majorly on crude oil imports to meet its domestic energy demand. To address this issue, biofuels like bioethanol are being promoted to reduce oil imports and GHG emissions. However, there are concerns about environmental effects with extended usage of biofuels. To understand the impact of biofuels like ethanol on the environment, it is crucial to perform the Life Cycle Assessment (LCA). There are limited studies on emissions and environmental impacts caused by ethanol usage in the Indian context. This study tried to address this gap by performing LCA of ethanol from sugarcane molasses with a cradle-to-grave approach, making it the first such study in India. A comparative LCA analysis is performed between Uttar Pradesh and Karnataka, the leading sugarcane and ethanol producers in northern and southern India, respectively. The functional unit considered is 1 ton of ethanol. Input and output environmental correlations were assessed using SimaPro software. ReCiPe Midpoint and Endpoint methods are used to estimate potential environmental impacts. Indicators reported are Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Eutrophication Potential (EP), land use, and water use. Primary data was collected and used for all the processes considered for LCA. The results show the contributions of all the processes on the impact categories for every ton of ethanol produced.

4 - A Multi-Period Hydrogen Refuelling Station Location Problem
Katarzyna Gdowska, Radosław Kapłan, Roger Książek

This study examines the integration of hydrogen propulsion technology into rail transport, a sector constrained by fixed infrastructure. The strategic placement of hydrogen refueling stations (HRS) is crucial for advancing fuel cell technology in railways. To address the HRS location problem, this study introduces the Multi-Period Hydrogen Refueling Station Location Problem for Railways (MPHRSLPR)

inspired by the Economic Order Quantity (EOQ) model which considers varying hydrogen demand, hydrogen availability, infrastructure costs, and operational constraints, and prices over multiple periods. This approach enables experimentation with diverse scenarios, aiding strategic decisions on deploying new technology at national and regional levels. A Mixed-Integer Linear Programming (MILP) model is developed to solve the MPHRSLPR, optimizing HRS placement at predefined locations over a 15-30-year horizon. The objective is to minimize total investment and operating costs while meeting regional hydrogen demand. The paper presents the problem definition, modeling approach, and MIP formulation, with an implementation based on exemplary instances from the Wielkopolska region in Poland. Support: ERJU FP4 - Sustainable and green rail systems (Horizon Europe, grant no. 101101917) and the Polish Ministry of Education and Science (International Co-Financed Projects , grant no. MEiN 5337/HE/2023/2). The project is implemented at the AGH University of Krakow in 2022-2026.

■ MB-48

Monday, 10:30-12:00 - Room: Parkinson B09

Advances in Location Analysis

Stream: Locational Analysis
Invited session
Chair: *Pawel Kalczynski*

1 - Sequential Trajectory Method for Solving Location Problems
Malgorzata Miklas-Kalczynska

We further develop the trajectory method for solving unconstrained non-linear optimization problems with differentiable objective functions. A parameter is introduced into the optimization problem in such a manner that the value of the objective is easy to find for its initial value. A trajectory connects the obtained solution to the desired solution. We trace the trajectory, and the solution to the optimization problem is at the end of the trajectory. This new solution then serves as the initial solution for an extension of the original problem, creating a sequence. This procedure results in optimal solutions to convex problems and can be used to obtain starting solutions to nonconvex problems. The idea is illustrated with examples from location analysis.

2 - Enforcing Stability in Capacitated Facility Location Problem with Ordinal Customer Preferences.
Adam Dunajski, Sergio García Quiles, Akshay Gupte

Classically in facility location problems both the choice of location and the customer allocation is completed by a central decision maker, and customers cannot choose amongst the open facilities. However, customer preferences may not align with those of the decision maker. Here customers can act as strategic agents and deviate from a proposed allocation. Such freedom of choice is present, for example, in school choice in the UK. Here parents have a right to express preferences over state schools, and all schools (except grammar schools) must offer a place to every child who has applied if they have space.

This work focuses on how known ordinal customer preferences can be incorporated into integer linear programming formulations for the capacitated facility location problem. We build on the work of Hanjoul and Peeters (1987) on the uncapacitated variant and subsequent work strengthening their proposed formulations.

We incorporate solution concepts from the algorithmic game theory and stable matching communities, including Nash stability and swap stability, into the capacitated problem. Both single source (each customer must have their entire demand satisfied by a single facility) and fractional (the demand of a customer can be split over multiple facilities) allocations are considered.

We propose new integer linear programming formulations which enforce the stability notions, and demonstrate their performance on benchmark instances.

3 - Pattern-based Kernel Search for the Single-source Capacitated Facility Location Problem
Hannah Bakker, Gianfranco Guastaroba, Stefan Nickel, M. Grazia Speranza

We introduce Pattern-based Kernel Search (PaKS), a two-phase heuristic expanding the successful Kernel Search (KS) for the capacitated facility location problem with single sourcing (SS-CFLP). KS leverages the fact that solving a sequence of small BIPs can be more efficient than solving one large BIP by partitioning decision variables into disjoint subsets—a kernel of "promising variables" and complementary buckets. An initial solution is obtained by solving the restricted BIP with only the kernel variables. Then, a sequence of restricted BIPs combining kernel and bucket variables is solved, progressively improving the solution and updating the kernel.

The performance of kernel search is critically impacted by the partitioning of the variables into kernel and buckets. While KS relies solely on information from the LP relaxation, PaKS uses pattern recognition to analyze a series of modified LP relaxations in its first phase. As a result, facilities and customers are divided into regions, each region corresponding to a bucket. Leveraging this implied spatial information allows to drastically reduce the size of the buckets. For the SS-CFLP, the largest instances solved in the literature contain up to 1000 facilities and customers each. Computational experiments show that PaKS outperforms state-of-the-art approaches even on benchmark instances containing up to 2000 facilities and customers each, demonstrating its strong potential for solving large-scale problems.

4 - The Planar p-Median Problem with Uniform Demand Density Over an Area
Pawel Kalczynski, Jack Brimberg, Taly Drezner, Zvi Drezner

Most location papers assume that demand is generated at points, which is convenient for designing models and solution methods. In many real applications, however, demand is generated in an area. We designed explicit expressions to calculate the exact value of the objective function and the average distance between all the points in the area to their closest facility when locating multiple facilities inside a convex polygon. Based on these formulations, heuristic procedures for finding the best locations of facilities are developed and tested with good results.

■ MB-49

Monday, 10:30-12:00 - Room: Parkinson B10

Business Analytics

Stream: Analytics
Invited session
Chair: *Carla Vairetti*
Chair: *Sebastian Maldonado*

1 - Automated Evaluation of Contact Center Agents Using Deep Learning Transformers for Enhanced Performance and Customer Satisfaction
Juan Pablo Karmy, Sebastian Maldonado, Carla Vairetti, Ignacio Mayer

In today's digital era, businesses operate in a highly competitive and evolving environment. Customer interaction is crucial for success, with contact centers serving as the primary contact point, helping to establish and maintain direct relationships with customers while ensuring satisfaction. However, evaluating the quality of service provided by agents is often done manually, leading to slow, costly processes that may introduce errors and biases. This project introduces an automated evaluation system utilizing deep learning transformers, such as BERT, ELECTRA, and RoBERTa, to assess agent performance in contact centers. The aim is to deliver an objective and comprehensive

analysis of performance across various tasks to enhance service quality and customer satisfaction. Our methodology involved developing the automated system and analyzing message distribution among agents, identifying patterns in interactions. All models achieved over 94% performance in four dialogue evaluation tasks, with RoBERTa outperforming others across all metrics. The Weighted-Sum Model yielded an average AQMScore of 57.5% for conversations from the first half of 2023. This contribution advances automated evaluation in contact centers, providing a flexible and reliable methodology to improve agent performance and facilitate better decision-making processes.

2 - Can Large Language Models Predict Credit Risk? An Empirical Study on Consumer Loans in Chile
David Díaz, Diego Beas

This study empirically evaluates the performance of Large Language Models (LLMs) in predicting credit risk for retail banking in Chile, comparing their effectiveness to traditional machine learning models. A variety of LLM configurations were tested, including models with and without fine-tuning, different chunking sizes, and several prompt engineering strategies, such as credit analyst roleplay, chain-of-thought reasoning, emotional stimuli, take a breather, and example-based learning (one-shot and few-shot). The analysis compared open-source models like Llama 3 and commercial models like GPT-3.5 and GPT-4.0. Results indicate that fine-tuned LLMs can achieve predictive accuracy levels comparable to traditional models such as logistic regression and ensemble methods like LightGBM. The top-performing fine-tuned GPT-3.5, GPT-4.0 and Llama 3 configurations achieved AUROC values near 80%, closely matching the best-performing LightGBM benchmark. A stability test was conducted to assess the consistency of predictions, crucial for credit risk applications. LLMs with a temperature setting of zero demonstrated high stability, producing consistent results across repeated queries, while higher temperature settings introduced variability, especially in default predictions, underscoring the importance of controlling this parameter for reliable results. Additionally, the LLMs were evaluated for their ability to explain their predictions.

3 - Unsupervised Deep Learning for Automated Fabric Defect Detection: Enhancing Quality Control and Sustainability
Luísa Silva, Vera Miguéis, Miguel Moura e Sá

Ensuring the quality of fabric labels is both challenging and essential for maintaining brand integrity while reducing material waste. Traditional quality control relies heavily on manual inspection, which is time-consuming, prone to human error, and inefficient in detecting subtle defects. Recent approaches leverage computer vision and machine learning methods for defect detection. However, the scarcity of defective samples creates an imbalance between defect-free and defective instances, making supervised machine learning approaches impractical. This research explores unsupervised defect detection methods to identify anomalies and mitigate inaccuracies in manual quality control inspections. By leveraging deep learning techniques, our approach learns the normal distribution of label patterns and flags deviations indicative of defects. A key challenge is the variability in label designs, requiring an automated approach to classify labels before defect detection. Each label type demands a tailored preprocessing strategy and a specific model to ensure optimal performance. To address these challenges, we adapt existing deep learning architectures to this context for effective anomaly detection. The expected contributions of this research include the development of an automated, scalable defect detection system, reducing reliance on manual inspection. By implementing such a system, textile producers can achieve higher quality standards, lower costs, and improved sustainability.

4 - Cost-sensitive Debt Collection via machine learning and segment-wise profit metrics
Sebastian Maldonado, Carla Vairetti, Catalina Sánchez

Banks and financial institutions frequently contend with a high number of debtors, resulting in significant financial losses. Their primary objective is to recover outstanding amounts in a cost-effective and timely manner. To address this challenge, these entities often outsource debt collection efforts to Contact Centers. However, these services do not always deliver the expected results, as reflected in the increasing number of debtors in recent years. This research explores the application of prescriptive models to enhance debt collection processes. We implement a wide range of statistical and machine learning methods to estimate the likelihood of a debtor making a payment in the near future. Additionally, we define tailored profit metrics that account for debtor heterogeneity, allowing us to select the optimal predictive model and its hyperparameter configuration based on profitability rather than relying solely on statistical performance measures such as accuracy. Finally, a sensitivity analysis provides valuable insights into how different write-offs should be defined for various debtor profiles. Another key contribution is the integration of multiple data sources. While conventional models primarily rely on financial and sociodemographic data, this study proposes incorporating an additional source—customer interaction records from Contact Centers—to enhance predictive performance.

■ MB-51

Monday, 10:30-12:00 - Room: Parkinson B22

Multiobjective optimization applications

Stream: Multiobjective and vector optimization
Invited session
Chair: Firdevs Ulus

1 - Using equitable optimization for the hazmat transport network design problem
Ozlem Karsu, Yunus Emre Cakir

The shipment of hazardous materials is challenging due to the risk that the population centers face during transportation. The policy makers often have concerns for ensuring a balanced allocation of the risks to the population centers. We structure this problem as an equitable optimization problem with multiple objectives aiming to minimize the risk exposure of different neighborhoods. The resulting multiobjective mixed integer linear programming problem is solved to provide the policy makers equitably nondominated options, each with different levels of efficiency (total risk) and fairness (allocation of risk).

2 - A Holistic Multiobjective Optimization Approach to Study Student Well-Being in Spain
Andrea Orozco Villodres

The academic performance of adolescents is a multifaceted issue influenced by various factors, including student well-being. Research highlights the strong link between well-being—encompassing social, physical, and mental dimensions—and academic achievement. Policies that promote well-being can enhance educational outcomes and reduce socioeconomic disparities. However, globalization, technological advancements, and the COVID-19 pandemic have introduced new complexities, reinforcing the need for data-driven policies. This study examines student well-being as a multidimensional concept using a multiple criteria decision-making approach. It differentiates between social, physical, and mental well-being, aiming to enhance these aspects among Spanish students. Using PISA 2022 data, three well-being indexes are constructed. Through econometric analysis, a multiobjective optimization model is developed to maximize these indexes simultaneously. This approach evaluates pathways for improving well-being and identifies the socio-educational conditions that support such improvements. Moreover, the model incorporates correlations among students' socio-educational characteristics to provide a comprehensive and realistic analysis. The findings reveal that students seeking to enhance their well-being holistically must balance different dimensions, emphasizing the importance of an integrated approach.

3 - Mass-Customized Multiobjective Optimization of Forest Management Decisions Using Open Data, Simulation and the DESDEO Software Framework
Vili Kärkkäinen, Juho Roponen

When making forest management decisions, forest owners must make compromises between conflicting objectives, like profit and climate effects. Forest management decisions are made on the level of individual forests. Because Finland has 600 000 forest owners, it is impossible to affect climate change without involving many of them, and presently there are no tools that easily provide forest owners information about climate impacts of their decisions. We are developing software that facilitates interactive multiobjective optimization of forest management decisions specific to each forest owner's needs. Based on the forest's registry ID, the software automatically procures the forest's openly available data hosted by Finnish governmental organizations and uses the data to simulate the effects of different management options in the forest. The software then formulates a data-driven multiobjective optimization problem. The forest owner can interactively solve this problem with the help of DESDEO, the open-source software framework developed for interactive multiobjective optimization. DESDEO hosts different interactive methods, like the classification-based NIMBUS method. By applying the NIMBUS method, the forest owner can find their most preferred management decisions when balancing between economic and climatic objectives. Preliminary results show that forest owners are willing to be more climate-smart if they get information about the climate effects of their decisions.

4 - Qualification management in a two steps manufacturing process.
Maxime Alouani, Claude Yugma, Stéphane Dauzere-peres, Renaud Roussel

In semiconductor manufacturing plants with a wide variety of products, machine qualifications play a crucial role. A qualification certifies that a machine is eligible to perform a given operation of a given product. Qualifications are essential to ensure high yield, production system flexibility and product quality. However, qualifying an operation on a machine and maintaining a qualification is often time-consuming and costly. Thus, when hundreds of different operations can be performed in a workshop with dozens of machines, it is impossible to perform all possible qualifications. Therefore, it is important to determine the best qualifications to optimize both the workload balance of the machines and the total processing time while ensuring demand satisfaction. We extend previous research to optimize the qualifications of two consecutive workshops in the manufacturing route of products which are connected by an automated transportation system. In this context, minimizing transportation times becomes important when optimizing qualifications for at least two reasons. First, unnecessary transport increases the use of vehicles that are not available for other tasks. Furthermore, excessively long transportation times can cause machines to wait for products, which hurts their productivity.

■ MB-53

Monday, 10:30-12:00 - Room: Liberty Moot Court

New Trends in Game Theory I

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Encarnación Algaba*
Chair: *Anjeza Bekolli*

1 - Agricultural cooperatives' strategic cooperation via association: The impacts of asymmetric bargaining power and yield uncertainty
Fengfeng Xie

Traditional agricultural cooperatives, despite achieving notable scales, encounter challenges in negotiations with powerful buyers, leading to low wholesale prices and production quantities, especially for those with weaker bargaining power. To address these challenges and amplify agricultural cooperative bargaining power, a novel form of collaboration—farmers' cooperative associations—has emerged. This study therefore investigates strategic decisions of agricultural cooperatives regarding forming cooperative associations and explores the impacts of varying bargaining powers and yield uncertainty. Focusing on a three-member supply chain consisting of two upstream cooperatives and a downstream supermarket, we consider separate and joint negotiation scenarios. We find that the wholesale price negotiated by the cooperative with stronger bargaining power in a separate negotiation may not always be higher than that negotiated by a cooperative with weaker bargaining power. Additionally, we observe that the wholesale price in a separate negotiation is not necessarily decreasing with the output level. Finally, we identify the conditions in terms of bargaining powers and yield uncertainty, under which the two cooperatives can achieve a win-win situation from the cooperative association.

2 - Equilibria in competitive location in a duopoly - An application to out-of-home delivery
Fabio Mercurio, Margarida Carvalho, Sonja Rohmer, Loe Schlicher

Collection points are rapidly expanding as couriers and public authorities promote their use to consolidate deliveries and reduce urban congestion. However, their placement is primarily driven by competition among delivery companies seeking market share rather than by public interest in maximizing accessibility. Our work investigates how delivery companies strategically open collection points in response to competitors and how their decisions diverge from an optimal public placement. We propose a competitive location model where collection points are placed on a network of districts, with customer choices modeled using a multinomial logit (MNL) framework. We analyze the Nash equilibria in this competitive setting and measure potential inefficiencies using the price of anarchy. Our analysis includes a theoretical two-district setting, where we find a significant mismatch between competitive and socially optimal placement, leading to potential efficiency losses of up to 33%. In contrast, a simulation based on Eindhoven's city center shows a narrower difference between optimal and strategic placements.

3 - Pricing and sustainability performance in a supply chain: the role of channel leadership.
Anshuman Chutani

We consider a two-echelon supply chain in which a manufacturer sells a product to a retailer who then sells it to environmentally conscious final consumers. Both the firms in the supply chain make their respective pricing decisions and both invest to improve their respective environmental footprint. The consumer demand is sensitive to the final retail price as well as to the supply chain's overall environmental performance. In addition, we also consider government policy that incentivizes each firm to reduce its respective environmental footprint. We consider game theoretic models with different leadership structures in the supply chain and obtain optimal price and sustainability investment decisions of both the firms. We investigate how pricing as well as sustainability investment decisions are impacted by leadership structures and by various model parameters, and benchmark these decisions against that of a centralized channel. We find that apart from channel leadership, the two firms' relative cost efficiency of sustainability efforts also has a major impact on the overall environmental performance achieved in the supply chain. We find that while the government policy of environmental taxation impact overall supply chain environmental performance in a positive way, it can also lead to higher consumer prices.

4 - Optimizing Agricultural Processing through Cooperative Game Theory
Anjeza Bekolli, Luis Antonio Guardiola, Ana Meca

Agricultural crop processing faces challenges in cost efficiency, capacity utilization, and fair profit distribution. This paper introduces a

cooperative game-theoretic framework to optimize inter-firm collaboration in processing. We define a HarvestTech (HT) situation, where firms share processing technologies and capacities, minimizing costs and maximizing profitability. To ensure equitable profit allocation, we propose the Collaborative Allocation (CO) method and introduce two compensation mechanisms: Best Technology Compensation (BTC) and Crop Reward Compensation (CRC). These ensure fair redistribution of gains while maintaining coalition stability. A case study on apple farming in Albania demonstrates the model's practical value. Our findings highlight cooperative game theory model as essential for optimizing agricultural supply chains, with future research focusing on dynamic pricing and uncertainty modeling.

■ MB-55

Monday, 10:30-12:00 - Room: Liberty 1.09

Network Optimization 2

Stream: Network Optimization
Invited session
Chair: *Mariia Anapolska*

1 - A Stackelberg game framework for hub design and pricing optimization in transportation networks
Seyed Parsa Parvasi, MirMohammad Musavi, S. Ali Torabi, Wei Yim Yap, Jasmine Siu Lee Lam

Reducing transportation costs and offering competitive service prices are key challenges in today's market, particularly for transportation companies operating as third-party logistics (3PL) providers. Designing efficient service networks through effective hub management plays a crucial role in addressing this challenge. This study focuses on how a new entrant can improve its competitive advantage by designing its hub-and-spoke network and setting competitive prices while considering the incumbent's responses. Using a bi-level mathematical model based on the Stackelberg (i.e. foresight) competition framework, this research examines customer preferences with a logit model and employs a novel decomposition-based solution technique. To solve this complex problem, a tabu search algorithm for solving the hub location sub-problem and a hybrid hyper-heuristic for solving the pricing sub-problem, are tailored. The findings reveal that the entrant can enhance its market share and profitability by strategically positioning its hubs and setting competitive prices, particularly when the incumbent operates with fewer hubs. The study also highlights that differences in discount rates between competitors significantly impact their profit, especially when customers' price sensitivity increases.

2 - Neighbourhood-constrained Bilevel Shortest Path Problem
Szymon Wróbel, Adam Kasperski, Pawel Zielinski

The Shortest Path problem has been extensively studied in the deterministic setting, where the arc weights are precisely known and all variables are controlled by a single decision-maker. Although in many cases it may be a sufficient model, the input data may be subject to uncertainty or not be fully controlled by the decision maker. One of the approaches that can be used in such scenario is bilevel optimisation, which is a framework in which the problem is divided into two hierarchically dependent subproblems: the leader and the follower.

Although bilevel versions of the Shortest Path problem have been explored in the literature, they have primarily focused on adversarial settings (network interdiction) or cooperative settings (leader and follower build a single path). The Neighbourhood-constrained Bilevel Shortest Path problem introduces a new bilevel version of the Shortest Path problem, in which the decisions available to the follower are restricted to a neighbourhood of the path selected by the leader.

Our main contribution is the formulation of the problem, its relations to other optimisation problems, and preliminary complexity results.

3 - Human-Robot Collaborative Patrol Routing Problem Balancing Hot Spot Coverage and General Area Patrolling
Pang Zezhao

Patrolling is critical for public safety, yet budget cuts have strained police resources. Patrol robots are introduced to adress above issue. We propose a human-robot collaboration model integrating patrol robots into policing operations. Multiple robots patrol police-frequented streets, handling routine tasks to reduce patrol time on general area routes, enabling police to arrive timely at hot spots to response to potential crimes. We formulate the problem based on the k-Chinese Postman Problem to optimize the deployment locations and number of patrol robots, as well as police patrol routes, with the objective of minimizing patrolling costs while satisfying coverage constraints for hot spot areas. The problem is solved using the Adaptive Large Neighborhood Search (ALNS) algorithm, where we designed several problem-based destroy and repair operators concerning the effectiveness of patrol robots' position and timing of police covering hot spots. Experimental results demonstrate that the human-robot collaboration model reduces the required number of police forces while ensuring hot spots coverage and reducing patrolling costs. Compared to traditional pure-police patrolling models, the proposed approach achieves lower patrolling costs. This study provides theoretical and methodological support for optimizing police resources, with significant practical applications.

4 - Flows over time with minimum peak cost
Mariia Anapolska, Emma Ahrens, Christina Büsing, Felix Engelhardt, Timo Gersing, Corinna Mathwieser, Sabrina Schmitz, Sophia Wrede

Flows over time extend the classical network flows by a temporal component: it takes a certain amount of time for particles to traverse every arc. We introduce a novel objective for flows over time called peak cost. The peak cost is a min-max type objective that describes the maximum cost a flow incurs at some moment of its time horizon, and thus models the amount of workforce or energy necessary to run a system at all times. In the resulting optimisation problem, we focus on temporally repeated flows due to their tractability and hence study the complexity of the Minimum-Peak-Cost Temporally Repeated Flow problem (MPC-TRF). As some applications require integral solutions, we consider not only the general fractional version, but also the integral version of the problem. We show that both the decision version and the optimisation version of integral MPC-TRF are strongly NP-hard, even under strong restrictions. At the same time, we identify two special cases for which, although the integral problem remains NP-hard for general demand values, an optimal maximum flow can be found in polynomial time: (i) unit-cost series-parallel networks and (ii) networks with a time horizon at least two times longer than the longest path in the network (with respect to the transit time). Furthermore, in the two listed cases, we provide polynomial-time solution approaches for the fractional version of MPC-TRF, the complexity of which in general remains open.

■ MB-56

Monday, 10:30-12:00 - Room: Liberty 1.11

CBBM: Drug Discovery

Stream: Computational Biology, Bioinformatics and Medicine
Invited session
Chair: *Marta Szachniuk*

1 - Knowledge Graph based Drug Repositioning Framework
Se-Jin Chung, Yurim Kim, Geon Hyeok Chun, So Young Sohn

The increasing expenses and prolonged timelines associated with drug development have sparked interests in alternative strategies, such as in-silico drug repositioning, that can accelerate the drug development process while reducing the cost. Among these alternative strategies, modern research has utilized artificial intelligence to analyze the Drug-Disease Associations (DDA) or Drug-Target Interactions (DTI). However, these approaches still face challenges related with overly optimistic prediction and incomplete integration of biological and chemical database. In this study, we propose an integrated knowledge graph-based drug repositioning framework that encompasses different biological, chemical and clinical entities. The diverse types of interactions within and between different types of entities are derived by utilizing various databases, and diverse knowledge graph embedding methods are compared for their treatment pathway prediction performance. We apply the proposed framework to type 2 diabetes, which is a clinical condition that is globally recognized for its prevalence, mortality and pathological complications.

2 - Modeling and analyzing complex biological systems with Holmes 2.0
Marcin Radom, Bartłomiej Szawulak, Piotr Formanowicz

Modeling biological systems presents challenges due to their inherent complexity. A precise and accurate model of such a system can significantly enhance the understanding of how the system works and how one can influence its behavior. Here we introduce Holmes 2.0, a Java-based software tool designed to aid in the creation and analysis of Petri net models of complex biological systems. Holmes allows creation and editing of Petri net models and their subsequent analysis. The intuitive interface ensures that novice and experienced users can easily construct and modify their models. An important feature of Holmes is its support for working with large Petri nets, common for biological models. To manage complexity, the software allows net division into subnets. These subnets can be nested at arbitrary depths, allowing hierarchical structures that preserve the integrity of the model. Holmes offers a wide array of analytical tools that can provide insights into the structure and behavior of the models. The knockout analysis tool is a significant feature that allows users to explore the impact of excluding certain areas from the net. Minimal Cut Sets module helps in identifying critical elements within the net whose removal could affect system performance, which can be particularly useful in disease modeling, where the objective may be to suppress certain factors such as pathogens or risk factors. The program also provides simulation algorithms which are highly configurable.

3 - Optimizing interface evaluation in molecular domain
Marta Szachniuk, Maciej Antczak, Olgierd Ludwiczak

Operations research plays a critical role in optimizing computational methods for macromolecular structure analysis, particularly in predicting complex molecular structures and evaluating their accuracy. In the latter, traditional scoring often overlooks the quality of intermolecular interfaces, which are crucial for the accurate formation and function of molecular assemblies. In this presentation, we introduce Intermolecular Interaction Network Fidelity (I-INF), a normalized similarity measure quantifying intermolecular interactions in multichain complexes. Additionally, we implement the F1 metric to complement I-INF in the intuitive assessment of predicted 3D models, emphasizing interchain contacts. We validate I-INF and F1 on 72 RNA-protein decoys, demonstrating their effectiveness in ranking models and identifying high-quality predictions.

■ MB-58

Monday, 10:30-12:00 - Room: Liberty 1.13

Optimization with Drones

Stream: Vehicle Routing and Logistics
Invited session
Chair: Dell'Olmo Paolo

1 - Inspecting Electric Lines with Drones
Cândida Mourão, Raquel Bernardino, Leonor S.Pinto

This study addresses the routing for the inspection of electric lines with drones in Portugal, managed by EDP Labelec, the partner company in this project. There is a set of electrical lines that need to be inspected and a set of points where the drone operator can stop managing the drone for inspecting those lines. The objective is to determine an inspection plan — that is, the points where the drone operator stops and the route performed by the drone — where all the service lines are inspected, that minimizes the inspection time. This problem is modeled as an Extended Capacitated Arc Routing Problem (ECARP). The CARP is known to be NP-hard, as is this ECARP since it generalizes the CARP. The developed model is solved using CPLEX on smaller real instances generated using a GIS (Geographic Information System) available at the EDP Labelec. Solution quality of the generated solutions is assessed by the total inspection time, as well as feedback from EDP Labelec team. This team evaluates the practical adequacy of the solutions, a crucial aspect for trips that need to be accepted by practitioners. Computational analysis will provide new insights for the development of new methodology to solve larger instances that feat the dimensions of the real ones.

Acknowledgments: this work was partially supported by the Projects CEMAPRE/REM - UIDB /05069/2020, financed by FCT/MCTES through national funds

2 - Routing of autonomous electric vehicles recharged by drones using public lines
Francesca Guerriero, Luigi Di Puglia Pugliese, Giusy Macrina

This work investigates an innovative delivery framework where a fleet of autonomous electric vehicles (AEVs) with limited battery capacity have to deliver orders to customers over the last mile. Due to the limited capacity of the AEVs, finding a solution to avoid service disruptions becomes a critical factor. We propose a recharging system where the AEVs can be recharged at the customer's location by drones equipped with wireless energy transmission technology. The drones can be launched from the depot as well as from some dedicated public stations. Each drone will then complete part of its journey on the roof of the public lines. We propose a mathematical model to represent the framework, then we analyse the potential benefits of using this innovative paradigm by comparing it with the classical recharging at the charging stations. Our computational study shows the effectiveness of the proposed system.

Keywords: Electric Vehicle Routing, Drone, Wireless Power Transmission, Public Lines

Acknowledgement This work was supported by the grants awarded by "European Union - Next Generation EU", under the "PRIN 2022 - PNRR" project: COSMO, CUP H53D23008850001 (G. Macrina), and under the "PRIN 2022" project: SMOTION (ID 2022EAECWJ), CUP H53D23002000006 (F. Guerriero), and CUP B53D23009270006 (L. Di Puglia Pugliese).

3 - Simultaneously optimizing delivery and monitoring tasks using truck and drone
Luigi Di Puglia Pugliese, Alessia Ciacco, Giusy Macrina, Francesca Guerriero

The concept of smart cities has become increasingly popular in the last year. This paradigm allows managing several processes in the urban area thanks to the availability of data and information taken from the environment. We consider the case in which drones are demanded to monitor areas of interest and/or collect data from sensors. Drones can perform deliveries in the urban area. Monitoring areas of interest and performing the delivery process are two difficult problems, i.e., the covering tour problem and the travelling salesman problem with drone, respectively. In this work, we consider the combined problem of delivering items by using a truck equipped with a drone, wherein both the truck and the drone may perform deliveries. During the deliveries, the drone may deviate from the optimal routes, with respect to the delivery problem, to reach areas of interest. We propose a mixed integer formulation to represent the outlined framework. A computational analysis is carried out to evaluate the benefits of the combined problem with respect to the resolution of the two problems separately. Keywords: Travelling Salesman Problem, Covering Tour Problem, Truck-Drone,

Monitoring Task. Acknowledgement Francesca Guerriero and Luigi Di Puglia Pugliese were supported by a grant awarded by "European Union - Next Generation EU" under the "PRIN 2022" project: SMOTION (ID 2022EAECWJ), CUP H53D23002000006 (Francesca Guerriero), and CUP B53D23009270006 (Luigi Di Puglia Pugliese).

4 - A Mathematical Model for Drone Coverage Path Planning

Dell'Olmo Paolo, Lavinia Amorosi, Justo Puerto, Carlos Valverde

We face the problem of finding a set of tours a drone, starting and ending at the depot, must perform to cover non overlapping areas represented by polygons in the plane, taking into account the drone limited endurance. We present a second order cone mixed-integer programming formulation for this monitoring system. The proposed formulation embeds the drone altitude selection from a set of possible values associated with each area. This is motivated by the necessity to inspect each area with different levels of precision. Moreover, it is assumed that there is a set of points, with limited cardinality, associated with each area, from where the drone can interrupt the monitoring and exit to reach another area where the same process can be repeated. When the drone attains its minimum energy level, it must go back to the depot to swap battery and start a new tour, until all the areas have been covered. The optimization is performed by minimizing the total completion time. Preliminary computational results on a testbed of artificial instances are presented together an analysis of the obtained solutions.

■ MB-59

Monday, 10:30-12:00 - Room: Liberty 1.14

Routing decisions

Stream: Transportation
Invited session
Chair: *Daisuke Hasegawa*

1 - A Lagrangian relaxation approach for the extended aircraft routing problem with itinerary-based revenue

Matteo Petris, Sébastien Deschamps, Frédéric Meunier, Axel Parmentier

In the Extended Aircraft Routing Problem with Itinerary-based Revenue (EARP-IR), an airline needs to design a schedule, i.e., the sequences of legs (flights) operated by its planes, with the aim of maximising the revenues. Estimating the revenue of a schedule relies on the fact that customers look for an itinerary, i.e., a sequence of legs from an origin to a destination, rather than a single leg. The estimation captures the behaviour of the customers and is encoded via an atomic and stochastic model where customers arrive one after the other and choose an itinerary or none of them according to a basic attraction model, a discrete choice model where the probabilities to buy an itinerary depend on attractiveness values. As the seats of a leg are limited, only itineraries composed of legs with free seats are sold. We show that this model is approximated by a linear program, the so-called Sales Based Linear Program (SBLP). The EARP-IR integrates the operational problem of designing a schedule with the itinerary-based revenue estimation model (the SBLP). The operational problem is an Aircraft Routing Problem enriched with gate and frequency constraints (NP-hard). We propose a mixed integer linear programming model for the EARP-IR. We exploit the structure of the model to devise a Lagrangian relaxation approach where we relax the constraints which link the operational problem with the SBLP. A Lagrangian heuristic is also devised to retrieve feasible solutions.

2 - Efficient decomposition methods for Large Scale, Multi-Period Log Truck Routing and Scheduling:Application to Canadian Forestry

Abdelhakim Abdellaoui, Issmail El Hallaoui, Loubna Benabbou, Francois Aubé

This work addresses the complex multi-period log-truck routing and scheduling problem encountered in the forest industry. We propose an improved mathematical formulation and decomposition approaches to efficiently solve large-scale instances of this problem. Given that timber harvesting operations in Canada extend far from processing facilities, efficient transportation is essential for economic viability and environmental sustainability.

Our research analyzes business rules within the forestry sector to develop a generalized framework for routing network design. We then formulate a comprehensive MILP, incorporating spatial and temporal constraints such as time windows, truck capacities, mill and harvest site accessibility, multi-period replenishment, and other resource constraints. To tackle the problem's combinatorial complexity, we apply a preprocessing strategy to reduce the search space. We further develop primal decomposition methods, introducing a new Price-and-Branch approach and an adapted Relax-and-Fix strategy. Our computational experiments, conducted using historical data from a Canadian forest company, demonstrate the effectiveness of our approach, achieving near-optimal solutions (within a 2% gap of the lower bound) in less than 10 minutes for the weekly routing and scheduling problem. This research contributes to ongoing efforts to enhance operational efficiency, reduce environmental impact, and maintain the competitiveness of Canada's forestry sector.

3 - A Stakeholder-Driven Approach to Handling Uncertainties in School Bus Routing for Pupils Living with Special Needs

Ozioma Paul, Julia Handl, Manuel López-Ibáñez

The School Bus Routing Problem is a well-established combinatorial optimisation problem that aims to determine the most efficient routes for transporting students while ensuring safety, cost-effectiveness, and time efficiency. In bus route generation for pupils with special educational needs and disabilities (SEND), assuming static travel times often proves impractical in the face of potential delays and disruptions to pick-up times, which are sometimes not easily prevented or predicted.

In a bid to address this, this study adopts an interdisciplinary approach by combining insights from stakeholder engagements with existing techniques for handling uncertainties in bus route optimisation. Through the engagements with decision-makers in the school bus ecosystem, variability and delays in the pick-up times were identified as a major source of uncertainty. These uncertainties around pick-up times were of particular significance for routes and buses catering to pupils living with SEND, as long wait times can affect the well-being and disposition of the pupils upon arrival at the schools. This study models the uncertainties as stochastic delays and evaluates the effectiveness of explicit and implicit averaging techniques in improving the robustness of the generated routes using real-world datasets.

Our findings demonstrate the role of these averaging techniques in reducing the impact of real-time disruptions, leading to more reliable bus routing solutions.

4 - Continuous approximation model for estimating average tour length in prize collecting traveling salesman problem and application

Daisuke Hasegawa, Yuichiro Miyamoto, Toshio Nemoto

The prize collecting traveling salesman problem (PCTSP) is to find routes and subset of nodes that minimize a tour distance with the constraint to be less than given rewards by visiting nodes. This study estimates the PCTSP travel distance using a continuous approximation model. Continuous approximation model does not search for routes, but it estimates the travel distance using the area of the region and the number of nodes. In our proposed model, the size of the delivery zone and the number of nodes is given, and the spatial distribution of the penalty is represented as a demand function. It replicates the concentration of population and economic value in the center of cities. This model enables the analytical derivation of the average tour length required to achieve a certain level of reward. By applying the proposed model, we propose a method for estimating the tour length of the PCTSP in cases involving multiple delivery zones.

■ MB-61

Monday, 10:30-12:00 - Room: Maurice Keyworth G.31

Advances in behavioral decision analysis 1

Stream: Behavioural OR
Invited session
Chair: *Jyrki Wallenius*

1 - Behavioral Decision Analysis: Theoretical lenses and behavioral levels
Gilberto Montibeller, Florian Federspiel, Matthias Seifert, Detlof von Winterfeldt

Decision Analysis has traditionally been about the design and application of logically consistent tools to support decision makers in structuring problem complexity, modeling uncertainty, generating predictions, eliciting preferences, and making better decisions. This approach operates under the assumptions that the decision makers' cognitive belief system is fully accessible and can be understood and formalized by trained analysts. However, a new line of research has emerged, challenging these assumptions: Behavioral Decision Analysis. To provide a clear structure in this complex field, we propose a framework that categorizes research based on task focus (prediction or decision) and behavioral level (individual or group). To study these issues, we employ two theoretical lenses: Descriptive Behavioral Decision Research and Prescriptive Behavioral Decision Research.

2 - De-biasing data-driven models in energy markets
Fahad Mehmood, Hussain Syed Kazmi

Data-driven models based on artificial intelligence and machine learning are increasingly being used in energy markets, especially for forecasting demand and ensuring supply security. However, the inherent balck-box nature of such models make them prone to number of biases and limits their explainability. This means that such data-driven models can make extremely inaccurate predictions in the worst-case scenario. In this study, we show the biased predictions of widely used models in energy markets. Using domain-informed counterfactuals for three case studies, we explore potential ways to de-bias the models and recommend possible solutions.

3 - Value trade-offs in sustainable supply chain management
Igor Barahona, Mohammed AlKhars, Gilberto Montibeller

A major underlying assumption of the Sustainable Supply Chain Management literature is that operations managers can make reasoned and consistent trade-offs in decision contexts in which they operate. But can they? Despite the increasing relevance and growth of behavioral operations management, we know very little about how operations managers make trade-off judgments, if they suffer from well-known biases when making these trade-offs, and if debiasing tools can help increase the consistency of their trade-off judgements. This work is an attempt to shed light on this issue. In this paper, we present the theory of value trade-offs, with the normative axioms required for their specification and the elicitation protocols that must be employed in practice by decision-makers. We also share the early results of a behavioral experiment that we conducted with executive education students at KFUPM in Saudi Arabia, in which experienced professionals and operations managers are asked to make value trade-offs among competing sustainability and cost priorities. We analyze if the managers are consistent in their prioritizations and if they suffer from the range-insensitivity bias. We also assess if the use of debiasing tools can improve the consistency of their judgements.

4 - Communicating commander's intent in a chain of command with multicriteria decision analysis: An experiment in air combat
Raimo P. Hämäläinen, Kai Virtanen, Heikki Mansikka, Mikko Kankaisto

Decision making in a chain of command with a rapid time frame is typical in military and emergency contexts, and yet the topic has received almost no attention in the MCDA literature. The commander's intent regarding the implementation of an operation is expressed at the top level of the command chain. The statement must be passed through different levels of the chain. Behavioral effects and biases can distort the interpretations of the intent at the lower levels. We introduce a new MCDA approach for supporting communication, planning and decision making in the chain of command. In the approach, criteria weights of an MCDA model are determined by the commander. Then, the commander's intent is communicated so that the message from the top level also contains these weights, and the MCDA model is utilized on the lower levels. The approach was evaluated in an air force test case. Two air force commanders tested the approach and used five weighting methods, i.e., SMARTER, Direct, Swing, SMART and AHP. They preferred the Direct and Swing methods. Air force staff officers planned the air operations by following the standard and the MCDA-supported planning procedures. The simulation of these operations revealed that the MCDA-supported ones were in better compliance with the commanders' original intention statements. Thus, the MCDA approach seemed to support the integrity of the command chain as the intent passed through the chain.

Monday, 12:30-14:00

■ MC-01

Monday, 12:30-14:00 - Room: Great Hall

Agostino Capponi

Stream: Keynotes
Keynote session
Chair: Marc Weibel

1 - Machine Learning in Finance: Supply Chain Asset Pricing and Data-Driven Dynamic Risk Management
Agostino Capponi

We develop new methodologies that integrate machine learning and AI techniques to address the two most challenging problems in financial engineering, specifically asset pricing and risk management.

Our asset pricing approach introduces a novel data-driven model that captures firm-level characteristics across local sub-graphs of the supply chain. By traversing the supply chain, the model learns how neighboring firm characteristics predict outcomes for a target firm, combining these characteristics non-linearly to create interpretable, tradeable asset pricing factors. These supply chain-derived factors are uncorrelated with those from traditional models and demonstrate positive out-of-sample Sharpe ratios, with most contributions coming from the top five factors. Our findings suggest that combining supply chain and firm characteristics systematically captures unique risks beyond firm characteristics alone.

For risk management, we construct a dynamic framework for high-dimensional factor models, using diffusion maps to uncover the underlying dynamics of common factors in a fully data-driven, nonparametric way. This framework generates low-dimensional embeddings that retain most explanatory power for time series of risk factors. Applied to equity portfolio stress testing across three major financial crises, we demonstrate that our approach outperforms standard methods, which often assume a zero conditional expectation for unstressed factors.

■ MC-03

Monday, 12:30-14:00 - Room: Esther Simpson 1.01

EEPA

Stream: EURO Excellence in Practice Award
Award Competition session
Chair: Frédéric Gardi

1 - BinPACKER
Katrin Heßler, Timo Hintsch, Lukas Wienkamp

One of the biggest challenges in transportation is to load a transport unit, such as a container, a truck, or a pallet, in a way that minimizes empty space and thus reduces costs. Manual planning is difficult and requires a lot of time. BinPACKER automizes this task subject to several practical constraints, such as load stability, consideration of non-stackable items, and weight distribution requirements. This not only leads to a significant reduction of empty space and transport costs but also considerably reduces manual planning effort.

2 - Logistics Performance Excellence: Optimizing the Dedicated Fleet of Mercado Livre
Toni Wickert, Alberto Kummer, Fabricio Nunes da Costa, Henrique Lima Baiao, Leila Abdala, Mateus De Paula Nascimento, Ricardo Mauricio Solar Vivanco, Cid Carvalho de Souza

In Latin America, road transport is by far the primary mode of transportation for transferring goods between different locations. Trucks are contracted from transportation companies mainly in two forms: full truckload (FTL) or dedicated fleet, each of which has its own advantages and disadvantages, depending on the existing operational restrictions. At Mercado Livre, the largest e-commerce company in the region, we face the challenge of finding the right balance between FTL and dedicated fleet trucks to minimize operational costs. This work presents a novel approach for composing a dedicated fleet of trucks used in Mercado Livre to tackle this prevalent challenge in the retail industry. We propose a mixed-integer programming method based on a heuristic algorithm that generates optimized itineraries for a fleet of vehicles organized into groups, considering both hiring and operational constraints. Each of these groups is assigned to different carriers, thereby avoiding reliance on a single provider. The tool was used in 2024 across the Brazilian and Mexican operations of Mercado Livre and generated savings exceeding US$ 10 million, along with improved service levels characterized by reduced delays and enhanced truck availability during peak seasons. Additionally, by contracting dedicated trucks, we can now operate 116 vehicles powered by natural gas or biomethane, thereby diminishing Mercado Livre's environmental impact.

3 - A Spatial Decision Support System for designing the network of Household Waste Recycling Centres in South Yorkshire
Serena Fugaro, Antonino Sgalambro, Filippo Santarelli

In the UK Government's 25 Year Environment Plan, the location of municipal waste collection and recycling facilities plays a crucial role in achieving the recycling targets. Locally, these services are provided to residents through Household Waste Recycling Centres (HWRCs). The UK Government recognises the need to plan the network of HWRCs carefully to ensure their efficient operation and appropriate use by residents. Local authorities are interested in reorganising HWRC networks with the dual aim of reducing operating costs and achieving high levels of user satisfaction, whilst meeting specific legislative requirements. In this project, in collaboration with the Sheffield City Council in South Yorkshire (UK), we have developed a tailored spatial Decision Support System (DSS) for the optimal reconfiguration of HWRC networks. The model base component of the DSS builds upon a novel Multi-Objective Covering-Location-Allocation problem that formalises the underlying real-world Waste Management scenario taking into account multiple goals and different stakeholders (i.e. local authorities and service users). A soft-constrained solution approach is developed to accurately capture the actual dynamics driving the network design process, and to explore the impact of facility capacity flexibility. The resulting Pareto sets are efficiently explored using a robust variant of the AUGMEnted ϵ-CONstraint method, and a computational characterisation of the proposed models is provided with benchmark instances from the real-world case study. The DSS is framed in the open source QGIS software through the design and implementation of an ad hoc plug-in that allows for an effective management of the DSS database component and a user-friendly graphical representation and comparison of Pareto Optimal solutions. The Graphical User Interface of the DSS has been co-designed with the local authorities to facilitate an intuitive visualisation of the characteristics of the alternative configurations generated by the model, and to enhance the usability of the tool by allowing the exploration of the trade-offs between objectives. A thorough scenario and sensitivity analysis demonstrates how the DSS is successful in producing alternative configurations for the HWRC network design problem and providing quantitative and qualitative insights to support strategic planning and decision-making.

■ MC-04

Monday, 12:30-14:00 - Room: Rupert Beckett LT

Data science meets strongly NP-Hard CO

Stream: Data Science meets Optimization
Invited session
Chair: *Dimitri Papadimitriou*
Chair: *Woo Seok Goh*

1 - Rethinking the Container Allocation Problem from a Machine Learning Perspective

Kavitha Chetana Didugu

While consulting for one of the largest Shipping Yard Companies in India, I took a different perspective to solve the Container Allocation Problem. Problem: Currently, the incoming containers were being haphazardly arranged. This causes high retrieval cost when customers come back to collect their containers. They were looking for an easy to implement, and easy to scale (across multiple yard locations across India) method for yard allocation that would reduce the retrieval cost. Retrieval cost is directly proportional to the number of picks or moves required by the crane (called reach-stacker) to retrieve a stacked container at the time of retrieval request.

Traditionally, this problem has been solved using an Optimisation (Operations Research) approach. Given the amount of complexity in building and executing this solution, I explore a novel ML approach to solve this problem. This breaks down a complex optimisation problem into a forecasting model. The ML approach offers the advantage of higher accuracy with larger data, faster execution time, and easy scalability.

This application-centred paper delves deeper into how to reformulate the container allocation problem within the ML framework, and further steps in the solution. For a set of unseen incoming container data, I compared the results of the company's existing plan versus the plan obtained from my method, and observed that my plan reduced the cost of operations by 66.67%. Additionally, the model also achieved a

2 - Linear quasi-shrinkage estimator for high-dimensional optimization with linear constraints

Naqi Huang, Nestor Parolya, Theresia van Essen

In large-scale, data-driven optimization problems, parameters are often only known approximately due to noisy and small-sized samples. We consider optimization problems with linear constraints where the true parameter matrix is not precisely known, and the number of constraints and number of variables are comparable and both tend to infinity. Our goal is to construct a linear estimator of the true parameter matrix by minimizing the Frobenius distance between the estimated and true parameter matrix. Our method possesses two advantages: 1) all parameters introduced in the linear estimators are consistently estimated, eliminating the need for further calibration, and 2) the constraints of the formulated optimization problem remain linear, ensuring computational efficiency. Simulation shows that our linear estimator consistently produces stable outcomes in terms of the objective value, the ratio of violated constraints and the magnitude of constraint violation across various scenarios, compared to other robust methods. Additionally, it demonstrates resilience against high-level noise, making it a robust choice under uncertainty.

3 - Extremal graphs for star forests with bounded clique number

Liying Kang

Let $mathcalF$ be a family of graphs. The Tur'an number ex$(n, mathcalF)$ of $mathcalF$ is the maximum possible number of edges in an n-vertex graph that contains no member of $mathcalF$ as a subgraph. The study of Tur'an number of graphs is a central topic in extremal graph theory. Recently, Alon and Frankl determined the exact value of ex$(n, mathcalF)$ when $mathcalF=K_k+1,M_s+1$, where K_k+1 is the $(k+1)$-clique and M_s+1 is the $(s+1)$-matching. Let tS_l be the disjoint union of t copies of the star S_l. In this talk we determine the exact value of ex$(n, mathcalF)$ when $mathcalF=K_k+1,(s+1)S_l$ and all the extremal graphs for sufficiently large n.

4 - Computational Analysis of DQN for the Binary Knapsack Problem

Woo Seok Goh, Seyoung Oh, Kyungsik Lee

In recent years, deep reinforcement learning (DRL) has been extensively applied to solve NP-hard combinatorial optimization problems (COPs), often achieving high-quality solutions. However, an in-depth investigation into DRL's performance has not been sufficiently addressed. In this work, we focus specifically on an end-to-end Deep Q-Network (DQN) approach tailored for NP-hard COPs. The binary knapsack problem is selected as our test suite for NP-hard COPs, since its true Q-values can be computed in pseudo-polynomial time, allowing a comprehensive performance analysis. We implement the Q-network using two different architectures: a multi-layer perceptron and a graph neural network. We evaluate the solution quality and computational efficiency of DQN. Additionally, we investigate the accuracy of the estimated Q-values from three perspectives: proximity to the true Q-values, consistency in the relative ordering of Q-values, and correctness in optimal action selection. Overall, our research deepens the knowledge of how DQN addresses NP-hard COPs, offering insights into its effectiveness and reliability.

■ MC-07

Monday, 12:30-14:00 - Room: Clarendon GR.01

Mathematical Programming in Scheduling

Stream: Scheduling and Project Management
Invited session
Chair: *Norbert Trautmann*

1 - A Novel Time-Indexed Formulation for the Single Machine Scheduling Problem with Sequence-Dependent Setup Times

Wonwoo Cho, Kyungsik Lee

In this talk, we address time-indexed formulations for the single machine scheduling problem with sequence-dependent setup times. In these formulations, each decision variable is associated with a job-time pair, indicating whether the job starts at that time. When sequence-depenedent setup times are introduced, the ideal formulation for the machine's capacity constraint, ensuring that the machine performs at most one processing or setup at a time, becomes unavailable. A naive formulation for the capacity constraint may either significantly weaken its linear programming (LP) relaxation or increase the number of constraints, severely hindering the model's solvability with commercial solvers. To address this, we propose a novel time-indexed formulation that enforces the capacity constraint through clique inequalities. The cliques are constructed via a two-phase algorithm. The first phase aims to reduce the number of cliques while ensuring model validity. In the second phase, cliques are constructed by solving an LP and then maximalized. Computational results demonstrate that the proposed formulation outperforms existing time-indexed formulations in terms of the number of constraints, computation time for solving the LP relaxation, and the LP relaxation bound.

2 - Logic-Based Benders Decomposition for Joint Routing and Scheduling of TSN networks in Avionics

Jesper Vines, Hannes Uppman, Mikaela Lindberg, Elina Rönnberg

In the electrical system in an aircraft, the avionic system, a large number of data packages need to be reliably transmitted and received on time. This can be achieved by jointly deciding how to route packages through the network and determining a schedule for the send times of packages. The recently proposed standards of Time-Sensitive Networking enable guarantees regarding latency and availability of such scheduled data. However, a challenging optimisation problem for the

routing and scheduling needs to be solved. The expected increase in avionic system sizes, and the number of data packages sent, require the development of optimisation methods that scale well.

We propose a Logic-Based Benders Decomposition scheme for joint routing and scheduling in a TSN network. There is a natural decomposition of this problem, where message routing is decided in the master problem and the remaining scheduling problem is solved in the subproblem. With this decomposition, the scheduling subproblem can become challenging to solve for larger problem instances. Therefore, we strengthen the master problem by taking scheduling partially into account at the outset, for example by considering network load or transmission delays. Through this, the size of the subproblem is reduced and larger problem instances can be solved.

3 - Optimizing shift assignments for tramway operations: a mixed-integer linear programming approach to generate fair and efficient solutions on large scale instances.
Nathan Lainé

Shift assignment is a critical challenge for public transport operators, impacting both operational efficiency and workforce well-being. To enhance working conditions while maintaining high service quality, the Parisian public transport system operator RATP Group collaborated with Artelys to develop an optimization-based shift assignment module for tramway operations. This module efficiently allocates shifts (driving shifts, shifts related to passenger information, flow channeling, ...) and time-offs using a mixed-integer linear programming approach. The case study highlights how Artelys leveraged a decomposition technique to generate fair and efficient assignments, enhancing both workforce well-being and operational performance in large-scale (assignments on a year for hundred agents) multi-objective scenarios (fairness between agents and multiple well-being criteria). Implemented with FICO XPRESS, this solution demonstrates how optimization can significantly improve manual assignment processes, offering valuable insights for transport planning and workforce management.

■ MC-08

Monday, 12:30-14:00 - Room: Clarendon SR 2.08

Preference Learning 2

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: *Roman Slowinski*
Chair: *Salvatore Greco*

1 - An Explainable Composite Indicator Based on Decision Rules
Silvano Zappalà, Salvatore Corrente, Salvatore Greco, Roman Slowinski

Composite indicators are widely employed in various fields to classify or rank alternatives evaluated on multiple criteria. Their construction falls within Multiple Criteria Decision Analysis (MCDA), where different methods are chosen based on key technical aspects, like measurement scales of criteria, degree of acceptable compensation between them, and potential interactions among criteria. However, beyond the final classification or score assigned to each alternative, ensuring result explainability and procedural transparency is crucial. This paper proposes a method for constructing an explainable composite indicator using decision rules. The Decision Maker (DM) provides simple preference information, either in the form of classifications (e.g., alternative a is assigned to class 1, while b is assigned to class 2) or pairwise comparisons (e.g., a is preferred to b) on some reference alternatives. We then apply the Dominance-Based Rough Set Approach (DRSA) to derive decision rules that systematically explain these preferences by relating class assignments of reference alternatives with conditions concerning threshold performances on some selected criteria. These rules explicitly link the DM's judgments to the performance of alternatives on subsets of criteria, clarifying the underlying rationale. Moreover, they serve as a basis to classify or rank new alternatives of interest. To illustrate our approach applicability, we present a real-world decision-making case study.

2 - Modelling Confidence and Optimism in Preference Learning
Sally Giuseppe Arcidiacono, Salvatore Corrente, Salvatore Greco

In this work, we explore a recently proposed model of ordinal regression within multicriteria decision analysis, which assumes that the decision maker considers the entire set of feasible weight vectors. The overall evaluation of each alternative is obtained through a non-additive average of the evaluations provided by each weight vector. This average is computed by considering a non-additive probability in the weight vector space and aggregating the evaluations with respect to each weight vector using the Choquet integral. The non-additive probability is derived as a transformation of an additive probability. The dispersion around a reference vector of the additive probability measures the decision maker's confidence, while the transformation itself represents the optimism, with higher values indicating greater optimism. We evaluate the ordinal regression methodology based on confidence and optimism across several datasets, discussing the performance and potential of the proposed approach.

3 - Kemeny median rankings: Necessary conditions for optimality and algorithmic advances
Nicola Morandi, Ivano Azzini, Giuseppe Munda

Let N and M be two integer numbers greater than or equal to 3. In a setting characterized by N alternatives and M rankings, i.e., permutations of (1, 2, ..., N), the Kemeny median ranking problem (KMRP) seeks to find all rankings that minimize the total Kemeny-Snell distance from the input set of rankings. This distance serves as a proxy for total disagreement with the input rankings, enabling applications in fields such as recommendation systems, genetics, air traffic control, defense decision support, and voting theory. Although approximable within a constant in polynomial time, the KMRP is NP-hard and challenging to solve, with current exact algorithms capable of consistently solving instances with N up to 14. We tackle the KMRP by reformulating it using antisymmetric matrices, and by identifying necessary conditions for optimal rankings. We then devise a branch-and-bound algorithm that incorporates these conditions as pruning rules. Our method solves instances with N up to 30 in one hour of computations and does not rely on commercial solvers, aligning with typical licensing and transparency requirement for institutional use.

4 - SAPEVO-H' a Multi-Criteria Hierarchical Model for Group Decision-Making at Different Levels of Responsibility in Sustainable Projects
Miguel Ângelo Lellis Moreira, Patrícia Oliveira, Carlos Francisco Simoes Gomes, Marcos Santos

Decision-making in complex environments, especially sustainability ones, requires flexible methodologies to handle multiple criteria and stakeholder perspectives. This study explores the Simple Aggregation of Preferences Expressed by Ordinal Vectors - Hybrid and Hierarchical Method (SAPEVO-H'), an extensive model from the SAPEVO family, which offers a multi-criteria analysis through a hierarchy of variables evaluated by groups partitioned into the levels concerning their respective responsibilities, without assigning disproportionate influence to any individual decision-maker. The model incorporates an axiomatic enhancement, allowing for a more versatile analysis that accommodates quantitative and qualitative data through cardinal and ordinal input, respectively. The viability of the methodology is demonstrated through a case study involving an automobile manufacturing company, which focuses on prioritizing sustainability projects based on multiple objectives aimed at minimizing polluting gas emissions. Within a five-level hierarchy, individual results reveal preferences and utility traceability, clarifying relationships among variables, established preferences, and stakeholder perceptions. In addition, a sensitivity analysis is applied, exposing the most sensitive variables to changes concerning

the highest levels. Then, we discuss the main contributions and limitations concerning the mathematical proposal and the conclusions with proposals for future work.

■ MC-09

Monday, 12:30-14:00 - Room: Clarendon SR 2.01

New challenges for risk management

Stream: OR in Finance and Insurance
Invited session
Chair: Mariacristina Uberti

1 - Risk mitigation in distribution of organic liquid fertiliser by using combined discrete event simulation model and linear programming tools
Remigio Berruto, Patrizia Busato

Logistics have been used to analyse agricultural operations, such as chemical application, mineral or organic fertilisation and harvesting-handling operations. Recently, due to national or European commitments concerning livestock waste management, this waste is being applied in many crops instead of other mineral fertilisers. The organic fertiliser produced has a high availability although most of the crops it is applied to have strict timeliness issues concerning its application. Here, organic fertilizer (as liquid manure) distribution logistic system is modelled by using a combined simulation and linear programming method. The method applies in certain crops and field areas taking into account specific agronomical, legislation and other constraints with the objective of minimising the optimal annual cost. Given their direct connection with the organic fertiliser distribution, the operations of cultivation and seeding were included. In a basic scenario, the optimal cost will be assessed for both crops in total cultivated area of 400 ha. Three modified scenarios are presented. Three scenarios related to the availability of equipment, storage locations are being evaluated and presented.

2 - A hidden Markov model for statistical arbitrage in international crude oil futures markets
Francesco Rotondi, Viviana Fanelli, Claudio Fontana

We study statistical arbitrage strategies in international crude oil futures markets. We analyse strategies that extend classical pairs trading strategies, considering two benchmark crude oil futures (Brent and WTI) together with the recently introduced Shanghai crude oil futures. We show that the time series of these three futures prices are cointegrated and we introduce a mean-reverting regime-switching process modulated by a hidden Markov chain to model the cointegration spread. By relying on this model and applying online filter-based parameter estimators, we implement and test several statistical arbitrage strategies. Our analysis reveals that statistical arbitrage strategies involving the recently introduced Shanghai futures are profitable even under conservative levels of transaction costs and over different time periods. Statistical arbitrage strategies involving only two of these three futures contracts or the three traditional crude oil futures (Brent, WTI, Dubai) deliver a lower investment performance. (This is a joint work with V. Fanelli and C. Fontana)

3 - A resource management optimisation model for Industrial Symbiosis
Rossana Mastrandrea, Giulia Sinisi, Mariacristina Uberti, Enrica Vesce

Industrial Symbiosis (IS) is a resource management approach where companies from different sectors collaborate to optimize the use of materials and by-products to create a sustainable production system. IS facilitates the exchange of resources between industries,fostering more efficient industrial ecosystems.The European Commission has recognized IS as a key tool for achieving circular economy goals(New Circular Economy Action Plan).A production residue from a company is reused as secondary raw material by another company,reducing disposal costs and the need for virgin materials.Often,an additional transformation step is required.Adopting IS is challenging and depends on factors such as industry type,financial incentives,geographic proximity.It requires careful economic evaluation,as it may incur additional costs such as transportation and material transformation.We propose an optimization model designed to evaluate the economic viability of switching to IS.This model enables companies to compare the costs of continuing to purchase virgin raw materials with those of shifting to the IS market.By considering factors like transportation,waste transformation,different potential options(such as setting up an internal waste transformation system or outsourcing to an external organization),the model identifies the optimal amount of waste to integrate into industrial processes,ultimately minimizing overall costs and supporting more informed decision-making for the adopting companies.

4 - Credit Scoring Model for Education Loan Using Data on Customers Rejected in Loan Screening
Masahiro Toshiro, Yusuke Hikidera, Kenzo Ogi, Norio Hibiki

Financial institutions employ credit scoring models to screen loan applications for approval or rejection. The models calculate credit scores based on explanatory variables such as customer attributes, past transactions, and credit history. Previous studies on models for education loans, such as Hibiki et al (2011) and Bandyopadhyay (2016), proposed models built to evaluate the default occurrence using data only on customers approved in loan screening. However, approved and rejected customers are likely to have different attributes, and models built using data only on approved customers may be inadequate for screening all loan applications. The contribution of this study is to clarify the effectiveness of using data on rejected customers in model building using 1.2 million education loan applications to Japan Finance Corporation from FY2011 to FY2022. We build a model to evaluate the default using data on approved customers only, and a model to evaluate the rejection using data on both approved and rejected customers. A total of 42 explanatory variables are selected in the two models, but only 5 are common. We then propose to integrate the credit scores calculated from these two models to screen loan applications. In validation comparing the AUC calculated as positive for both defaulted and rejected customers using out-of-sample data, the integrated score is consistently more than 5 points higher than the credit score calculated by the model to evaluate the default.

■ MC-10

Monday, 12:30-14:00 - Room: Clarendon SR 1.06

Integrated Healthcare Timetabling Competition II

Stream: Automated Timetabling
Invited session
Chair: Andrea Schaerf

1 - A matheuristic approach for integrated healthcare timetabling problems
Rosita Guido, Antonio Candelieri, Domenico Conforti

The integrated healthcare timetabling problem (IHTP) is a complex combinatorial optimization task emerging from the unification of three critical planning problems in the healthcare sector: patient admission scheduling within a time window, surgical case scheduling, and nurse-to-room assignment. Complexity of IHTP relies on the interdependencies between these three problems, requiring innovative approaches to achieve feasible and high-quality solutions. In this work, we adapt the matheuristic FiNeMath, which hybridizes mathematical programming and heuristic techniques, to address the IHTP effectively. A warm-start procedure provides a good initial feasible solution, then the approach systematically explores the vast solution space using a combination of exact methods and heuristic strategies. Experimental results on the thirty benchmark instances show that FiNeMath outperforms standalone methods in terms of solution quality, computational efficiency, and scalability. The approach represents a practical and flexible

tool for healthcare managers, enabling optimal resource allocation and optimal scheduling while balancing operational constraints and stakeholder preferences. This work highlights the potential of matheuristic approaches in tackling large-scale, integrated optimization problems, especially in the healthcare sector.

2 - A Benders Decomposition Approach for the Integrated Healthcare Timetabling Problem
Simon Paulus, Felix Engelhardt, Tabea Brandt, Johanna Leweke

The Integrated Healthcare Timetabling Problem (IHTP) is a challenge set out as part of the Integrated Healthcare Timetabling Competition (IHTC). The IHTP combines three fundamental optimisation problems in hospitals: surgical case planning, patient admission scheduling and nurse-to-room assignment. It addresses the broader trend of moving towards integrated planning healthcare. Each of the three partial problems has multiple hard and soft constraints that get aggregated into an overall objective. Since mixed-integer linear programming is an established technique for either of the partial problems, we formulate the problem as a mixed-integer linear program (MILP). By definition, the MILP structure allows for a natural Bender's decomposition. Here, the nurse assignment problem, which only contains soft constraints and therefore is always feasible, is chosen as the sub-problem, and the combined case planning and patient admission as the master problem. In this talk, we explain specific modelling choices that contribute to the MILP performance. We also show how we modified the classical Bender's approach to deal with an integer subproblem - a known but notoriously tricky case to implement. We then provide computational results and discuss the advantages and disadvantages of using a quasi-exact MILP method compared to heuristic solution approaches.

3 - An iterated local search approach for the Integrated Healthcare Timetabling Competition (IHTC)
Lisa Garcia Tercero, David Van Bulck, Karel Devriesere, Sam Bakker, Dries Goossens

We propose a solution to the integrated healthcare timetabling problem, linked to the Integrated Healthcare Timetabling Competition (IHTC-2024). The problem integrates three healthcare timetabling problems: surgical case planning, patient admission scheduling, and nurse-to-room assignment. We propose a multi-neighbourhood iterated local search algorithm with optimizing perturbation. For the local search phase, we consider seven neighbourhoods, each focusing on one of the three problems (surgical case planning, patient admission, or nurse-to-room assignment). The perturbations are carried out by optimizing a part of the problem with an IP-based operator. We consider four such operators, one of which integrates all three problems simultaneously.

4 - A MIP with warm start to solve the IHTC problem
Lotte Berghman, Per Kampman, Wouter Kool, Judith Mourits, Martijn van Brink, Eva van Rooijen, Qing Chuan Ye

We propose a solution method for the IHTC problem (ihtc2024_problem_specification.pdf) that employs a combination of a sequential construction algorithm and a mixed integer program (MIP). A patient construction sequentially tries to admit a patient and assign it to a room and operating theater, adhering strictly to the feasibility constraints. This is repeated until no more patients can be admitted. The algorithm is randomized by randomly skipping candidate patients during constructions. Afterwards, nurse constructions loop over the days and rooms and simply assigns the nurse that will result in the least increase in cost. Our MIP introduces additional variables that represent combinations of decisions (i.e. a patient treated by a nurse on a specific day in a specific room). When the MIP is too large to solve (large instances), we sequentially solve different subMIPs. In the first stage, we only assign patients to days and operating theaters. This solution is warm started with the patient and day assignments of the best construction. In the second stage, we fix days and operating theaters and assign patients to rooms. Finally, we fix the day/operating theater/room assignments and solve the nurse assignment. The best overall result is returned.

■ MC-11

Monday, 12:30-14:00 - Room: Clarendon SR 1.03

Scheduling and queuing in healthcare

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Philipp Baumann*

1 - A sequence-based approach to shift planning in Swiss healthcare institutions
Maude Bersier, Philipp Baumann

Shift planning is a key task in healthcare because it affects both operational efficiency and the working conditions of employees. Improving employee working conditions has become a key focus to address healthcare personnel shortages in various countries. In this work, we tackle a real-world shift planning problem originating from Switzerland that consists of assigning shifts to employees subject to operational and employee-specific requirements. While the operational requirements align with established shift planning problems, the employee-specific requirements extend those commonly studied in the literature by including a large number of sequence-based constraints. Such constraints apply to sequences of consecutive shifts and are intended to improve the work patterns of employees. Because of these sequence-based constraints, established approaches require modifications to be applicable, which reduces their effectiveness. Therefore, we propose a new two-step approach. In the first stage, we generate sequences of shifts while considering all sequence-based constraints. In the second stage, we use integer programming to assign sequences to employees subject to the remaining constraints. To assess the performance of our approach, we conduct an experimental analysis based on real-world instances from Swiss health care institutions.

2 - Mixed-integer programming solutions for wellbeing-based scheduling of nurses in acute wards
Talia Emmanuel, Carlos Lamas-Fernandez

Multiple scheduling goals must be considered during the generation of effective and efficient nurse rosters. These traditionally include achieving staffing level targets, adhering to legal and contractual working time regulations, and mitigating the risks of shift work and night work. Amid ongoing issues with recruitment/retention of health care staff in England, there is now also increased demand to proactively consider nurses' scheduling needs and wishes. While the Nurse Scheduling Problem (NSP) has been extensively studied, a significant research-to-application gap remains due to inherent challenges in modelling real-world rostering. This paper presents a new mathematical model for nurse scheduling designed to capture real-world shift/staffing configurations and produce ward rosters optimised for nurses' working time preferences and wellbeing. The model was formulated as a mixed-integer linear program (MILP) that minimised solution values according to constraints limiting the assignment of shifts that contradict nurses' scheduling needs and/or increase likelihood of sickness absence. Improved schedules were produced across a series of experimental scenarios, including: rostering a team of nurses with varied working hours contracts, rostering 20 randomly generated wards with varied coverage requirements and team sizes, and rostering with customised penalisation of shift assignments depending on the 'preference profile' assigned to individual nurses.

3 - Service rate flexibility in diagnostics under congestion
Kjell Raaijmakers

In this work, we study a diagnostics model in which an agent must determine the type of arriving customers through imperfect tests. However, testing takes time, during which additional customers arrive, which leads to congestion costs. To mitigate these costs, the agent can adjust the test rate against an increased cost, or release a customer by providing a diagnosis. Misclassifying a customer also incurs a cost, creating a trade-off between testing accuracy, waiting costs, and service rate costs.

We formulate this problem as a Markov Decision Process (MDP) and establish the existence of a search interval: whenever the agent's belief about a customer's type falls within the search interval, testing continues; otherwise, classification occurs. We will demonstrate that, as congestion increases, the test interval shrinks. Furthermore, we show that as congestion increases or as the agent's belief approaches the decision threshold, the optimal policy prescribes a higher service rate despite the associated increased rate costs.

4 - Modelling the UK government's ambition to reduce the NHS elective waiting list and improve waiting times
Tineke Poot

Reducing NHS elective waiting times is one of the UK government's six main missions. The complexity of informing decisions at a national level requires a responsive and adaptable approach to modelling, capable of addressing constantly shifting scenarios, evolving challenges, and tight timeframes. This talk will present an overview of the national NHS elective demand, activity, and waiting list modelling, which I lead within NHS England to guide government decision-making. I will explore the practical application of simple yet powerful modelling techniques, such as basic forecasting and queuing theory, to provide rapid insights for policymakers.

I will use this example to challenges the notion that modelling requires big data and complex code. A key benefit of using simple tools is that they facilitate closer collaboration with finance colleagues, allowing for quicker, more effective cross-disciplinary problem-solving. Highlighting the challenges of working with imperfect data and responding rapidly to urgent queries, this session will provide valuable perspectives on the flexibility and resilience required in operational research to support real-world decision-making in the public sector.

[Note: I'm not sure which stream this would best fit. I've suggested health, but could be relevant for something more practitioner focussed.]

■ MC-12

Monday, 12:30-14:00 - Room: Clarendon SR 1.02

Advanced analytics in manufacturing

Stream: Scheduling and Project Management
Invited session
Chair: Erwin Pesch
Chair: *Alena Otto*

1 - A quantitative analysis of the benefits of lot streaming in hybrid flow shop manufacturing
Janis Sebastian Neufeld, Maximilian Hubmann, Markus Höfling, Daniel Zähringer

Lot streaming is a well-known technique to speed up production processes by forwarding some job units to the next production stage before the entire job has been processed. Especially for small-sized instances, significant reductions in makespan can be achieved by this strategy. However, a quantification of the actual potential in hybrid flow shop settings is still missing in the literature, especially for medium and large problems. For this purpose, we formulate a MILP model and develop a problem-specific iterated greedy algorithm to efficiently solve the hybrid flow shop scheduling problem with lot streaming. In a comprehensive computational study, we analyze the impact of relevant parameters such as setup times, processing time distributions, the maximum number of sublots, and the impact of policies with equal or consistent sublot sizes. The results highlight the relevance, effect, and limitations of lot streaming in hybrid flow shop settings and enable decision-makers to assess under which circumstances the benefits outweigh the additional organizational complexity.

2 - Decentralised lot sizing: Collaboration and smart contracting
Anton Klymenko, Margaretha Gansterer

Collaborative lot sizing usually relies on a centralised decision-maker to reap the benefits of joint operations. While this often leads to optimal results, concerns about transparency and dependency prevent agents from working together in practice. We aim to explore an alternative approach to decentralisation in lot sizing using smart contract auctions. We develop and compare two models: a centralised optimiser that achieves the best possible objective value and a decentralised mechanism where agents submit self-generated bids. An off-chain combinatorial algorithm determines the optimal allocation, and the results are published on-chain via smart contracts to ensure transparency and auditability. We also investigate the role of smart contracts in contracting for lot sizing. Preliminary results suggest that while the decentralised model worsens the objective value, increased incentives for collaboration can compensate for this trade-off. Based on a computational study, the potential of smart contracts to enable dynamic real-time pricing and enhance transparency is analysed.

3 - Optimizing Reconfigurations in Matrix Assembly Systems Under Demand Uncertainty
Baturhan Bayraktar, Merve Bodur, Martin Grunow, Rainer Kolisch

The automotive industry is undergoing a major changeover driven by technological progress, government regulations, and economic instability. This transition results in shifting and uncertain demand patterns, necessitating flexible assembly layouts for original equipment manufacturers. Matrix assembly layouts—where workstations are arranged on a grid—are gaining popularity due to their reconfigurability while maintaining mass production efficiency. In this study, we address the design of reconfigurable matrix assembly layouts under demand uncertainty. Our key decisions include station activation, task-to-station assignment, reconfiguration timing, and product flow allocation. We employ sample average approximation and multi-stage stochastic optimization to solve this problem. Our objectives are to minimize the number of active stations and the expected number of reconfigurations. We compare matrix assembly layouts against traditional assembly lines with reconfigurations. Finally, we provide our managerial insights by assessing the value of the stochastic solution, the benefits of a multi-period approach, and the stability of the solutions.

4 - Resolving the curse of poor data quality: Optimization perspective on data collection and validation
Alena Otto, Benedikt Finnah, Jochen Gönsch

Insufficient data quality prevents data usage by decision support systems (DSS) in many areas of business. This is the case for data on precedence relations between tasks, which is relevant, for instance, in project scheduling and assembly line balancing. Inaccurate data on unnecessary precedence relations cannot be used, otherwise the recommendations of DSS may turn infeasible. So, unnecessary relations must be satisfied, diminishing the baseline problem's solution space and the business result. Experts can validate the data, but their time is limited. We apply an optimization lens and formulate the data validation problem (DVP). Restricted by the available time budget, an expert dynamically receives queries about specific data entries and corrects or validates them. The DVP searches for an interview policy that states queries to the expert, each using up some of the time budget, to maximize the (weighted) number of removed precedence relations. We model the DVP as a dynamic program, derive optimal policies for several important special cases and design a heuristic interview policy LSTD. In a case study of an automobile manufacturer, this policy substantially reduces the stations' idle time after selectively addressing about 8% of the data entries. We prove theoretically and numerically that data validation by experts can lead to significant savings.

■ MC-13

Monday, 12:30-14:00 - Room: Clarendon SR 1.01

Medical applications

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Nicole Cristina Cassimiro de Oliveira

1 - Minimax-based optimization for enhanced proton therapy
Nicole Cristina Cassimiro de Oliveira, Aurelio Oliveira, Juliana Campos de Freitas

Proton therapy is a promising cancer treatment technique, known for its ability to deliver energy with precision while minimizing the dose absorbed by healthy tissues. However, uncertainty in the Bragg peak position can compromise treatment quality. To address this challenge, this study initially proposes an optimization model based on the minimax method, which minimizes the maximum dose in the tumor, ensuring better protection of critical organs and adequate tumor coverage. The model is validated using data from the TROTS database, with a focus on head and neck cancer cases, where structures such as the oral cavity, larynx, and brainstem are highly sensitive to radiation. Additionally, treatment robustness is explored by accounting for anatomical and patient positioning variations through multi-objective optimization, using goal programming as a strategy to enhance proton therapy. The results demonstrate more robust and safer treatment plans, contributing to the effectiveness of proton therapy in clinical practice.

2 - Balancing Personalized Medicine and One-Size-Fits-All: Navigating Trade-Offs in Complexity, Efficiency, and Equity
Reza Skandari, Niloofar Zamani Foroushani, Narges Mohammadi

Personalized medicine improves outcomes and reduce health disparities by tailoring guidelines to individual characteristics but are often challenging to implement. We propose an explainable clustering method to decide the optimal intensity and configuration of population stratification, aiming to minimize health inequalities while ensuring the guidelines remain practical and implementable.

3 - Identifying Combination Therapies for Diabetes and its Comorbidities
Hyungsuk Lim, Yucheol Kim, Geon Hyeok Chun, So Young Sohn

Type 2 diabetes mellitus is one of the most serious health conditions globally recognized for the diversity in related comorbidities. Since each patient is exposed to different diabetic comorbidities with varying level of risk, personalized combination therapies are necessary for managing both diabetes and its related comorbidities. However, current diabetic treatment guidelines fail to comprehensively address the unique susceptibility of individuals to various diabetic comorbidities, thereby facing challenges in identifying personalized combination therapy. Furthermore, previous studies on diabetic treatments are mostly focused on the impact of antidiabetic drugs on diabetic comorbidities, without considering the drug-drug interactions among antidiabetic drugs and other drugs for diabetic comorbidities. In this study, we suggest a novel framework that identifies combination therapies for the treatment of both diabetes and diabetic comorbidities in terms of not only maximizing synergism but also minimizing antagonism among drugs. We first utilize the link prediction based on multiplex disease network and community detection to identify different sets of diabetic comorbidities while incorporating diverse aspects of diseases. Afterward, we apply integer programming to drug-disease associations in each identified combination of diabetic comorbidities. Our framework is expected to contribute to the establishment of personalized combination therapy with optimal treatment effect.

4 - Expanding Naloxone Accessibility: A Lifesaver or a Risky Setback?
Junyang Cai, Noa Zychlinski

Governments have expanded naloxone access to reduce overdose deaths, but this raises concerns about moral hazard and opioid misuse. We develop a dynamic compartmental model to analyze the impact of naloxone accessibility on the opioid epidemic, capturing transitions between susceptible individuals and those with opioid use disorder (OUD).

Our optimization framework determines the optimal naloxone accessibility level, balancing overdose mortality reduction against potential increases in new OUD cases. We find that full naloxone access is optimal when either minimizing new OUD cases and naloxone effectiveness is lower than moral hazard or prioritizing overdose mortality reduction when naloxone effectiveness exceeds moral hazard. In other cases, restricting naloxone access is optimal.

When moral hazard is significant, expanding access may unintentionally increase overdose mortality despite reducing new OUD cases. This reversal highlights the critical role of moral hazard in shaping optimal policies.

We extend our model to incorporate social interactions, revealing consistent solution properties, including a bang-bang structure and moral hazard's reversal effect on the optimal policy. Policymakers must carefully balance accessibility and risk to mitigate unintended consequences.

■ MC-15

Monday, 12:30-14:00 - Room: Esther Simpson 1.08

Relaxation and Decomposition

Stream: Combinatorial Optimization
Invited session
Chair: Laura Galli
Chair: Adam Letchford

1 - Strengthening the Conic Quadratic Relaxation of the Optimal Transmission Switching Problem
Juncheng Li, Guglielmo Lulli

The goal of the Optimal Transmission Switching (OTS) problem is to identify a topology of the power grid that minimises the total energy production costs, while satisfying the operational and physical constraints. The problem is formulated as a non-convex mixed-integer nonlinear program, which poses extraordinary computational challenges. A common approach is to solve the mixed-integer second-order conic programming (MISOCP) relaxation of the OTS problem instead of the original non-convex problem.

In this talk, we introduce new valid inequalities, called disjunctive cycle-bound inequalities, to strengthen an existing MISOCP relaxation of the OTS problem. We propose additional valid inequalities based on integer programming theory to mitigate the extra computational burden imposed by the big-M formulation of the disjunctive cycle-bound inequalities. We prove that some of these valid inequalities are facet-defining and also provide an efficient separation algorithm. Computational experiments conducted on benchmark instances from PGLib demonstrate the effectiveness of the proposed approach.

2 - Improving the Semi-Lagrangian Relaxation Approach to the Simple Plant Location Problem
Lauren Durrell, Thu Huong Dang, Adam Letchford

The Simple Plant Location Problem (SPLP) is a much-studied combinatorial optimisation problem with many applications. In 2012, Beltran-Royo et al. devised an intriguing exact algorithm for the SPLP, based on semi-Lagrangian relaxation. We show that one can speed up that algorithm considerably by (a) using a fast method to initialise the

Lagrangian multipliers, and (b) eliminating redundant variables from the relaxed problem. The enhanced algorithm performs extremely well on several hard benchmark instances.

3 - Non-Standard Benders Decomposition for the Multiple Knapsack Assignment Problem
Adam Letchford, Laura Galli

The Multiple Knapsack Assignment Problem (MKAP) is a strongly NP-hard combinatorial optimisation problem, with several practical applications. We present a new exact algorithm for the MKAP, based on Benders decomposition. For reasons which will become clear, we use a non-standard decomposition strategy, together with specialised feasibility cuts and a primal heuristic. Our preliminary computational results suggest that our new approach works very well when the number of knapsacks is relatively large.

■ MC-16

Monday, 12:30-14:00 - Room: Esther Simpson 2.07

Optimization in Agriculture

Stream: Sustainable Food & Agroforestry
Invited session
Chair: *Carlos Monardes*
Chair: *Mauricio Varas*

1 - Location models in ecological agriculture
Marian Reiff, Juraj Pekár, Ivan Brezina

Traditional farming practices often prioritized immediate yield gains without consideration of long-term environmental consequences, such as soil degradation and loss of biodiversity.

The proposed mathematical programming location models for ecological agriculture aim to optimize land use, enhance ecosystem services, and improve overall sustainability. This presentation examines point and line location models that support decision-making in ecological management. These models promote biodiversity without compromising the productivity of agricultural operations.

Specifically, the models focus on the optimal allocation of nesting aids for alternative pollinators and the strategic placement of biobelts, with the goal of fostering biodiversity while minimizing losses in agricultural production.

By utilizing mathematical programming and optimization techniques, these approaches provide structured, data-driven solutions that enhance agricultural sustainability. They balance the economic output of farming businesses with the principles of environmental stewardship.

2 - A two-stage stochastic programming approach for optimizing wine purchasing decisions considering climatic uncertainty
Carlos Monardes, Alan Toledo, Elbio Avanzini, Mauricio Varas, Franco Basso, Raul Pezoa

Wine supply chain planning faces several operational challenges, including uncertainty in grape production due to climatic variations. This paper proposes a novel two-stage stochastic programming formulation for supporting tactical decision-making processes in winemaking, including market policies, farms, and industrialization. Previous studies have focused mainly on isolated links in the supply chain without comprehensively considering the impact of uncertainty in multiple stages of the process. The methodology used relies on an optimization model structured in two steps. The first focuses on decision-making regarding acquiring resources and raw materials by buying grapes with forward contracts considering variations in grape quality due to climate. The second covers the operational management of the resources obtained, including allocating grapes to fermentation tanks and scheduling them. The solution obtained is verified to reach the established market quota. Otherwise, the model can react by buying spot contracts. Therefore, wine production is formulated according to the availability of bulk wine to satisfy the market. This approach provides excellent flexibility in uncertainty management, offering efficient solutions with few computational resources. The model's effectiveness is evaluated through simulations, providing valuable insights into the trade-offs between resource allocation, production costs, and the ability to meet demand under uncertainty.

3 - Use of digital transformation technologies in agricultural sector water management : A bibliometric analysis
Macarena Alvarez, Izabela Rampasso, Rosley Anholon, Carlos Manzano, Tiago Sigahi

The water crisis in the world is a challenge that affects the availability and quality of water, greatly impacting agriculture. In this situation, digital transformation can provide solutions to optimize water use in agriculture. This article aims to investigate the connection between digital transformation technologies and water management in the agricultural sector. To carry out this research, a bibliometric analysis was carried out based on documents collected from Web of Science. The software VOSviewer was used to create network visualization maps. Through the analysis performed, 5 main clusters that were identified. The red cluster showed the use of digital transformation technologies, such as precision agriculture, used in soil irrigation or vegetation improvement. The blue addresses the issue of climate impact and sustainable development goals and the importance of using irrigation strategies in crops. The green focused on the use of sustainable and innovative resources in water management. The yellow shows the interest in improving agricultural production, focusing on climatic conditions. Finally, the purple focus on the policies applied to reduce impacts on farms. This study analyzed the literature on water management in agriculture using digital transformation technologies. Its results offer a broad overview of the topic for researchers and guide future research, while practitioners can identify opportunities for improvement in their processes.

■ MC-17

Monday, 12:30-14:00 - Room: Esther Simpson 2.08

Cross dock door platforms design, assigment and scheduling

Stream: Combinatorial Optimization
Invited session
Chair: *Laureano F. Escudero*

1 - Multi-objective cross-docking optimization under uncertainty in Physical Internet hubs
Fatma Essghaier, Tarik Chargui, Hamid Allaoui

The Physical Internet (PI) is an emerging paradigm designed to enhance the efficiency and interoperability of supply chains through open, hyper-connected networks. A key component of this system, cross-docking, enables the direct transfer of goods between inbound and outbound transport modes, reducing storage requirements and improving operational flow. However, managing such operations is inherently complex due to uncertainties, such as truck arrival times, capacity constraints, and real-time disruptions. These factors may cause inefficiencies and increase operational costs. Beyond these logistical challenges, supply chain sustainability and environmental concerns have become critical. To address these pressing issues, we propose an innovative truck scheduling approach for rail-road Physical Internet hubs. Our methodology employs Fuzzy Chance-Constrained Programming to effectively manage uncertainties in truck arrival times, while the ϵ-constraint method is used for multi-objective decision-making to minimize truck delays and reduce the cumulative energy consumption of

PI-containers within the PI-conveying area. Preliminary analysis confirms the efficiency and robustness of our model. It shows that the integration of uncertainty management with multi-objective optimization significantly enhances operational efficiency and sustainability, promoting more resilient and environmentally conscious supply chains.

2 - On two-stage stochastic optimization for cross-dock door platforms design
M. Araceli Garin, Laureano F. Escudero, Aitziber Unzueta

The Cross-dock Door Design Problem (CDDP) consists of deciding the strip and stack doors and nominal capacity of the cross-dock infrastructure under uncertainty. The CDDP is represented using a stochastic two-stage binary quadratic model. The first stage decisions are related to the infrastructure design and the second stage ones are related to the node-to-door's assignments. The aim is to minimize the construction cost of the infrastructure and its exploitation expected cost in the scenarios. Given the difficulty of solving this combinatorial problem, a mathematically equivalent MILP formulation is introduced. However, searching an optimal solution is still impractical for commercial solvers. Thus, a scenario cluster decomposition-based matheuristic algorithm is introduced to obtain feasible solutions with small optimality gap and reasonable computational effort. A broad study to validate the proposal gives solutions with a much smaller gap than the ones provided by a state-of-the-art general solver. In fact, the proposal provides solutions with a 1 to 5% optimality gap, while the solver does it with up to a 12% gap, if any, and requires a wall time two orders of magnitude higher.

3 - On two-stage distributionally robust optimization for cross dock door platforms design
Laureano F. Escudero, M. Araceli Garin, Aitziber Unzueta

The Cross-dock Door Design Problem (CDDP) consists of deciding the strip and stack doors and nominal capacity of the cross-dock infrastructure. The problem combines three highly computational difficulties, namely, NP-hard combinatorics, uncertainty in the main parameters and their probability distribution. Distributionally Robust Optimization (DRO) is considered to deal with the different uncertainties. A two-stage DRO mixed binary quadratic model is presented for CDDP solving; the first stage decisions are related to the infrastructure design; the second stage ones are related to the commodity flow assignment to the doors in a scenario set for each ambiguity set members. The goal is to minimize the total highest cost, subject to the constraint system for each member and the stochastic dominance risk averse functional. Given the problem solving difficulty, a MILP-based scenario cluster decomposition and a min-max based constructive matheuristic are proposed for obtaining lower and upper bounds, respectively. A computational study validates the proposal; the approach overperformances the straightforward use of the state-of-the-art solvers Cplex and Gurobi.

■ MC-18

Monday, 12:30-14:00 - Room: Esther Simpson 2.09

OR for Sustainable Development III

Stream: OR for Sustainable Development
Invited session
Chair: Sarfaraz Hashemkhani Zolfani

1 - On Sustainable Mining Supply Chains: An Overview of Issues and Modelling Challenges
A. Akofa Amegboleza, M. Ali Ülkü

With alarming concerns about the climate crisis yet with increasing demand for rare earth elements for technological production, extraction industries are under double-edged sword pressure. The mining industry plays a critical role in global economic development but remains heavily challenged by high energy consumption, environmental degradation, inefficient resource management, and social conflicts. Sustainable operational efficiency in mining requires an integrated approach that optimizes energy transition, enhances water management, and strengthens supply chain resilience. In this research, we develop an optimization framework that balances cost, emissions reduction, resource efficiency, and regulatory compliance within the quadruple-bottom-line framework (i.e., economy, environment, society, and culture). Along with the modeling challenges, we highlight pressing issues that warrant further research to instill sustainability into mining supply chain operations and supply chains.

2 - The Value of Information Design in Manufacturer Audit Selection: Self-Reporting vs. Active Inspection?
Jiaxuan Li

In responsible sourcing, when auditing suppliers with potential compliance risks, manufacturers face the decision of whether to allow suppliers to conduct and report their own internal audits or to engage third-party audit firms. While many studies highlight that internal audits can lead suppliers to overstate their compliance, resulting in inaccurate or misleading information, manufacturers such as Walmart and Nike still prefer to use internal audits. This raises two key questions: First, what motivates manufacturers to choose internal audits? Second, when should manufacturers opt for internal audits versus external audits? This paper develops a game-theoretic model to explore how information design and transmission influence manufacturers' audit strategy decisions, considering the impact on corporate reputation. Our findings challenge conventional wisdom: internal audits are not inherently a bad choice. Although there is a risk of internal corruption, in some situations, allowing internal audits can be more effective—especially in minimizing hidden biases and improving information accuracy. Additionally, external audits are not a guaranteed solution; while they are perceived as independent, our study shows that the interaction between auditors and suppliers can still affect audit outcomes. These findings offer a new perspective on information design in audit decision-making and provide theoretical support for responsible sourcing practices.

3 - Optimising sectoral climate mitigation efforts against multiple sustainability indicators: a multi-objective integrated assessment
Alexandros Nikas, Dirk-Jan Van de Ven, Clàudia Rodés Bachs, Theo Rouhette, Russell Horowitz, Jon Sampedro, Natasha Frilingou, Kimon Georgiou, Xin Zhao, Abhishek Chaudhary, Konstantinos Koasidis

The sustainable development agenda involves complex transformations that significantly interact with climate action. Developing long-term sustainable development pathways typically relies on integrated assessment models (IAMs) by exploring co-benefits and trade-offs between climate policy and sustainable development goals (SDGs), and hardcoding policies into models to understand sustainability implications of climate action. However, most IAMs apply least-cost approaches for defining marginal mitigation efforts, disproportionally favouring maximising performance on economic rather than broader sustainability indicators. Here, we introduce an integrated approach leveraging multi-objective optimisation algorithms linked with IAMs, and Monte Carlo simulations to simultaneously optimise mitigation in terms of multiple SDG indicators, while considering stochastic uncertainty. Our aim is to optimise global mitigation effort allocation across economic sectors based on the performance in indicators along multiple SDGs and assuming a wide range of socioeconomic assumptions, towards developing long-term pathways with balanced sustainability performance. We validate this approach with the GCAM model and the AUGMECON-R algorithm, identifying trade-offs in sectoral and sustainability performance, notably between economic and environmental dimensions. Finally, we highlight the advantages of our approach to inform climate policy by comparing our SDG-balanced pathways with least-cost ones.

4 - Collaborative off-grid energy solutions for electricity capacity limitations
Jop Schouten, Frans Cruijssen, Peter Borm, Martijn Schoot Uiterkamp

Electricity capacity limitations and grid congestion have become increasingly problematic and are affecting the energy transition in the transport sector. Innovative approaches are needed to meet the rising energy demands for the electrification of conventional diesel trucks. In this research, we explore the potential of collaborative off-grid energy solutions and in particular examine how cooperation among multiple companies can overcome these challenges. By employing game theoretic tools, we aim to provide insights into the dynamic relationship between collaborative energy production, storage and consumption in off-grid systems. In particular, we study how economic incentives should be designed to overcome hesitance of companies to collaborate.

■ MC-20

Monday, 12:30-14:00 - Room: Esther Simpson 2.11

Metaheuristic algorithms

Stream: Combinatorial Optimization
Invited session
Chair: *David Pisinger*

1 - Random-Key Optimizers for Solving Combinatorial Optimization Problems
Antonio Chaves, Mauricio Resende

This work presents the Random-Key Optimizer (RKO), a modular stochastic local search framework for combinatorial optimization. RKO encodes solutions as random-key vectors that are transformed into feasible solutions using problem-specific decoders. The framework integrates multiple metaheuristics: simulated annealing, iterated local search, variable neighborhood search, particle swarm optimization, genetic algorithms, large neighborhood search, and greedy randomized adaptive search procedures. These metaheuristics can operate independently or collaboratively through an elite solution pool. RKO's problem-independent architecture requires only a decoder implementation to adapt to new problems. The framework features novel continuous-space local search heuristics using randomized variable neighborhood descent that combines an adapted Nelder-Mead with other optimization techniques. Implemented in C++ with multithreading capabilities, RKO enables solution sharing among concurrent metaheuristics. We demonstrate its effectiveness on four NP-hard problems: the tree of hubs location problem, traveling thief problem, portfolio problem, and node-capacitated graph partitioning problem. Results confirm RKO's robustness and adaptability as an effective tool for combinatorial optimization. The RKO solver is publicly available on GitHub.

2 - A scenario decomposition metaheuristic for solving two-stage stochastic problems with integrality constraints
Kristine Børsting, David Pisinger

Many important modern-day problems involve uncertainty, such as meeting electricity demand with a growing fraction of variable energy sources. Stochastic programs facilities making decisions based on all realizations of the uncertain parameters, however the number of variables in these models grow with the number of scenarios considered. Several years of historical data may be available, providing a rich description of the uncertainty, but if the problem contains integrality constraints it is limited how many scenarios can be considered before it becomes intractable.

Progressive Hedging is a scenario decomposition method originally developed for convex problems. The non-anticipativity constraints are Lagrangian relaxed, making it possible to solve a series of computationally easier subproblems that only account for a few scenarios each. Consensus is then enforced between subproblems through objective penalties. This method has also been used as a heuristic for problems with integer variables, however, only minor modifications have been made to the framework which still reflects a non-integer design.

In this presentation, we will introduce novel improvements to the Progressive Hedging framework for use as a metaheuristic for stochastic linear problems with integer variables. Computational results for various two-stage stochastic optimization problems underline its general usefulness.

3 - Enhancing the convergence of the Feasibility Pump through variable decomposition
Lucas Assuncao, Sebastian Urrutia, Andréa Cynthia Santos

Feasibility Pump (FP) is a well-known heuristic for mixed integer linear programming that iteratively moves fractional solutions toward integer feasibility by minimizing their distance to target integer points while maintaining the original linear constraints. Due to its simplicity and effectiveness, FP is widely used in commercial solvers, with many variations improving its convergence and solution quality. This work introduces a novel acceleration technique relying on the intuition that not all binary variables are active in a feasible solution. A kernel search strategy identifies a subset of promising binary variables, while the remaining ones are grouped into ranked buckets based on their likelihood of appearing in a feasible solution. FP sub-problems prioritize the kernel and gradually incorporate other variables as needed. To our knowledge, this is the first decomposition-based approach within the FP framework. Computational experiments on MIPLIB 2017 benchmark and two additional problems in vehicle routing and scheduling show improved success rates and reduced running times. Notably, the proposed method surpasses FP's performance and finds feasible solutions in cases where CPLEX fails within an hour.

4 - Stochastic ALNS for the the stochastic team orienteering problem
David Pisinger

The team orienteering problem is a generalization of the selective traveling salesman problem. A fleet of vehicles is available to visit a subset of customers within a given time limit. Each customer has an associated profit, and the profit can only be collected once. In the stochastic version of the problem, the customers are split into subscription customers that must be visited every day, and stochastic on-demand customers. The task is to select a subset of the subscription customers, such that the expected profit of served subscription and on-demand customers is maximized.

We present a stochastic Adaptive Large Neighborhood Search (SALNS) algorithm for the problem, in which an upper-level local search method operates on the first-stage decision variables, while a number of lower-level local search methods optimize the individual scenarios. Both customers, demands and travel times can be stochastic as long as they can be represented by a number of scenarios. Various destroy and repair neighborhoods are presented for both the upper-level and lower-level ALNS algorithms.

Computational experiments show that the algorithm scales well with the number of scenarios, making it possible to solve instances with up to 1000 customers and 64 scenarios.

■ MC-21

Monday, 12:30-14:00 - Room: Esther Simpson 2.12

Irregular packing and cutting

Stream: Cutting and packing (ESICUP)
Invited session
Chair: *Tetyana Romanova*

1 - Algorithms for Bar Nesting Software
Rhyd Lewis

In manufacturing and construction industries, bar nesting software is often used to help optimise the cutting patterns of linear materials such as reinforcing bars, girders, pipes, wooden joists, and window frames. The primary objective of such software is to minimise material wastage by determining efficient arrangements for cutting the desired items from lengthy stock materials. This process not only reduces costs but also supports sustainable practices by maximizing resource utilization. Several companies offer bar nesting in construction-focused CAD tools, including AutoRebar, RebarCAD, AutoBarSizer, and TopSolid Design.

In this presentation, we introduce an algorithmic framework to address several previously unsolved problem variants in bar nesting. These include optimizing cuts for materials with asymmetric cross-sections, handling items whose sides lie on different planes, and tackling the minimum score separation problem. The talk will cover the correctness proofs, computational complexities, and empirical results of the proposed algorithms, providing both theoretical insights and practical applications.

2 - Motorail loading problem with two-dimensional irregular constraints: Formulation, optimization and implications
Songtao Wang, Peiyao Liu, Yichen Li, Mingda Liu, Mingyao Qi

Railway transportation, renowned for its safety, efficiency, and environmental friendliness, is favored by transportation companies for long-haul automobile distribution, necessitating excellence in loading management and operations. However, manual scheduling, particularly for JSQ6 wagons, suffers from inefficiencies and suboptimal wagon utilization, leading to idle space and revenue loss.

In contrast to the prevalent focus in the existing literature on simplified bin packing assumptions and regular-shaped containers, our paper seeks to handle not only irregular wagon spatial constraints but also dynamic deck positioning. To this end, we propose a mixed-integer programming model to account for irregular loading constraints, drawn from the operational practices of our industry partner. Our research develops a novel branch-and-price algorithm to produce exact solutions, leveraging variable neighborhood search metaheuristics for initial warm-up and integrating tailored pricing problems for different deck positions.

Our computational experiments demonstrate that this framework achieves 90% time savings over manual scheduling while improving wagon utilization by 0.4%. Empirical results also reveal that prioritizing vehicle loading length over quantity and maintaining a balanced composition of vehicles maximizes space efficiency. The findings also offer valuable managerial insights in terms of objective selection and vehicle composition for better decision-making.

3 - Solving the 2DBPP on circular bins
Mauro Dell'Amico, Andrea Corsini, Matteo Magnani, Giovanni Tamburoni

The classical Two Dimensional Bin Packing Problem (2DBPP) asks to pack a given set of rectangular objects into the minimum number of identical rectangular bins. Recently [1] a variant has been introduced in which the bins are circles (2DCBPP. These problems find application in industrial settings, such as the placement of chips on circular silicon wafer. In this work we study how effective solution methods developed for 2DBPP can be adapted to the 2DCBPP, by highlighting the challenges posed by the circularity of the bin. We also propose a Non-Linear convex mathematical model for the exact solution of the problem. We analyze the behavior of the exact and heuristic approaches through extensive computational experiments. [1] T. Zhang, R. Wang, H. Zhang, Q. Liu and L. Wei (2024), "A skyline-based heuristic for orthogonal packing rectangles in a circle", Computer and Oper. Res. 167.

4 - Packing Irregular Polygons in A Shape Optimized Convex Container
Tetyana Romanova, Julia Bennell, Josef Kallrath, Igor Litvinchev, Olexandr Pankratov, Yifu Wei

One of classical problems in computational geometry is constructing a convex hull of a given set of convex polygons. This problem has important applications in logistics, manufacturing, operations research, chemistry and mechanics. Corresponding problems arise, e.g., in animation to facilitate collision detection, in epidemiology to represent a spatial extent of an epidemic. However, if the polygons are freely moving without overlapping, then different convex hulls can be constructed depending on the translated/rotated positions of polygons. Correspondingly, the problem to find a minimum perimeter/area convex hull arises. Another interpretation of this problem is packing irregular polygons in a shape-optimized (soft) convex polygonal container. The container is represented by a convex polygon with at most m unknown vertices, while the side lengths of the container can be bounded. The convexity and metric conditions for the container are formulated, as well as the non-overlapping and containment constraints for arbitrary polygonal objects. The objective function to be minimized is either the area of the soft container or the length of its perimeter. A corresponding nonlinear programming problem is formulated, and a multistart model-based heuristic is proposed. Computational results are reported to demonstrate the efficiency of the proposed approach.

■ MC-23

Monday, 12:30-14:00 - Room: Esther Simpson 3.01

OR for Better Africa - OR@Africa 1

Stream: OR for Societal Development
Invited session

Chair: Issmail El Hallaoui
Chair: Youssef Diouane
Chair: Fatima Ezzahra Achamrah

1 - Or in Africa : big challenges and big opportunities
Issmail El Hallaoui

Over the last decade, I have had the opportunity to work on several operations research (OR) projects across Africa. In this talk, I will present an overview of some of these projects, many of which have been successful and even received awards or were finalists in international competitions. I will highlight the key factors behind their success, as well as common pitfalls to avoid. A particular focus will be placed on the implementability of OR tools, addressing the unique challenges we face in the African context.

2 - Fostering Robustness in Supply Chain Network Design
Walid Klibi, Milena Janjevic

Supply chain network design (SCND) problems deal with strategic decisions on the reengineering of the network structure, in terms of deployment of long-term resources and the planning of the role of those resources' and their mission in terms of capacities to assign and policy-making for the primary Supply Chain (SC) activities. Strategic investments in resources, policy-making, and deployment are becoming key challenges in Africa's agriculture, mining, manufacturing, healthcare, retail & e-commerce, and energy supply chains. From an operations research perspective, while there is abundant literature in this area, there are significant opportunities to develop decision-support approaches that better capture the complexities of modern SC systems. In this talk, we start by revisiting the concept of robustness in SCND, and reviewing its current use in the literature. We identify critical challenges and opportunities for future research in this area to foster the robustness of SCND solutions. These are articulated around expanding the scope of SCND models, increasing the precision level of operations anticipations, enhancing methodologically the accuracy of SCND models under uncertainty, and improving solution methods and decision-making approaches. They link future contributions to surrounding fields of decision support, operations management, data analytics, and behavioral OR. We identify concrete opportunities for future research fostering the robustness of SCNDs in Africa.

3 - Enhancing healthcare access in refugee camps of the Gambella Region, Ethiopia
Laura Davila-Pena, Maria Paola Scaparra, Mahdi Shavarani, Fabio Manenti

The Gambella Region in western Ethiopia hosts over 350,000 South Sudanese refugees across seven camps and settlements. Non-governmental organizations (NGOs), such as Doctors with Africa CUAMM, work to strengthen the health system, focusing on infrastructure and workforce planning to improve accessibility, equity, and quality of care. In collaboration with CUAMM, we develop a location-allocation model that captures the multi-service, hierarchical structure of healthcare provision in refugee camps. The proposed multi-objective mixed-integer linear programming model optimally locates health posts and health centers. It also allocates essential services (e.g., basic and maternal care) and workforce (e.g., medical doctors, nurses, and midwives), promoting an equitable distribution of resources. By analyzing different scenarios, we provide decision-support tools to help CUAMM advocate for donor funding—both for establishing new health facilities and expanding workforce capacity.

4 - Simulating HIV/AIDS for Africa: A web-based platform for improving service management
Usame Yakutcan, Eren Demir, Shola Adeyemi, Adekunle Adeoti, Christian Isichei

The HIV/AIDS epidemic remains a significant challenge in African countries where over 25 million people live with HIV/AIDS. They risk losing remarkable progress due to the cessation of funding by the United States, contributing about 73% of financial support. More than ever, decision-support tools are needed to improve service effectiveness and resource allocation while stopping the disease's spread. We developed a web-based simulation platform powered by a discrete event simulation approach. The patient pathway in HIV treatment, including services and resources, was captured with experts from three African countries (Nigeria, Kenya, and South Africa). The pathway and model were further validated by experts in HIV treatment and management.Data were collected from various sources, including hospitals and experts from African countries as well as the UNAIDS website, reports, and literature.The tool's user-friendly interface makes the model easy to use, with pre-populated country-specific inputs (e.g., costs, incidence rates). Moreover, dashboards - dedicated to demand and utilisation, prevention strategies, UNAIDS targets, human resources, and budgeting - with easy-to-interpret charts enable scenarios and intervention evaluation.We ran scenarios on preventative therapies, improvements in the UNAIDS goal, and the introduction of mobile health applications.The results showed the impact of these interventions on key metrics, supporting decision-making and policy implementation

■ MC-24

Monday, 12:30-14:00 - Room: Esther Simpson 3.02

Tutorial: Societal Complexity

Stream: Tutorials (and Workshops)
Tutorial session
Chair: Gerhard-Wilhelm Weber

1 - Tutorial Societal Complexity
Dorien DeTombe

This tutorial Societal Complexity will explain handling complex societal problems in theory and practice based on the Compram methodology. The theoretical background of Methodology of Social Problems will be explained and the practical guide of the Compram Methodology described. The Compram methodology gives guidelines for the government (local or general) and large organizations and companies to handle complex societal problems

Complex societal problems are the problems that are on the frontpage of the daily quality newspapers. Problems like floods, earthquakes, climate change, pollution, traffic congestion and pandemics. Problems that need a multidisciplinary approach. The Compram Methodology focuses on methodologies, methods and tools for analyzing, structuring, advising, guiding and evaluating complex societal problems.

Complex societal problems are often policy problems that occur in many fields, like in the agro-industry (water pollution by too much manure, fowl plague), in the transportation sector, in healthcare (Malaria, HIV/Aids, Flu, Covid), in water affairs and in economy (credit crisis). The field focuses on handling local safety problems like large city issues and natural disasters as flood, earthquakes and hurricanes, and global safety problems like climate change and terrorism. Although many of these issues have different causes, they have so much in common that they can be approached in the same way by using the Compram methodology, a methodology based on the cooperation of experts of different fields and actors and the opinion of the people in a democratic way.

Complex societal problems, as such, are unstructured, dynamical, constantly changing and have a large impact on society on macro, meso and micro level. Handling complex societal problems needs a special multi-disciplinary approach. The content knowledge comes from content experts. The process knowledge comes from facilitators. The power is in the hand of actors. The attention of field of "Methodology of Societal Complexity" is on the methods and tools facilitators need for guiding these kinds of problems. The facilitators use methodologies specially created for the field of societal problems combined with methods and insights derived from fields like medicine, law, economics, societal sciences, methodology, mathematics, computer sciences, technology, engineering sciences, socio-cybernetic, chaos theory and operational research combined with content knowledge of the specific problem. Often a combination of methods is needed as is prescribed by the framework methodology for handling complex societal problems.

A complex societal problem should be handled according to the guidelines of the field of Methodology of Societal Complexity. This scientific field advised to have Knowledge Institutes, advocated by the OECD in 2006, that are ready to act as soon as a complex problem arrives. Then based on the Compram methodology (DeTombe, 2015) they can start inviting experts and actors to discuss the problem and to decide, based on their models of the problem, which changes would be the most fruitful and sustainable. With this scientific work they could advice the government in its decision. In this way decisions of the governmental are based on scientific advice and are more sustainable in a democratic may. Handling this way the governments would have saved more lives, sorrow and money.

The Compram methodology is developed by DeTombe (1994-2025). The Compram methodology is a scientific methodology for handling complex societal problems in a democratic, transparent and structured way. Handling means policymaking: analyzing, decision making, guiding and evaluating interventions. The Compram methodology focuses on the whole spectrum of the problem handling process. The OECD advised to handle Global Safety according to the guidelines of the Compram Methodology (2006). The Compram methodology is used in all continents and on many kind of complex societal problems.

Complex societal problems involve many disciplines, many fields, many phenomena, many actors and many people. The Compram methodology consist of six handling steps. In the first step a team of experts guided by a facilitator analyzes the problem and suggest interventions. In the second step in the Compram methodology the actors are invited to give their view on the problem. In the third step the experts and the actors try to get an agreement. In the fourth step the opinion of the people is asked and in the five step the interventions are implemented and in the sixth step evaluated.

■ MC-25

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.32

Exploring System Dynamics: Getting started and applications in consulting

Stream: Making an Impact: The Practitioners' Stream 2
Making an impact session
Chair: Siôn Cave

1 - Exploring System Dynamics: Getting started and Applications
Martin Kunc, Siôn Cave

System Dynamics is a powerful methodology for analysing and managing complex systems by capturing feedback loops and simulating system behaviour over time. This talk will introduce its core principles and demonstrate how it can be used to model interconnected systems in a wide range of contexts. We will explore its applications in consulting, showcasing how System Dynamics helps address strategic and operational challenges across industries. Additionally, we will discuss best practices for developing robust models, including key techniques for validation, documentation, and effective communication. The discussion around documentation will also reflect on the clarity, transparency, and impact required to enable publication. The speakers have a long track record of delivering successful System Dynamics-based projects, bringing real-world expertise to the discussion.

■ MC-26

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.33

Generative AI for Intelligent Decision Support Systems

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: Sofiane Oussedik

1 - AI and Logistics - A strategic partnership?
Dominik Berbig

Artificial Intelligence (AI) are reshaping supply chains — but too often, companies focus only on isolated tools or single use cases. Today, there is a wide range of AI tools designed to support specific tasks e.g. within purchasing, production, or crisis management, enabling faster and more informed decision-making. Numerous proof-of-concept projects and theoretical discussions demonstrate the potential benefits of these tools in their respective areas.

However, when taking a closer look, it becomes clear that most approaches focus only on individual processes or isolated parts of the supply chain. What seems to be largely missing is a comprehensive, practical strategy:

How can companies implement AI tools in a reasonable and ideally sustainable way - in what order, and for which use cases? Recent literature review confirms this gap. This leads us to the key question: What could a practical "hands-on guide to AI" for logistics look like, especially for small and medium-sized enterprises (SMEs)?

In our speech, we will share deeper insights from our research, present initial strategy recommendations, and outline the next steps necessary to ensure that AI becomes a real driver of value - not just a buzzword - in the logistics sector.

2 - Generative AI for Optimization & Decision Support Tools
Jens Schulz

The field of generative artificial intelligence (GenAI) has seen exponential growth over the past few years in research papers and publications. A hype train is rolling around how to best leverage GenAI in the fields of Operations Research: code generation, chatbots for documentation, generation of mathematical optimization models, allowing business users to easier navigate through an application... User productivity as the main goal.

Yet, Large language models (LLMs) occasionally produce incorrect or misleading results, a phenomenon commonly called "hallucinations". At FICO we are approaching GenAI in Optimization by combining technological advancements with ethical considerations and human oversight. GenAI will not replace optimization techniques, yet, it can play a role to democratize the use of Operations Research.

3 - Generative AI, from experimentation to production
Sofiane Oussedik

In this presentation we'll introduce Generative AI and cover topics like foundation models and large language models while taking a look at IBM's watsonx.ai platform. We'll also discuss how coding assistants support developing applications in general and optimization applications development in particular.

Also, as Generative AI is moving from experimentation to production, we'll discuss the need to create business value with responsible AI and the importance of trusted data, governance and guardrails to enable the adoption of generative AI and manage compliance with a multitude of emerging AI regulations.

4 - Generative AI: Panel discussion
Making An Impact, Dominik Berbig, Jens Schulz, Sofiane Oussedik

In this session, following three presentations with different talks on Generative AI and its actual and potential future impact on the development of Decision Support applications, we'll host a panel discussion with the attendees and our three panelists:

- Jens Schulz, Product Manager for FICO Xpress and president of GOR working group 'Practice of Mathematical Optimization'. He holds a PhD in applied mathematics from TU Berlin (2012). Before joining FICO in 2018, he worked at BASF SE and Lufthansa Systems and as teaching assistant at TU Berlin.

- Dominik Berbig, Professor of Logistics Operations Management at Pforzheim University since 2021. Prior to his appointment, Dominik Berbig worked at Robert Bosch GmbH in different areas and functions including acting as a project manager worldwide for leveling, and senior manager for warehousing, packaging and transport in the Power Tools business unit. Most recently, he managed the area Intralogistics and Material Flow as part of the project to introduce SAP S/4HANA & SAP EWM in the Mobility Solutions business unit.

- Sofiane Oussedik, Data Science & AI tools technical leader at IBM EMEA and Chair of the Euro practitioners Forum. He has a PhD in Computers Science/Operations Research (2000). As a lead Data Scientist, he works to support industry clients and business partners harness the value of AI and optimize usage of their resources in a wide range of industries, including manufacturing, energy and utilities, finance and logistics.

■ MC-27

Monday, 12:30-14:00 - Room: Maurice Keyworth G.02

Advances in Stochastic optimization

Stream: Stochastic and Robust optimization
Invited session
Chair: Milos Kopa

1 - Reduction of a Markov decision process with non-linear discounting to a stochastic game with standard total undiscounted criterion
Xinran Zheng

We consider a Markov decision process (MDP), whose total discounted utility is aggregated recursively with a concave discount function that is not necessarily linear. The state and action spaces are Borel spaces, and the utility function is nonnegative. We show that the MDP problem can be reduced to a turn-based two-player stochastic game with the standard total undiscounted criteria. Then we apply this reduction result to showing the existence of a stationary optimal policy when we want to minimize the iteratively aggregated discounted utility.

2 - Stability of stochastic programs specified by distortion risk measures with the application in the game theory
Lukáš Račko, Petr Lachout

In this paper, we deal with the stability of stochastic programming problems that are specified by distortion risk measures. The distortion risk measure is a specific type of risk functional that is defined as the Choquet integral of a random variable with respect to some distorted probability. The distortion of the probability measure is governed by a distortion function that encodes the agent's "distorted perception" of the true probability measure. Distortion risk measures characterize risk functionals that are monotone with respect to first-order stochastic dominance. This class of risk measures covers most of the commonly used risk measures, in particular, all coherent risk measures are distortion risk measures. The stability of stochastic programming problems has been in great extent covered by the work of Werner Römish, our goal is to extend this work to cover stochastic programs that are specified in terms of some distortion risk measures. Our main results are qualitative and quantitative conditions for the stability of such programs. We formulate these conditions in terms of program-canonical distances on the sets of probability measures, but we also show the conditions for the stability with respect to risk-neutral version of these distances that correspond to distances used by Römish. We apply these results to the problem of finding generalized equilibria in the model of a game with random payoff.

3 - Probability maximization model for demand side management
Rajmund Drenyovszki, Edit Csizmás, Csaba Fabian

Implementing demand-side management strategies in electricity grids has proven effective for aligning energy consumption with generation. However, the inherent uncertainties associated with renewable energy sources and the increased adoption of electric vehicles (EVs) introduce significant challenges. This presentation proposes a probability maximization model aimed at optimizing day-ahead scheduling for storage systems and intermittent devices. Specifically, surplus energy generated by EVs can be stored in battery storage and subsequently released during peak demand periods. The optimization solver, designed and implemented by our research team, employs an approximation scheme.

4 - A copula-based scenario generation method for discrete data
Ondrej Komora

Stochastic optimization relies heavily on scenario generation, which has a large impact on the tractability of optimization methods and the quality of obtained solutions. Despite its importance, scenario generation for discrete data is rarely studied and even when it is, it often involves a problem-oriented method. However, the development of these methods is resource-intensive, resulting in a situation where viable easy-to-use alternatives to sampling are missing. In this article, we attempt to remedy the situation by proposing a new copula-based scenario generation method for discrete data. The method is based on extending discrete random variables and subsequent use of the so-called extension copula. We demonstrate the effectiveness of this method on the stochastic knapsack problem by using several metrics like in-sample stability, out-of-sample evaluation gap, and optimality gap. The results show that our method outperforms sampling and can serve as a more challenging benchmark for problem-oriented methods.

■ MC-28

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.03

Manufacturing and Industrial Decision Support

Stream: Decision Support Systems
Invited session
Chair: *Uchitha Jayawickrama*

1 - Tactical decision support model for part feeding in flexible assembly lines
Gohar Porbar, Emmanouil Thanos, Veronique Limère, El-Houssaine Aghezzaf

In the current competitive market, the growing demand for customized products requires manufacturers to produce a wide range of product variants. Mixed-model assembly lines allow these product variants to be assembled on the same line. However, limited Border of Line (BoL) space makes storing large quantities of parts impractical. To address this constraint, manufacturers use various part-feeding policies. The BoL space usage can be reduced by grouping and repackaging parts into smaller containers; however, this increases logistics costs. We look at five part-feeding policies: Line Stocking (full pallets at the BoL), Boxed Supply (repackaging parts into smaller boxes), Sequencing (presenting parts in assembly order), Stationary Kitting and Traveling Kitting (grouping parts required for a single product). Depending on its characteristics and demand, each part can be assigned to a feeding policy. These policy assignments impact space utilization, material flow, logistics and operational costs. Our research proposes an exact solution approach to optimize policy assignments while minimizing logistics costs. The developed MIP formulation accounts for real-world constraints, including vehicle fleet, fixed layout, preparation cell sizes and limited BoL space. The model is validated using a variety of real-world instances. By integrating real-world constraints, this model serves as a decision-support tool to help manufacturers in making better informed part-feeding decisions.

2 - Data-Driven Job Dispatching Under Uncertainty: A Case Study in Weaving Process
Wen-Chih Chen, Feng-Yu Wu

This study is motivated by a real-world application in Taiwan's textile industry, specifically the development of a decision support system for job dispatching in the weaving process. The problem presents several key challenges, including uncertainties in decision-making, limited available data, the need to balance trade-offs in learning from past outcomes, and the dynamic nature of the operational environment. To address these challenges, we propose an online learning algorithm that adapts to evolving conditions. Numerical experiments demonstrate the effectiveness of the proposed approach in improving decision quality under uncertainty.

■ MC-29

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.04

Pricing Strategies in Food & Service Platforms

Stream: Pricing and Revenue Management Innovations
Invited session
Chair: *Arqum Mateen*

1 - Optimizing Service Fees and Driver Payments for Restaurant Food Delivery
Candace Yano, Gabriel Deza

We address a restaurant food delivery platform's problem of setting customer and restaurant service fees along with compensation for delivery drivers to maximize profit. We generalize earlier models by incorporating realistic consideration of how the number and mix of participating restaurants affects the customers' willingness to utilize the platform and their restaurant choices. Restaurants are heterogeneous in the service charge rate they are willing to pay, and drivers are heterogeneous in their reservation wage. Customer demands are affected by the number and variety of participating restaurants, the service charge rate imposed on customers, and waiting times. We seek a solution that satisfies equilibrium conditions and participation constraints in view of these interactions.

We develop a nested optimization algorithm with an embedded queueing model. Each level of the problem is solved while considering the conditionally optimal solutions of decisions at lower levels and pertinent equilibrium conditions.

We present numerical examples and characterize the platform's optimal choices and the participants' equilibrium behavior. We find that the platform's profit is sensitive to the delay in assigning drivers to orders, so platforms need to carefully calibrate decisions to ensure the "best" utilization level is achieved. We also find that interesting tradeoffs arise in our problem setting that do not arise when restaurants are homogeneous or passive.

2 - Managing Food Waste: Pricing Strategies for Food Redistribution Restaurants
Priyanka Laskar, Soumyadeep Kundu

Food-sharing platforms, like Too Good to Go, offer a novel way of dealing with surplus food, connecting restaurants with consumers to distribute this surplus food at a considerably discounted price through the sale of "surprise bags". For consumers, the surprise element is introduced in the form of uncertainty about the contents of these bags, which intrigues consumers, thus requiring them to rely solely on the perceived quality of the restaurant. To keep pricing simple and attract more buyers, restaurants use fixed discount rates like 50% or 33%, avoiding the complexity of setting variable prices. We thus develop a game-theoretic model to explore the restaurant's optimal pricing strategy for these surprise bags and determine the quantity of surprise bags to offer over a period, while maximizing the revenue for the restaurant from the sale of these surprise bags. In addition, we also examine how competition among restaurants, listed on these food-sharing platforms affects these dynamics. Our study incorporates the uncertainty arising from these surprise bags, the perception of quality among consumers, and competition among restaurants, examining how such factors influence the pricing and quantity decision on the number of surprise bags offered by the restaurants. The study provides actionable insights for restaurants to better deal with such food-sharing platforms, including pricing and other operational decisions, all the while reducing food waste and benefiting consumers.

3 - Channel Strategy in the Electric Vehicle Rental Market
Arqum Mateen, Sanchari Guha Niyogi, Srikanth K.

Electric vehicle (EV) rentals are rapidly growing, with platforms investing in linked services. However, EV manufacturers (EVMs) increasingly offer rentals directly, impacting platform partnerships. This research explores EVM channel strategy, considering linked services, range anxiety, and green sensitivity within an EV/gasoline vehicle (GV) duopoly. We develop a three-stage game involving a platform, manufacturers, and consumers. Platform partnerships can be beneficial for EVMs. Partnering with GV platforms yields higher profits when range anxiety, green sensitivity, and linked service receptivity are high. Conversely, partnering with EV platforms is preferable with low range anxiety and high green sensitivity. Our findings suggest that B2B partnerships with GV platforms can benefit EVMs targeting eco-conscious consumers, while direct rentals are more advantageous when range anxiety dominates.

■ MC-30

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.05

Stochastic lot-sizing

Stream: Advanced Lot Sizing and Inventory Strategies
Invited session
Chair: *Sila Cetinkaya*

1 - A two-stage stochastic optimization model for preventive buffer allocation in a fixed production and maintenance plan
Mehdi Sharifyazdi, Stéphane Dauzere-peres

This paper addresses the challenge of managing deviations from a fixed production or maintenance plan in uncertain environments where corrective flexibility is limited. The problem arises in settings where the core operational plan, such as a production schedule in Make-to-Stock manufacturing or a maintenance program in power grid operations, is predetermined and cannot be adjusted during execution, due to contractual, regulatory, or logistical constraints. In such cases, planners must rely on preventive buffer allocation decided before operations start, and reactive recovery actions taken after deviations occur. The key constraint is that buffer resources, such as overtime labor or specialized crews, are limited and must be distributed among time periods upfront and cannot be transferred to other periods later. We propose a two-stage stochastic optimization model that jointly determines the optimal allocation of these limited buffer resources and the recovery actions to be taken in response to realized deviations. The model minimizes the expected total cost of deviations, preventive buffers, and recovery interventions. A two-phase solution algorithm is developed, combining stochastic dynamic programming with a branch-and-bound procedure to efficiently solve the problem and provide upper and lower bounds on the objective function. Numerical experiments illustrate the model's performance and value in supporting robust contingency planning under uncertainty.

2 - Stochastic Clearing under a Nonlinear Penalty for Service Delay with Applications in Inventory Management and Distribution
Sila Cetinkaya, Bo Wei, Daren Cline

We revisit the traditional stochastic clearing problem widely applicable in the context of inventory management and distribution. We consider the case where the order process is Poisson and service delay (customer waiting) associated with clearing frequency is subject to a nonlinear penalty. The penalty is designed to capture the customers' impatience related to waiting times caused by service delays. We analyze three practical, renewal-type clearing protocols (known as quantity-based, time-based, and hybrid policies) for operating the underlying inventory system. Our goal is to compare and contrast these policies in terms of service performance and cost. Unlike the case of linear delay penalty, investigated previously in the literature, we find that quantity-based policies are not necessarily optimal with respect to service or financial performance. Further, one can potentially compute a hybrid policy that dominates the cost-optimal quantity-based policy in terms of both dimensions of performance. This new finding regarding bi-criteria dominance potential of hybrid policies validates the value and importance this class of clearing protocols in establishing operational guidelines in practice.

3 - New Algorithms and Comparison Analysis for Multi-product Cyclic Joint Replenishment and Heterogeneous Fleet Routing Problem
Ming-Jong Yao, Chin Sum Shui, Chin-Wei Wu

This study investigates a Multi-Product Cyclic Joint Replenishment and Heterogeneous Fleet Routing Problem, which integrates the multi-product cyclic inventory routing problem and the joint replenishment problem. It is inspired by a paint importer's Vendor Managed Inventory (VMI) business model, which aims to satisfy the demand for multiple products for its customers through cyclic replenishments. The

manager's goal is to determine the replenishment cycle and the scheduled replenishment date for each product for every customer. Additionally, they must plan the deployment and routing of vehicles for each day of the planning horizon, to minimize the average daily total cost. This study examines two decision-making scenarios: a fixed-vehicle scenario, in which each route uses a specific vehicle and a relaxed scenario that removes this restriction. For both scenarios, we formulate a mixed-integer programming model that can be solved using the commercial optimization software GUROBI. Furthermore, we propose two algorithms for addressing the problem: the Non-nested Joint Replenishment (NJR) algorithm and a Simulated Annealing Algorithm (SAA). Our numerical experiments demonstrate that, for a large-scale problem involving 20 vehicles and 1,000 items, the NJR algorithm produces better solutions than the SAA while taking less than 0.02% of the time required by the latter.

4 - Robust Production Planning Under Inherent Supply Chain Disruptions
Amin Javanmard, Kerem Akartunali, Ashwin Arulselvan

This study explores a robust optimization approach to capacitated lot-sizing under inherent supply chain disruptions, including bursty demand patterns and uncertain transition dynamics. An iterative adversarial framework assesses worst-case scenarios, enhancing production planning resilience. Various uncertainty representations are considered to model fluctuations and transitions. The framework integrates a structured demand process and optimizes decisions under uncertain conditions. Future research will refine uncertainty modelling, incorporate advanced forecasting techniques, and improve computational efficiency. This work contributes to resilient supply chain management by supporting adaptability in unpredictable environments.

■ MC-31

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.06

Stochastic Optimization for Energy Transition

Stream: Stochastic and Robust optimization
Invited session
Chair: *Patrizia Beraldi*
Chair: *Albert Solà Vilalta*

1 - From Sample Average Approximation to Surrogate Models in Smart Grids Operation
Antonio Alcántara

Modern smart grids incorporate renewable energy, smart inverters, and battery storage systems, introducing significant uncertainty that challenges traditional operations. Two-stage stochastic programming offers a framework to address these challenges, but Sample Average Approximation (SAA) approaches often result in computationally intensive "monolithic" problems as scenarios multiply.

This presentation explores surrogate modeling alternatives, focusing on Quantile Neural Networks (QNNs) to approximate second-stage objective distributions in stochastic programming. Unlike conventional methods that only consider expected values, this distributional approach enables risk-aware optimization, including Conditional Value at Risk (CVaR) assessments crucial for reliable grid management.

By embedding QNN-based distributional approximations into first-stage problems, we create a framework that balances computational efficiency with solution quality. The approach bridges optimization theory and machine learning with practical power system applications, providing grid operators with tools for decision-making under uncertainty. Through computational case studies featuring mixed-integer optimization problems, we demonstrate how this methodology supports risk-averse grid operations while maintaining tractability, ultimately enhancing reliability and efficiency in renewable-rich power systems.

2 - Optimal placement of wind farms via quantile constraint learning
Wenxiu Feng, Antonio Alcántara, Carlos Ruiz

Wind energy is becoming an important energy source and holds a significant share in the energy generation mix. Selecting optimal combinations of wind farm locations and turbine sizes can enhance wind power outputs, mitigate power fluctuations, and improve the stability and reliability of energy distribution. In this study, we investigate two wind farm location portfolios under different risk measures. Aggregated uncertain power outputs of these location portfolios are estimated using the quantile constraint learning methodology based on the Quantile Neural Network (QNN). We embed the QNN-based power output constraint in optimization of wind farm locations and turbine sizing. Our objective is to trade off revenue for wind power outputs and costs for turbines and transmission lines. The optimization problem is examined under two risk measures: risk-averse (Conditional Value at Risk, CVaR), which mitigates worst-loss scenarios, and risk-seeking (Conditional Value at Best , CVaB) which captures best-gain scenarios. A case study is conducted in the Asturias region, Spain. The results reveal that the optimal wind farm portfolio and turbine sizing vary with different risk-aversion and risk-seeking levels, providing insights into strategic decision-making for wind energy investments under uncertainty.

3 - Optimal Participation of Energy Communities in Electricity Markets under Uncertainty. A Multi-Stage Stochastic Programming Approach.
Albert Solà Vilalta, F.-Javier Heredia, Ignasi Mañé

An energy community is a legal figure, recently coined by the European Union, that creates a framework to encourage active participation of citizens and local entities in the energy transition to net-zero. In this work, we study the optimal participation of energy communities in day-ahead, reserve, and intraday electricity markets.

The motivation to do so is that there are time periods where energy communities cannot meet their internal demand, and periods where they generate excess electricity. This is because the electricity they generate often comes from variable renewable resources like solar and wind. Electricity market participation is a natural way to ensure they meet their internal demand at all times, and, simultaneously, make the most of the excess electricity.

We propose a multi-stage stochastic programming model that captures variable renewable and electricity price uncertainty. The multi-stage aspect models the different times at which variable renewable generation is considered to be known and electricity prices from different markets are revealed. This results in a very large scenario tree with 34 stages, and hence a very large optimization problem. Scenario reduction techniques are applied to make the problem tractable. Case studies with real data are discussed, considering different energy community configurations, to analyse proposed regulatory frameworks in Europe. The added value of considering stochasticity in this problem is also analysed.

■ MC-32

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.09

Stowage Planning and Vessel Operations

Stream: Maritime and Port Logistics
Invited session
Chair: *Dario Pacino*

1 - Multi-visit Arc Routing Problem with Time Windows and Heterogeneous Manpower Groups in Automotive Terminal: Formulations and Heuristics
Ziqiao Mei, Zhou Xu, Feng Chen

This study addresses the Multi-visit Arc Routing Problem with Time Windows and Heterogeneous Manpower Groups (MVARPTWH), inspired by real-world operations at a large automotive terminal in China. Loading and unloading tasks are modeled as single arcs, visited multiple times by one group with time window constraints. Heterogeneous groups under dual-cycling operations are scheduled in one shift. We introduce a non-split-arc model that outperforms traditional split-arc models. Due to its NP-hard, we propose a hybrid bilevel memetic search algorithm that explores solutions at both group and arc levels for efficient solving. It begins with three constructive heuristics: a decomposition-based math-heuristic, a rule-based heuristic derived from manual experience, and a spring-based parallel insertion heuristic ensures population diversity. Then, a random and a directed crossover operators generate offspring solutions. To improve solution quality, we propose a bilevel variable neighborhood descent method combined with four efficient operators. Two diversification-based mutations and two quality-and-distance population management strategies are used to help the search escape from local optima. Computational experiments on 24 new instances show that our approach outperforms CPLEX, reducing CO2 emissions of groups by 50% compared to manual scheduling. Additionally, we test the sensitive parameters and assess the impact of key algorithmic components.

2 - AI-Driven Neighborhood Selection in Large Neighborhood Search for Representative Container Vessel Stowage Planning
Jaike van Twiller, Djordje Grbic, Rune Jensen

The representative container vessel stowage planning problem (CSPP) is a large-scale combinatorial optimization challenge with numerous constraints and decision variables. Due to its complexity, exact solution methods often struggle to find feasible or optimal solutions within a reasonable timeframe, necessitating the use of heuristic approaches. A widely used metaheuristic is the large neighborhood search (LNS) framework, which has demonstrated effectiveness across various combinatorial optimization problems with a manageable number of neighborhoods. However, a full-featured CSPP requires a large and diverse set of neighborhoods, rendering conventional selection heuristics ineffective in identifying promising neighborhoods during the search process. This reduces the overall performance of LNS, highlighting the need for more intelligent neighborhood selection strategies.

In this planned work, we will leverage an AI-driven neighborhood selection heuristic within the LNS framework to solve representative instances of the CSPP. The search process will be formulated as a Markov decision process, where state features capture solution characteristics, neighborhood selection serves as the action, stochastic transitions update solutions based on neighborhood operators, and rewards are based on objective value and feasibility satisfaction. Our AI-assisted LNS framework will be evaluated on real-life problem instances. Its performance will be compared to a baseline vanilla LNS to a

3 - RoRo Stowage planning with uncertain cargo weights
Oliver Rise Thomsen, Dario Pacino

In Roll-on/Roll-off stowage planning, there are two main elements of uncertainty: The arrival time of the cargo and weight. The weight of the cargo is often not known precisely at loading time, thus forcing the loading planner to be conservative when creating their stowage plan. To our knowledge, the impact of the uncertain weight has not yet been studied. We thus propose the Roll-on/Roll-off stowage planning problem with respect to uncertain cargo weights. We introduce a two-stage stochastic model that places cargo in the first stage and ensures the vessel's stability in the second stage. The model aims to stow as much cargo as possible under uncertainty while ensuring that the vertical centres of gravity, shear force and bending moment are within their respective limits. The uncertain weight is determined by a fitted weight distribution from an industry partner. We hope that our finding can shed light on the impact of the uncertainty of the cargo weight and if it is beneficial to include it in stowage planning problems. Further, we will study the effect of binning cargo into weight categories and how the number of bins impacts the solutions.

4 - Stochastic Dual Cycling in RoRo shipping
Dario Pacino, Magnus Vilhelm Barrett Levinsen, Line Reinhardt

In recent years, academic interest in Roll-On Roll-Off (RORO) shipping decision support has grown. The increase has particularly revolved around studies on automated stowage planning. RORO planning problems, in contrast to their container-based counterparts, have a high degree of uncertainty. In this presentation, we will explore the dual-cycling problem, where the sequence in which cargo is loaded and discharged is optimized. Dual-cycling exploits the possibility of concurrently executing load and discharge operations, and hence aims to minimize the empty trips of terminal vehicles. Optimal (or near-optimal) solutions can be efficiently solved with state-of-the-art techniques when considering a deterministic problem. Unfortunately, the RORO industry operates with up to a 60% uncertainty in cargo data. In this study, we will present a two-stage stochastic program that models the uncertainty in cargo arrival times. We also propose an efficient rolling horizon approach to solve the problem.

■ MC-33

Monday, 12:30-14:00 - Room: Maurice Keyworth 1.31

Decision Processes

Stream: Decision Analysis
Invited session
Chair: Jutta Geldermann

1 - Decision Processes in Emergency Medical Service Location Planning: A Case Study from Duisburg, Germany
Jutta Geldermann, Isabel Wiemer

The primary goal of emergency medical services (EMS) is to provide rapid and efficient assistance in critical situations. The strategic planning of ambulance station locations - serving as dispatch points for ambulances - is essential to ensuring effective emergency response. Key decisions in this context include site selection and station capacities, to maximize coverage or minimize response times. We present the decision-making process of the fire department responsible for EMS and its collaboration with the university project team in a comprehensive case study from Duisburg, Germany. As the third-largest city in the Ruhr metropolitan area, Duisburg faces unique geographical challenges: a densely populated city center contrasts with sparsely populated outskirts, while the Rhine and Ruhr rivers divide the city into multiple areas connected only by bridges, impacting the accessibility of the EMS. The presentation outlines the essential steps in problem structuring, data collection and preparation for several years, model development, and effective communication with the EMS decision-makers. The case study provides insights into how Operations Research methods support EMS location planning, addressing real-world challenges to improve coverage and emergency response.

2 - When "Optimization" Ruins Everything: School Assignment in Antwerp, Belgiumy
Kenneth Sörensen

In 2010, the city of Antwerp, Belgium introduced a centralized school assignment system, initially for primary education (kindergarten, ages 2.5+). From then on, parents were asked to communicate an ordered list of preferred schools, after which an algorithm would assign the free seats. This system used a variant of the school-proposing deferred acceptance algorithm with priority given to students residing closer to schools.

In 2017, the city extended this system to high schools but removed the distance priority criterion. The system was strategy-proof, but not Pareto efficient, which meant that children could get a seat at each other's higher-ranked school. Following parental protests, Antwerp then introduced an "optimization" algorithm designed to swap students in this situation.

In this talk, we discuss why such optimization measures are actually detrimental. While the modifications aim to achieve Pareto optimality (where no student could be made better off without making another worse off) they undermine the system's strategy-proofness, a crucial property ensuring that families cannot game the system by misrepresenting their preferences.

Using a computational experiment we demonstrate that such misrepresented preferences undermine the performance of the system, and can potentially lead to disaster. We also discuss several alternative algorithms that achieve the same efficiency without compromising fairness and strategy-proofness.

3 - Goal-Oriented Dynamic Group Decision Making Based on Ordinal Consensus
Yuanyuan Yin, Jianfeng Cai

In response to the goal-oriented dynamics of initial decision-maker selection schemes in a hesitant fuzzy linguistic preference environment, this study proposes an optimization-based consensus model. First, a fuzzy C-means clustering method based on ordinal similarity, considering hesitation and fuzziness, is proposed within the hesitant fuzzy linguistic preference environment to form subgroups with shared goal interests. Within these subgroups and trust networks, the decision-maker with the highest support for their preferences is selected as the subgroup leader, and the leader is replaced if their preferences repeatedly deviate from those of the subgroup members. Second, an optimization adjustment mechanism based on maximum ordinal consensus is proposed, which identifies the two decision-makers within the subgroup with the least support and categorizes their preferences into two types of behavior: in-group biased behavior and trust-oriented behavior. Finally, the effectiveness of the proposed model is validated through a case study of a company selecting a supply chain platform. Comparative and sensitivity analyses are also conducted to examine the impact of trust relationships and the cooperation-competition dynamics within and between subgroups on both the final consensus opinion and the speed at which consensus is reached.

4 - Constructing an Evaluation System for Senior-Friendly Mobility Using Dynamic Z-Numbers and the Fuzzy Delphi Method
Jian-Hua Xia, James Liou, Sun-Weng Huang, Gwo-Hshiung Tzeng, Luna Y. F. Yu, Cc J. H. Chen

With the rapid aging of society, creating a senior-friendly mobility environment has become increasingly crucial for enhancing the quality of life and urban accessibility for elderly populations. Traditional urban planning and evaluation frameworks frequently overlook the specific needs and challenges seniors encounter during mobility. Therefore, this study aims to construct an evaluation system centered on the mobility requirements of seniors by integrating the perspectives of experts and stakeholders. First, semi-structured interviews were conducted to identify essential indicators and mobility needs pertinent to seniors. Subsequently, the Dynamic Z-number method was employed to quantify inconsistencies and uncertainties within expert decision-making processes. Finally, the Fuzzy Delphi Method was utilized to aggregate consensus and identify refined core indicators for senior-friendly mobility. The findings of this study can serve as valuable references for future urban planning and policy-making, further advancing the comprehensive development of senior-friendly cities.

■ MC-35

Monday, 12:30-14:00 - Room: Michael Sadler LG15

Nonlinear Optimization Algorithms and Applications: 2

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: *Ya-xiang Yuan*
Chair: *Xin Liu*
Chair: *Cong Sun*
Chair: *Zaikun Zhang*

1 - The Distributionally Robust Optimization Model of Sparse Principal Component Analysis
Xin Liu

We consider sparse principal component analysis (PCA) under a stochastic setting where the underlying probability distribution of the random parameter is uncertain. This problem is formulated as a distributionally robust optimization (DRO) model based on a constructive approach to capturing uncertainty in the covariance matrix, which constitutes a nonsmooth constrained min-max optimization problem. We further prove that the inner maximization problem admits a closed-form solution, reformulating the original DRO model into an equivalent minimization problem on the Stiefel manifold. This transformation leads to a Riemannian optimization problem with intricate nonsmooth terms, a challenging formulation beyond the reach of existing algorithms. To address this issue, we devise an efficient smoothing manifold proximal gradient algorithm. We prove the Riemannian gradient consistency and global convergence of our algorithm to a stationary point of the nonsmooth minimization problem. Moreover, we establish the iteration complexity of our algorithm. Finally, numerical experiments are conducted to validate the effectiveness and scalability of our algorithm, as well as to highlight the necessity and rationality of adopting the DRO model for sparse PCA.

2 - A momentum-based linearized augmented Lagrangian method for nonconvex constrained stochastic optimization
Xiao Wang

Nonconvex constrained stochastic optimization has emerged in many important application areas. Subject to general functional constraints it minimizes the sum of an expectation function and a nonsmooth regularizer. Main challenges arise due to the stochasticity in the random integrand and the possibly nonconvex functional constraints. To address these issues we propose a momentum-based linearized augmented Lagrangian method (MLALM). MLALM adopts a single-loop framework and incorporates a recursive momentum scheme to compute the stochastic gradient, which enables the construction of a stochastic approximation to the augmented Lagrangian function. We provide an analysis of global convergence of MLALM. Under mild conditions and with unbounded penalty parameters, we show that the sequences of average stationarity measure and constraint violations are convergent in expectation. Under a constraint qualification assumption the sequences of average constraint violation and complementary slackness measure converge to zero in expectation. We also explore properties of those related metrics when penalty parameters are bounded. Furthermore, we investigate oracle complexities of MLALM in terms of total number of stochastic gradient evaluations to find an $epsilon$-stationary point and an $epsilon$-KKT point when assuming the constraint qualification. Numerical experiments on two types of test problems reveal promising performances of the proposed algorithm.

3 - Primal-Dual Algorithms for Saddle Point Problems—Convergence Analysis and Equilibrium Properties
Deren Han

The saddle point problem is a significant class of issues in the fields of optimization and game theory, where both theoretical and applied research have consistently garnered widespread attention. Among the core algorithms to address this problem are those based on primal-dual methods. This report presents a convergence analysis for some fundamental saddle point problems and introduces a novel algorithm that considers the equilibrium between primal and dual aspects.

4 - A Block Coordinate Descent enhanced metaheuristic for the Euclidean Traveling Salesman Problem with Polygonal Neighborhoods
Ernesto G. Birgin, Paula C. R. Ertel

The Traveling Salesman Problem with Neighborhoods (TSPN) is a generalization of the well-known Traveling Salesman Problem. In the TSPN, given a finite set of regions of the Euclidean space, the goal is to find an order of these regions and a visit point in each region so that the length of a tour that visits them only once and returns to the starting point is minimized. Most of the literature on the TSPN focuses on the case where the regions are disks. In this work, we focus on the case where the regions are given by arbitrary (nonconvex) polygons. Considering the Euclidean distance, the problem can be modeled as a mixed-integer quadratically constrained programming problem. We propose an Iterated Local Search (ILS) metaheuristic to find solutions to large instances of the problem. The proposed ILS combines a block coordinate descent method to determine the visit points with different neighborhood structures widely used in the TSP literature to generate the permutations. Numerical experiments illustrate the performance of the proposed method.

■ MC-38

Monday, 12:30-14:00 - Room: Michael Sadler LG19

Automating the Design, Generation and Control of Optimization Algorithms 2

Stream: Data Science meets Optimization
Invited session
Chair: Ender Özcan
Chair: *Andrew J. Parkes*

1 - Genetic programming based algorithm for managing of rescue teams in crisis situations
Adam Górski, Maciej Ogorzałek

Crisis situations like traffic accidents, tsunamis, fires, etc. demands coordinated cooperation of many rescue teams. Such teams can be: emergences, fire brigades, police, divers, etc. In crisis situations time is critical. Rescue teams need to help people unless it is too late. Therefore an appropriate management of the teams including choosing the number and type of rescue teams and the assignment of given tasks is very important. We present a genetic programming based algorithm which is able to optimize the cost of rescue action by choosing the number and type of rescue teams and assignment of the tasks. the algorithm starts from initial population which is consistent of randomly created genotypes. Each genotype is a tree. In the nodes of the tree are decisions about sending a new rescue team or assigning the tasks to the teams. The next generations of individual are created using standard genetic operators: selection, mutation and crossover. We believe that proposed methodology is able to make the rescue action more effective, faster and cheaper.

2 - Designing branching strategies with genetic programming
Simon Renard, Bernard Fortz, Quentin Louveaux

Branching strategies play a crucial role in the efficiency of branch-and-bound algorithms for solving combinatorial optimization problems. Traditional heuristics rely on handcrafted rules that remain fixed across different problem instances, while recent advances have used machine learning to learn problem-specific branching strategies.

In this work, we propose a novel approach to designing branching strategies using genetic programming. Our method simulates an evolutionary process in which individuals represent scoring functions that define branching decisions. This approach not only enables the discovery of new strategies without relying on existing heuristics but also provides interpretable strategies in the form of simple mathematical expressions.

3 - Using Genetic Programming to generate Dispatching Rules for a Large-Scale Project Scheduling Problem
Nuno Marques, Gonçalo Figueira, Luís Guardão, Luis Guimarães

Scheduling in real-world settings is becoming increasingly challenging due to more complex products, pressures from customers and competitors, continuous adjustment to new technologies, and frequent unexpected events such as breakdowns, illness and supply chain disruptions. A sector in which scheduling is deeply affected by uncertainty is the aircraft maintenance and repair operations (MRO) business. Optimizing scheduling in MRO is important to reduce costs, plane unavailability and promote safety. There are three main types of aircraft MRO: Line, Light and Heavy. Due to its complexity, this work focuses on heavy maintenance, as it encompasses thousands of tasks and can ground a plane for over two months. Moreover, uncertainty is constantly present in three main dimensions: planes' arrival dates, task durations, and a large amount of unplanned work. Lastly, aircraft MRO scheduling encompasses several subproblems: task scheduling, staff allocation and work centre allocation. When facing such a complex, large and uncertain problem, one needs reactive solution methods such as dispatching rules (DRs) that can schedule tasks on the fly. Manually updating schedules or using approaches based on exact and meta-heuristics methods is not feasible as they would take too long. Therefore, in this work, Genetic Programming was used to generate new DRs for the aircraft MRO scheduling problem. These novel AI-generated DRs outperform existing DRs while maintaining a compact form.

4 - Online Resource Allocation Problem with Departures
Yusuf Amidu

In this paper we propose a novel primal-dual algorithm for the following online resource allocation problem. Requests arrive over time to a set of resources and upon arrival, the time a request may occupy a resource becomes known. We assume that the duration of stay of a request is deterministic, may depend on the resource and that resources may have different capacities. The goal is to decide whether to accept/reject a request upon arrival and to which resource to allocate it such that the reward obtained over a time T is maximized. We show that the proposed primal-dual algorithm achieves a competitive ratio of O(R/r), where R is the maximum reward and r is the minimum reward that can be obtained. Through numerical experiments, we show that the primal-dual algorithm has lower computation times than a recent algorithm proposed in the literature, while having a similar performance in practical instances.

■ MC-41

Monday, 12:30-14:00 - Room: Newlyn GR.01

Soft OR/PSMs Foundations and History

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: Robert Dyson
Chair: *Mike Yearworth*

1 - The history and foundations of SSM
Karthik Suresh

This paper will review the development of SSM as "a genuine attempt to deal, in a rational way, with the actual reality of organizational life."

SSM evolved in a Lancaster University research programme that, for 30 years, carried out "practical action research in real-world situations outside the University", addressing the research question "could the systems engineering approach be successfully used in a broad spectrum of management problems?".

Three books demarcate the stages of SSM, each published roughly a decade apart. Published in 1981, Systems Thinking, Systems Practice, developed the main techniques of SSM, articulated its philosophical stance and introduced the "seven-stage" method. Soft Systems Methodology in Action, published in 1990, discusses a mature methodology informed by reflective use in practice, with a clearer philosophy, refined techniques and a flexible three-part method. Information, Systems and Information Systems, published in 1998, discusses the wider application of SSM with particular reference to information systems. Following these three publications, "Learning for Action: a short, definitive account of soft systems methodology and its use for practitioners, teachers and students", published in 2006, aims to help anyone teach SSM or use it in real situations.

SSM continues to be one of the most widely applied Soft OR methods today, due to its ability to capture and model rich descriptions of real-world situations.

2 - The Strategic Choice Approach: Decades of Evolution and Future Prospects
Isabella Lami

In the minds of the pioneers of the Strategic Choice Approach (SCA), the method was conceived as a learning process that facilitates problem perception and fosters the emergence of new knowledge and perspectives. The emphasis on representing the problematic situation reveals a distinct SCA aesthetic—as sensitive knowledge—that conveys insight into the process supporting decision-making. Moreover, SCA inherently enables the expression of problems in more accessible forms, leading to a deeper understanding and the development of shared knowledge at a collective level. This, in turn, strengthens group decision-making by fostering more robust and widely accepted choices among participants. Designed to manage multiple sources of uncertainty, SCA has demonstrated remarkable adaptability across diverse decision-making contexts, evolving over time with the support of specialized software tools. This presentation traces the history of SCA and its latest applications, emphasizing its enduring relevance today.

3 - SODA: Foundations, History, and Where Next?
Viktor Dörfler

The term SODA was originally introduced by Colin Eden in 1989 (Rosenhead, 1989). Coming from an engineering background with a keen interest in tackling real world problems, Colin conceptualized SODA as an alternative way for dealing with problems of such complexity that defied quantitative methods, not only because of the excessive need for calculations but also because many significant variables could not be measured. In this sense, SODA is Colin's response to what he formulated a decade earlier about the nature of problems in consulting practice (Eden et al., 1983). In addition to this view of the problems the foundations include the role of the facilitator who wants to engage with the clients in person and aspires to action more than discovery, the political feasibility of the process, the negotiated order as an outcome of which the participants have ownership. Importantly, the intuitions and emotions of participants and their pain points are as important for SODA as what can be calculated and/or logically argued. Further principles were added as tools were developed, and the map became a boundary object and a transitional object, the length of the process became increasingly important given time constraints of clients, and the steps got more explicitly formulated resulting in a set of formalized processes. The use of mapping in litigation SD modelling was also a significant development with attention to the client experience of why projects go wrong.

■ MC-42

Monday, 12:30-14:00 - Room: Newlyn GR.02

Sustainable apparel supply chains

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: *Kumudu Saranga Kaluarachchi*

1 - A bilevel programming approach to optimizing textile recycling strategies
Dámaris Arizhay Dávila Soria, Mario A. Aguirre-López, José-Fernando Camacho-Vallejo

In this work, we propose a bilevel programming problem enhancing collaboration between society, recyclers and re-manufacturers to promote longer garment life cycles within the supply chain. In this problem, a private recycling company collects used garments through strategically placed collection containers. The collected garments are sorted for upcycling and material extraction. This recycling company aims to maximize its profit by selling textiles to remanufacturers, who bid on the entire contents of the containers without prior inspection, considering location and expected quality. The allocation process of the collection containers is subject to capacity and accessibility constraints. The bilevel model frames recycling company as the leader and remanufacturers as the followers. Due to the characteristics of the resulting model, it is then reformulated as a single-level problem using KKT conditions. For small instances, an exact method is proposed, while a metaheuristic is designed to handle large instances. Computational experiments are conducted to validate the algorithm's efficiency, and a case study in Chile is presented, analyzing the trade-off between maximizing the recycling company's profit, strengthening the link with local remanufacturers, and minimizing the environmental impact of the collected garments. Through this analysis, we highlight key insights that can guide more sustainable and economically viable decision-making in textile recycling.

2 - Inventory Management and Assortment Planning in an Apparel Closed-Loop Supply Chain
Heletje van Staden, Hannah Yee

We consider an apparel rental platform with a fixed membership pool and non-stationary demand with partial observability. The platform aims to optimize garment purchasing decisions to best meet customer demand while minimizing operational costs. We model the problem as an ambiguous partially observable Markov decision process, which allows us to account for both uncertainty regarding the underlying demand distributions governing the demand and ambiguity regarding the platform members' demand preferences. We analyze the structure of the optimal policy and use reinforcement learning to approximate the optimal inventory control and assortment decisions. For the instances considered, we find that the algorithm improves on the static order up to policy by 6%, on average. By adjusting the inventory position to changing demand, our policy is able to limit dissatisfaction among members at the expense of holding slightly more inventory. Our work contributes to the closed-loop supply chain literature and can be used to support rental platforms with inventory and assortment procurement decisions given ambiguous and uncertain trends in customer preferences.

3 - Lean and Resilience Strategies in the Apparel Supply Chain: Pathways to Sustainable Competitive Advantage
Kumudu Saranga Kaluarachchi, Dr Dewan Md Zahurul Islam, Amna Farrukh

The textile and apparel industry in Sri Lanka significantly contributes to the country's export revenue but faces challenges such as global economic slowdowns, geopolitical tensions, and supply chain disruptions, including order cancellations and shipping congestion during the pandemic. While lean and resilience strategies have been studied individually, there is a research gap in understanding their integration for sustainable competitive advantage in supply chain management. This study explores the integration of lean and resilience strategies in Sri Lanka's textile supply chain, focusing on identifying enablers, core competencies like risk absorption and recovery, and implementation constraints. Using Dynamic Capability Theory and the Knowledge-Based View, the research employs a mixed-methods approach, combining quantitative surveys and qualitative interviews. Expected findings include key enablers such as stakeholder relationships, technological innovation, and continuous improvement, alongside constraints like cultural barriers, resource limitations, and inadequate planning. The study aims to develop a framework for achieving sustainable competitive advantage and provide practical recommendations for apparel

firms in developing economies. By examining recovery strategies during the 2022 financial crisis, the research offers insights into enhancing supply chain resilience and efficiency, emphasizing collaboration, innovation, and adaptability in a volatile global market.

4 - Decentralised Technologies in Electric Vehicle Battery Closed-Loop Supply Chains: Applications, Trends, and Feasibility Through Advanced Text Mining Techniques
Quang Huy (James) Duong

The rapid transition to electric vehicles has intensified challenges in electric vehicle battery (EVB) closed-loop supply chains (CLSC), especially in material traceability, transparency, and recycling efficiency. Decentralised technologies show promise but remain underexplored in integrated applications across CLSC stages. This study develops a comprehensive framework for understanding and evaluating decentralised technology adoption in EVB CLSCs using a novel methodological approach that combines advanced text mining techniques, including Dynamic Latent Dirichlet Allocation and Burst Detection Analysis. By analysing 588 academic articles and 1,168 industry documents, we map current applications of decentralised technologies across CLSC stages and identify emerging trends. Using the Technology-Organisation-Environment (TOE) framework, we assess feasibility and uncover barriers such as integration complexity, expertise gaps, and regulatory uncertainty. While blockchain and digital twins demonstrate established applications, emerging technologies like Web3 and metaverse applications face adoption challenges. Our study contributes theoretically by developing an integrated framework for evaluating decentralised technology in resource-intensive CLSCs and extends the TOE framework to emerging technology contexts. For practitioners, we provide actionable insights and guidance for implementing technologies across CLSC stages and addressing adoption barriers.

■ MC-43

Monday, 12:30-14:00 - Room: Newlyn GR.07

Digital Philosophy, Academic career models and OR

Stream: OR and Ethics
Invited session
Chair: Leonidas Sakalauskas

1 - Analysis of the Impact of Open Government Data on the Effectiveness of Development Program Implementation
Akhmed Baikhojayev, Mafura Uandykova, Anel Yeleukulova

Open Government Data (OGD) is crucial for transparency and trust in governance. Despite Kazakhstan's high E-Government Development Index (EGDI = 0.9009), OGD potential is not fully used. Our study analyzes factors affecting citizens' trust in digital government services in the context of public development programs. Survey data from Almaty region, analyzed using STATA, reveals low trust in government digital platforms (2.8/10 average) and limited e-service usage (76% use less than monthly). Instead of what was expected, socio-demographic factors showed no significant influence on trust levels ($p > 0.05$). The most significant factors were service quality satisfaction ($r = 0.45$, $p < 0.001$) and accessibility. Comparative analysis with Uzbekistan and Kyrgyzstan indicates similar regional trust issues despite different digitalization rates. We propose an OGD ecosystem enhancement model including: improved data quality, feedback mechanisms, educational campaigns, and developer-friendly environments. This model addresses post-Soviet countries' specific context. Our research contributes to OGD value creation theory, demonstrating that digital platforms alone cannot increase public trust or governance efficiency. We offer practical mechanisms to bridge the gap between digital initiatives and effective governance in Kazakhstan and neighboring countries.

2 - The Hyperbolic Lasso: a regularized regression model with applications to health data
Vinicius Layter Xavier, Claudia Jakelline Barbosa Silva

The Lasso regression method has been widely studied due to its characteristic of selecting a subset of variables, thus avoiding the problem of overfitting. The constraint that defines the Lasso is a non-differentiable optimization problem. We propose a differentiable formulation based on hyperbolic smoothing and the Hyperbolic Penalty method, thus allowing the use of continuous optimization methods. The lasso constraint is defined by the sum of the norm of the coefficients being less than equal to a constant t. Usually, the problem is solved indirectly, for different values of the lambda parameter. The proposed formulation has the characteristic of solving the constraint for specific values of t, thus allowing a better search for the possible values that the constraint can assume. The method's efficiency is illustrated by the use of healthcare datasets.

3 - Enhancing Spam Detection with Large Language Models and Hybrid Learning Approaches
Madina Mansurova, Leonidas Sakalauskas, Assem Shormakova, Mukhammed-Ali Kumisbek

Detecting spam and phishing attacks requires adaptive models that can distinguish between legitimate and deceptive messages. Traditional supervised methods, such as logistic regression, classify known spam patterns with high precision but struggle against novel threats. Unsupervised models, like Isolation Forest, detect anomalies without prior labels but often misclassify legitimate messages. A hybrid approach combining both methods enhances detection accuracy by leveraging pattern recognition from supervised learning and anomaly detection from unsupervised techniques. Large Language Models (LLMs) further improve classification by extracting deep linguistic features that traditional methods overlook. Transformer-based models such as BERT and LLaMA enhance spam filtering by understanding contextual nuances, making them effective against evolving phishing tactics. The hybrid system integrates LLMs with machine learning models, increasing recall while maintaining precision. Evaluation results show that combining logistic regression, Isolation Forest, and LLM embeddings reduces false negatives and improves detection of unseen phishing attempts. While computational costs increase, adaptive thresholding optimizes inference speed. Future improvements include expanding multilingual detection and integrating retrieval-augmented generation for enhanced phishing prevention. The hybrid approach provides a scalable, robust solution for modern spam filtering challenges.

4 - Digital and National Identity as Determinants of Social Harmony: Theoretical Framework for Operational Research
Kuanysh Sailau, Yermek Toktarov

The research provides a theoretical and methodological framework for studying the intersection of digital and national identities and their impact on social harmony in the context of digital transformation. It examines philosophical and political science concepts of identity based on the approaches of Z. Bauman, J. Baudrillard, N. Luhmann, M. McLuhan, and M. Castells, which emphasize the dynamism and multiplicity of modern forms of identity shaped by digital technologies. National identity is explored through B. Anderson's concept of "imagined communities" and its transformations under the processes of digitalization and globalization. Social harmony is analyzed from a political science perspective through the lens of social capital, trust, and collective efficacy (Putnam, 2000). The article also proposes specific approaches to operationalizing the studied categories, facilitating the transition from abstract theoretical concepts to measurable empirical indicators necessary for subsequent application of structural equation modeling (SEM), multi-agent modeling, network analysis, reflexive game theory, and probabilistic models (Sakalauskas, 2022). As such, the study substantiates the significance of the proposed interdisciplinary model for examining the interconnections and mechanisms of influence between digital and national identities on social harmony in the context of digitalization and globalization.

■ MC-44

Monday, 12:30-14:00 - Room: Newlyn 1.01

Multi-criteria energy systems modelling

Stream: Energy Economics & Management
Invited session
Chair: *Jonas Finke*

1 - Exploring near-optimal-solutions of energy system models to increase energy system resilience
Tino Mitzinger

A comparative assessment of the resilience of different future energy concepts is crucial to provide a basis for decision-making and to identify reliable transition paths. To address the question of improving the resilience of energy systems under near cost-optimal conditions, a methodology has been developed. The initially step entailed the optimization of the heat supply for an urban district. The immediate vicinity of the optimal solution was then examined in order to localize near-optimal alternatives. Therefore, the Modeling to Generate Alternative (MGA) optimization approach was used. These near-optimal solutions were then analysed in terms of diversity, redundancy and buffer capacity in order to identify more resilient system configurations. The methodology was applied to a linear optimization model based on the Open Energy Modelling Framework (oemof). The analysis of the heat supply scenarios has shown that resilience, measured by the indicators used, could be increased at a low additional cost (diversity by 37%, redundancy by 6%, and buffer capacity by 160%). In conclusion, this research employs a methodology that provides a comprehensive framework for optimizing future energy systems based on multiple criteria. The integration of resilience considerations in the decision-making process ensures that energy systems become not only cost-efficient but also reliable in the face of unpredictable challenges.

2 - A Modified Simplex Algorithm to Efficiently Explore Near-Optimal Spaces
Christoph Funke, Linda Brodnicke, Francesco Lombardi, Giovanni Sansavini

Modeling to generate alternatives (MGA) is an increasingly popular method in energy system optimization. MGA explores the near-optimal space, namely, system alternatives whose costs are within a certain fraction of the globally optimal cost. Widespread MGA adoption is hampered by its additional computational burden. Current MGA methods identify boundary points of the near-optimal space through repeated, independent optimization problems. Hundreds of model runs are usually required, and such individual runs are often inefficient because they repeat calculations or retrace previous trajectories. In this study, we transcend such limitations by introducing a novel algorithm called Funplex, which uses methods from multi-objective Simplex to optimize many MGA objectives with minimal computational redundancy. For a simple linear-programming energy hub case study, we show that the proposed algorithm is five times faster than existing methods and yields higher-quality near-optimal spaces. Furthermore, sensitivity analyses suggest that the algorithm scales well with the number of investment variables, making it promising for capacity planning models. Future developments based on advanced versions of Simplex may overcome computational barriers and make MGA accessible and standard among energy modeling teams.

3 - Mitigating Technology Raw Material Supply Risks in Energy System Planning: A Multi-Objective Approach
Suzanne Le Bihan, Karl-Kiên Cao, Tobias Naegler, Schlosser Steffen Johannes, Aileen Homey

The development of resilient future energy systems requires consideration of various factors. One key aspect is the current and future availability of raw materials for the energy production and storage technologies. To address this, we introduce an approach that integrates the minimization of raw material supply criticality into an energy system optimization model, alongside traditional cost minimization. Thus, we consider three key dimensions: system cost, geopolitical criticality, and market-based criticality. A multi-objective optimization framework is used to observe trade-offs between our 3-dimensions of interest. We examine the technology mix in a continental Europe energy system network over a transformation pathway until 2050. However, this ambitious scope combined with the solving difficulty introduced by the multi-objective framework poses significant computational challenges. We delve into these challenges, providing a deeper understanding of the solver numerical issues and their impact on the computation of Pareto-optimal solutions. Our preliminary results reveal that prioritizing supply criticality over cost leads to a shift in the capacity expansion of renewable power generators and storage technologies, highlighting the importance of considering raw material supply risks in energy system planning.

4 - Modelling to generate near-Pareto-optimal alternatives (MGPA) - A novel multi-criteria optimisation approach for energy planning
Jonas Finke, Valentin Bertsch

Energy system models (ESMs) have been used for decades in research and industry to support decision-making for the energy transition. These models mostly minimise overall costs subject to rather technical constraints. The energy transition, however, involves a large number of decision-makers and stakeholders with multiple, conflicting interests beyond this techno-economic sphere. Modelling to generate alternatives (MGA) and multi-objective optimisation (MOO) are two approaches used to address multiple such interests in ESMs. First, we review both approaches and synthesise their strengths and limitations to find that they are complementary. Then, we develop modelling to generate near-Pareto-optimal alternatives (MGPA) as a new approach that combines the paradigms and strengths of MGA and MOO. Finally, we demonstrate the advantages of the novel MGPA approach for supporting the energy transition in two German municipalities.

■ MC-46

Monday, 12:30-14:00 - Room: Newlyn 1.07

Energy systems decarbonisation studies

Stream: Energy Economics & Management
Invited session
Chair: *Jens Schmugge*

1 - A study on Ireland's energy system decarbonization for 2050.
Anibal Baradei, Matteo Pozzi, Aldo Bischi, Paul Deane

Ireland's energy system will face a considerable challenge in its decarbonization pathway. Currently, the country strongly relies on fossil fuels for transport as well as electric energy generation and residential use, with natural gas imported mainly via interconnectors with the UK. This situation raises both a considerable decarbonization and energy security problem: the loss of these pipelines could cause massive energy shortages and impacts on all sectors. This unique situation reinforces the need to shift the overall system to achieve more sustainability, cost-effectiveness and energy security, by integrating more renewable energy sources, storage solutions, enhanced grid flexibility and demand-side management.

This paper uses a MILP optimization model to study the path to a carbon neutral system for Ireland. It has coupled electric and heating sectors, generation and network expansion models, a linear network model with multiple state-of-the-art electric equipment models, multiple storage and generation technologies, district heating and geographical spatial constraints. The instance consists of a yearly problem with hourly time steps. The objective function is the minimization of the overall system cost, and it includes investment, maintenance, fuel prices, etc.[U+202F] Multiple scenarios are considered with various

analyses to tackle uncertainty considering fuel availability, natural resources, different technologies, regulations, load profiles and time evolution.

2 - Assessing the feasibility and resilience of a 100% Renewable Electricity System in Colombia
Monica Castaneda

Colombia's electricity system is highly dependent on hydropower. By 2024, about 64% was produced from hydroelectric power plants and approximately a 29% came from fossil fuel power plants. This reliance makes Colombia vulnerable to severe droughts caused by the El Niño Southern Oscillation phenomenon. During El niño events, low levels of water in hydropower dams lead to use gas and coal power plants to compensate the energy shortage.

This paper presents different technical solutions for achieving a 100% renewable energy electricity system in Colombia, by utilizing the H2RES model to represent the hourly energy balance of wind, solar, and hydro resources. The study also considers the future decommissioning of fossil fuel plants, the role of the reliability charge to ensure the security of supply, and the development of future transmission lines. To reach this objective, a multizonal H2RES model was built clustering power plants into 5 regions: Caribe, East, Southwest, Antioquia, and Northeast. Special attention has been given to intermittent sources such as wind, solar, and hydro; particularly, hydro that have high interannual variability and whose integration shape the power system's supply. To address the Colombian case, various alternative solutions were tested: energy storage in batteries and green hydrogen, energy efficiency measures, and distributed renewable generation.

3 - Myopic pathway optimisation of an unprecedentedly large multi-sector European energy system model towards climate neutrality
Jens Schmugge, Hans Christian Gils, Hedda Gardian

As of 2025, there is a wide consensus in research that future energy systems need to be interconnected on a large scale, decentralised, and integrated across multiple sectors to reach climate neutrality. A persisting challenge of research is to find optimal pathways towards such systems. There are lots of studies that cover parts of these characteristics, yet studies that cover all of them are rare for a multitude of reasons. Therefore, we are presenting a case study of a large-scale energy system optimisation model for the European continent that comprises more than 100 technologies and integrates the sectors electricity, gas, heat and transport. Starting from today's state we calculate myopic pathways in hourly resolution and a spatial detail of 57 nodes towards climate neutrality in 2050 for ten-year steps and a variety of different scenarios. These differentiate between high and low hydrogen import costs in future worlds dominated by the use of electricity, hydrogen or synthetic fuels. Our results show how large shares of volatile renewable energy sources can be integrated into the energy system. Key insights are that all analysed future decarbonised systems are dominated by electricity from photovoltaics followed by wind turbines. Short-term flexibility is provided by thermal heat storage units and battery-electric vehicles, gas caverns and hydro reservoirs act as seasonal storage. A developing hydrogen network is built up from existing and some newly built pipelines.

4 - Assessing inhabitants' preference towards Energy Community participation: a preference learning approach
Giulio Cavana, Marta Bottero, Cristina Becchio, Alexis Tsoukias, Giovanna Fancello

Energy communities are legal entities that aim to increase the production and self-consumption of renewable energy, with the potential to promote the decarbonisation of the building stock and tackle energy poverty. Despite their benefits, there is a lack of bottom-up initiative and various trade-offs in their formation. This study investigates the preferences of individuals in engaging with Energy communities and the likelihood of alternative configurations to be formed in a case study. To assess this, a questionnaire was distributed asking respondents about their willingness to participate in alternative Energy Communities and to indicate an order of preference among options. A combination of regression analysis, UTA methods and classification algorithms was used to extrapolate characteristic sets of value functions associated with types of respondents defined by vectors of socio-economic attributes. Finally, a synthetic population generator was used to spatialise the results. 144 types of individuals were identified and their decision models were spatialised in maps of potential participation across the city. Furthermore, each type was assigned a set of value functions and the most preferred alternative in each census tract was evaluated. Such results could help policy makers to identify areas of sub-optimal diffusion of Energy communities and identify corrective actions to the current policy framework to support residents' participation in the energy transition.

■ MC-48

Monday, 12:30-14:00 - Room: Parkinson B09

Location and Energy

Stream: Locational Analysis
Invited session
Chair: Hatice Calik

1 - Charging Ahead: Optimal Location of In-Motion Charging Infrastructure to Electrify Urban Roads in the Rectilinear Plane
Thomas Byrne, Yudai Honma

Most experts agree that transportation sector electrification will be vital to tackling climate change. Indeed, if all cars on the road became electric, we could cut almost one-fifth of global emissions. The two widely accepted chief barriers to switching to an electric vehicle (EV) are cost and range anxiety. Recently-developed in-motion charging technologies solve both: by directly and efficiently receiving power while travelling along an 'electric road', battery size and charging time can be saved. This revolutionary technology is being widely heralded as the future of transport. However, it is prohibitively expensive and of little value if not effectively implemented. Urban environments, with lower average speeds and reduced areas compared to motorways, represent an application with lower investment cost and likely higher utilisation. To this end, we design an optimisation model to identify optimal segments of a general urban transport network to electrify, taking into account the continuous distribution of population and the behaviours of the transport infrastructure's users. In order to maximise the number of EV users of the road network, we exploit classic grid-like urban structures and utilise geometric results to quantify the benefit of electrifying select edges, all while incorporating re-routing behaviours seldom approached in previous studies: we adjust routes in order to pass a petrol station, so why should the same not be true for passing over an electric road?

2 - A Novel Bi-Objective Mixed Integer Linear Programming Model for Optimal Location of Dynamic Wireless Power Transfer Systems
Mohammadjavad Eslami, Thomas Byrne, Mahdi Doostmohammadi

The transportation sector is rapidly developing as nations address energy crises and climate change. Hence, it is shifting toward sustainability, with electric vehicles (EVs) offering energy efficiency and zero emissions. However, challenges such as range anxiety, long charging times, and high battery costs hinder widespread adoption. Dynamic wireless power transfer systems (DWPTSs) allow EVs to charge while in motion via an inductive power transfer embedded in roads. This reduces dependence on large batteries and enhances the practicality of EV adoption. Countries like Germany, Japan, the U.S., and South Korea have successfully implemented the DWPTS infrastructure. Despite its benefits, DWPTS deployment is expensive, making optimal charger placement critical to minimizing costs while increasing EV feasibility and usage. Hence, strategic decision-making is essential for effective implementation. Thus, the research develops a bi-objective

mixed-integer linear programming model to optimize DWPTS locations, balancing deployment costs and capturing EV flow while incorporating real-world constraints like environmental limitations and battery-level requirements. Advancing prior research, our model integrates additional realistic constraints, such as deployment limitations and battery-level requirements, ensuring practical feasibility. Finally, numerical experiments on a Scottish road network validate the model's effectiveness in supporting real-world transportation planning.

3 - Exploiting p-center methods for solving power system restoration problems
Hatice Calik, Dirk Van Hertem, Hande Yaman

Efficient and effective power system restoration is crucial in case of partial or complete blackouts. The power network has to be energized sequentially beginning with the black-start (BS) generators which are capable of restarting themselves. The BS generators then energize the remaining generators and critical loads such as hospitals, traffic lights etc. which all require a certain amount of power to be started. The non-BS generators can only generate power after a certain period of cranking and with a certain increase rate before reaching their maximum generation capacity. When the goal is to start the entire network as quickly as possible, finding the optimal start-up sequence leads to an NP-Hard optimization problem. We investigate multiple variants of this minimax optimization problem and develop integer programming methods inspired by the well-established p-center formulations and algorithms. The novel solution methods provide considerable improvements in terms of computational efficiency which is highly crucial and valuable in obtaining solutions for emergency situations such as blackouts.

■ MC-49

Monday, 12:30-14:00 - Room: Parkinson B10

Analytics and the link with stochastic dynamics 1

Stream: Analytics
Invited session
Chair: Gerhard-Wilhelm Weber
Chair: *Anna Nagurney*
Chair: *Sadiye Eylul Sadanoglu*
Chair: *Yong-Hong Kuo*

1 - A data-driven make-to-order system under operational uncertainty
Shu-Jung Sunny Yang, Yingying Huang

Manufacturing sectors with make-to-order systems often need long production planning horizons for product delivery. Despite the predetermined demand planning, there remains an inherent challenge in striking a balance when ordering raw materials due to the operational costs tied to procurement, alongside the risks of over-ordering and under-ordering, especially when these costs are not apparent during the decision-making phase for production and inventory. Traditionally, the "Predict-then-Optimise" (PO) approach has attempted to mitigate these issues by separating the tasks of prediction and optimisation. However, this methodology tends to falter, especially with scarce or volatile historical data. This study employs the emerging "Smart Predict-then-Optimise" (SPO) framework, which harnesses limited data to derive optimal decisions to develop a data-driven optimisation model that integrates machine learning and mixed-integer linear programming. A proximal SPO (PSPO) loss function is proposed to improve convergence and performance. We perform numerical experiments on both real-world and synthetic data to empirically verify the success of our data-driven optimisation model in comparison to the standard PO and SPO approaches. We show that the SPO-based solutions tend to diversify the production schedule to mitigate the inherent risks of cost fluctuations, while the PO-based solutions tend to produce more in the periods with predicted low operational costs.

2 - Establishing a Modern Approach to Property Valuation in the Public Sector
Andy Grayson

The Valuation Office Agency (VOA) plays a pivotal role in determining property values for Council Tax Bands, generating billions of pounds for local authorities. In response to Welsh Government's decision to reband Council Tax for the first time in two decades, a multi-disciplinary team of operational researchers and statisticians joined forces with expert valuers to create a cutting-edge valuation modelling function. This initiative saw the introduction of predictive models, known as Automated Valuation Models (AVM), in a model-assisted approach to accurately estimate current house prices and re-band properties. External experts have validated our approach, praising its novel structure and reliability.

This presentation will explore: The series of models that comprise the AVM, including the groundbreaking Gaussian Markov Random Field approach for assessing the impact of location.

Our development of a comprehensive suite of tools and processes that empower valuers to validate and adjust these valuations.

The challenges faced and lessons learned from a comprehensive dry run, along with our plans for future enhancements.

Through collaboration of interdisciplinary expertise, our team has successfully integrated these advanced models into the valuation process, providing a robust framework for property assessment. Looking ahead, we are committed to continuous improvement and innovation, to refine and improve our models further.

3 - Reinforcement learning with delayed rewards for optimizing the parking permit prices
Daiki Min, Jihee Seo

This study proposes a reinforcement learning model to address the dynamic pricing problem in O2O (Online to Offline) parking platforms. To manage uncertainty from the time gap between permit purchases and actual usage, we design a dynamic pricing model that incorporate lead time considerations. The proposed model leverages DQN with a backtracking mechanism, which redistributes delayed rewards to earlier decision points, allowing the model to adjust for penalties caused by overbooking and capacity constraints. Parking demand is modeled using probabilistic distributions, incorporating time variations and cross-elasticity between parking permits. Numerical tests show that the proposed reinforcement learning model outperforms conventional approaches by optimizing the reward function while reducing vehicle rejections. Comparisons with baseline strategies reveal that our approach optimally balances revenue and operational stability.

4 - Aging Welfare Policies in the UK and South Korea: Diverging Paths of Individual Responsibility and State Intervention
Jisu Kang, Kangbae Lee, Minho Ryu, Sungho Park, Ham Seunghoon, Jeeseung Han, Hyeonji Hwang, Siyeon Lee

This study compares welfare policy changes in response to population aging in the UK and South Korea. Despite similar demographic challenges, these countries have pursued contrasting approaches shaped by their distinct socio-cultural contexts. The UK shifted from post-war welfare expansion toward neoliberal reforms emphasizing individual responsibility and market solutions. South Korea transitioned from family-centered care to state-led welfare expansion, notably through long-term care insurance introduction. The UK's reforms prioritized cost reduction and efficiency through healthcare and pension privatization, achieving fiscal objectives but creating increased social inequalities and individual welfare burdens. South Korea's approach institutionalized state responsibility through social insurance expansion, responding to rapid family structure changes. However, significant family financial burdens and regional service disparities remain challenging. These contrasting trajectories offer valuable insights for other welfare states. The UK case demonstrates both benefits and limitations of market-centered approaches, while South Korea illustrates possibilities and sustainability concerns of state welfare expansion. The comparison reveals that effective aging policy requires balancing individual

responsibility with collective support, suggesting the need for continuous institutional adaptation and social consensus-building in addressing demographic transitions.

■ MC-50

Monday, 12:30-14:00 - Room: Parkinson B11

Splitting algorithms

Stream: Variational analysis, equilibria and nonsmooth optimization
Invited session
Chair: Adrian Lewis

1 - Regularized splitting method for three operators inclusion problems of "two maximal monotone + one cocoercive" and its applications
Xingju Cai

This paper considers finding a zero point of A + B + C, where A and C are maximal monotone and B is ξ-cocoercive. The three-operator splitting method, proposed by Davis and Yin, is a popular algorithm for solving this problem. Observing that the x-sequence and the y-sequence in Davis-Yin method have the same accumulation point and B's information is only utilized in the second subproblem, this work proposes a new splitting method named the regularized splitting method (RSM), where "x = y" is introduced as a penalty term and the forward step is also employed in the first subproblem. The penalty term can balance the differences between the two subproblems and the additional forward step enables utilizing B's information in both subproblems simultaneously. We establish the convergence of the proposed method and demonstrate its sublinear convergence rate concerning the fixed-point residuals, assuming mild conditions in an infinite dimensional Hilbert space. This approach not only generalizes the Douglas-Rachford splitting method and Davis-Yin method, but also, to our knowledge, uniquely correlates with the symmetric alternating direction method of multipliers-a correspondence that is absent in current maximal monotone operator splitting algorithms. We also give some application of this method.

2 - Forward-backward algorithms devised by graphs
Rubén Campoy, Francisco Javier Aragón Artacho, César López Pastor

In this talk, we present a methodology for devising forward-backward algorithms for minimizing the sum of a finite number of convex functions. We extend recent techniques to cover the case involving a finite number of smooth functions, which should be directly evaluated through the gradient instead of computing their proximal mapping. The algorithms are induced by three graphs that determine how the algorithm variables interact with each other and how they are combined to compute the iteration. The hypotheses on these graphs ensure that the algorithms obtained have minimal lifting and are frugal, meaning that the ambient space of the underlying fixed point operator has minimal dimension and that each proximal mapping and each gradient are evaluated only once per iteration. This framework allows to recover some known methods, as well as generating new ones.

3 - A unifiying graph-based analysis of projection algorithms for linear subspaces
César López Pastor, Francisco Javier Aragón Artacho, Rubén Campoy

This work develops a general analysis for the fixed points of the operators defining the graph splitting methods by Bredies, Chenchene and Naldi. We particularize it to the case of projection algorithms for closed linear subspaces and provide an explicit formula for the limit points of the graph splitting schemes. We exemplify these results on some particular algorithms, unifying in this way some results previously derived as well as obtaining new ones. This is a joint work with Francisco J. Aragón Artacho, Heinz H. Bauschke and Rubén Campoy.

4 - An Approximate Subgradient Based Method to Solve Nonsmooth Optimization Problem Under Data Uncertainty with Application to Portfolio Selection
Priyanka Roy

This study introduces an approximate subgradient-based method to address nonsmooth optimization problems under data uncertainty. Traditional optimization techniques often struggle with nonsmoothness and uncertainty, particularly in real-world applications. Here we consider the nonsmooth objective functions whose coefficients are varying within a closed interval under data uncertainty. The proposed method integrates advanced concepts from interval analysis and nonsmooth optimization to deliver robust solutions under uncertainty. This method utilizes the generalized Hukuhara subdifferential concept with epsilon approximation to compute an approximate solution within tolerance level that can handle nonsmoothness with interval uncertainty. Based on theoretical analysis, we proposed the approximate gH-subgradient method to solve nonsmooth interval-valued optimization along with detailed convergence analysis and suitable numerical illustration. As an application, we applied the proposed algorithm to portfolio selection models. The approach minimizes interval-valued risk with uncertain returns and covariances. It generates portfolios that stabilize risk across best- and worst-case scenarios, offering pragmatic solutions for financial decision-making under uncertainty. A numerical case study with three assets illustrates the method's efficacy, converging to portfolio weights that stabilize risk within tolerance bounds.

■ MC-53

Monday, 12:30-14:00 - Room: Liberty Moot Court

New Trends in Game Theory II

Stream: Game Theory and Mathematical Economics
Invited session
Chair: Alberto Pinto
Chair: *Markku Kallio*

1 - Optimal strategy against learning algorithms in repeated games and periodicity of the system
Yifen Mu, Xiaoguang Yang

With the widespread adoption of learning algorithms in many intelligent systems, the repeated human-machine games, also referred to as the interaction between the learner and optimizer in the literature, in which the machine is the learning algorithm and the human aims to optimize the averaged utility, arise naturally in various settings. In this work we study the repeated human-machine games where the machine adopts some and popular classical learning algorithm in game theory, Fictitious Play (FP) or Hedge algorithm. Against Fictitious Play algorithm, we construct and prove the optimal strategy of the human for all 2×2 games. The ratio of payoff differences under different machine actions and the same human action turns out to be crucial for the problem. Under the human's optimal strategy, the system will be periodic for rational ratio and be quasi-periodic for irrational ratio. Against Hedge algorithm, the problem becomes more challenging. However, we prove that the periodicity of the dynamical system still holds when the human takes the myopic best response or globally optimal strategy for rational zero-sum games. Additionally, Nash equilibrium strategy emerges in the human's periodic action sequence. Issues of extension to general games, robustness of the optimal strategy and the identification of learning algorithm will also be discussed.

2 - Stochastic Games for Energy Management in the Smart Grid with Renewable Energy
Siying Huang, Yifen Mu

In this work, we formulate the real-time pricing (RTP) problem in the smart grid with renewable energy as a multi-stage Stackelberg game between an aggregator and multiple end-users. The aggregator, as the leader, sets the pricing mechanism, while end-users, as followers, determine their electricity purchasing, consumption, and storage strategies at each stage. Different from existing work, we take the prediction errors of renewable energy output into account and model them as a stochastic process. Due to the coupling between the pricing mechanism and the uncertainty of renewable energy, end-users naturally engage in a finite-horizon stochastic game and aim to achieve a Markovian Equilibrium (ME), which is a necessary step in solving the optimal pricing problem but also poses the core challenge of the problem. To address privacy concerns in energy storage, we introduce the concept of Private Markovian Strategy (PMS), where users make decisions based only on public information and the private storage information. We then prove the existence of Private Markovian Equilibrium (PME), which is a natural alternative to ME. Next, by extending the idea of fictitious play into stochastic games, we design a distributed algorithm, MDP-FP, and establish its convergence to PME under certain conditions. We validate our method through simulations and obtain new insights into user behavior. Via our PME-solving approach, algorithms for the optimal pricing of the leader can be easily developed.

3 - Strategic Procurement Contract Design and Selection under Raw Material Price Volatility

Chen Yang, Songsong Liu, Qirui Cheng

Although extensive research has examined the impact of raw material price volatility on order quantities, fewer studies have explored its effect on the types of procurement contracts selected by procurement firms. This study focuses on how a buyer can optimize procurement strategies to manage the risks associated with raw material price volatility by selecting between fixed-price contracts (FP) and spot-price contracts (SP). It is assumed that a buyer chooses one supplier for collaboration from multiple ones under raw material price volatility, then sets sale prices for demand sensitivity. The Black-Scholes model is applied to parameterize raw material price trajectories, enabling analysis of volatility impacts on bilateral equilibrium outcomes across different contract types. The analysis reveals that under a fixed-price contract, suppliers tend to purchase raw materials in advance to avoid the risk of increasing price, which shifts inventory holding costs to the buyer. Conversely, spot-price contracts reduce the incentive for early procurement but share price volatility risk between buyer and supplier. The results demonstrate that spot-price contracts are more flexible in long-term procurement, particularly when procurement timing is optimized, leading to reduced wholesale prices and increased expected profits. Additionally, multi-supplier strategies help mitigate risks and enhance supply chain resilience, especially in volatile price environments.

4 - Dynamic Lindahl equilibrium under uncertainty

Markku Kallio, Iivo Vehviläinen, Hanna Virta

We study the value of a cooperative solution to the global climate externality problem in a world that is uncertain and dynamic. Our analysis incorporates negative emissions technologies that seem critical to resolving the crisis, especially if the climate future proves catastrophic. We generalize earlier theoretical results for Lindahl's equilibrium and integrate with an up-to-date version of Nordhaus's pioneering RICE model to quantify regional economic impacts. Low-income regions end up with the highest relative value of cooperation through three distinct channels: lower damages, equilibrium compensations, and burden sharing of abatement actions.

■ MC-55

Monday, 12:30-14:00 - Room: Liberty 1.09

Network Optimization 3

Stream: Network Optimization
Invited session
Chair: *Pablo A. Miranda*

1 - Dynamic Network Analysis of Legal Citation Networks (esp. medical) in South Korea (1951-2023)

Chloe Kim, Sungwoong Kim

We analyze approximately 86,000 legal cases from South Korea (1951-2023) by constructing (complex) citation networks, modeling each case as a node and citation relationships as edges. Through centrality/hub analysis, we identify key hub cases. We extract and analyze a focused subnetwork comprising medical-related cases. Segmenting the network along presidential cycles reveals that the distribution of medical hub cases changes over time. Cases related to criminal liability in medical accidents were prominent hubs from the late 1990s to early 2000s, whereas subsequent administrations saw civil rulings on patients' rights and institutional responsibilities become new hubs. This analysis illustrates structural reorganization within the network. From an optimization perspective, we apply the minimum dominating set (MDS) approach, supplemented by AI-assisted heuristics, to extract a minimal influential subset within the medical subnetwork. Complexity analysis shows power-law degree distributions with the exponent approximately 2.1, indicating scale-free characteristics. An AI-assisted optimization, balancing sparsification and policy relevance, facilitates a more targeted identification of legally and policy-relevant cases. We suggest quantitative investigations into the structural features and dynamic evolution of legal citation networks in the medical domain. These provide practical implications for legal and policy decision-making in healthcare governance.

2 - On the economic performance of e-grocery delivery: growing profitable or die trying?

Jan K. Strackbein, Moritz Fleischmann

Industry experts and scholars commonly consider grocery home delivery (e-grocery) in developed economies as unprofitable. Nevertheless, both the number of companies offering e-grocery services and the share of online grocery sales continue to grow. In this study, we investigate the interplay between growth and profitability in e-grocery services. To this end, we develop an analytic model that captures the key profit drivers and evaluate it using publicly available real-life data. At the core of our model is the economic structure of the delivery operations. We consider a two-echelon distribution network, reflecting a commonly observed fulfillment strategy, where orders are assembled in a central fulfillment center (FC) and delivered by trucks to transshipment hubs. At these hubs, larger order batches are broken down and delivered to customers using smaller delivery vans. We use continuous approximation to assess delivery distances in such a network and determine the profit of a given FC. We derive analytical results on the level of an individual service area as well as on a system level, considering a growing number of orders and their spatial distribution. In this process, we identify and discuss internal and external constraints that limit the systems' growth potential. Finally, we calibrate the model by conducting numerical experiments based on real-world data to quantitatively assess conditions under which e-grocery services can achieve profitability.

3 - Integrating Warehouse Design Issues into an Inventory-Location Problem for Designing a Supply Chain Network

Pablo A. Miranda, Patricio Hidalgo, Francisco J. Tapia-Ubeda, Carlos Monardes

Designing and operating warehouses or distribution centers significatively affect the actual performance and capacities of supply chains. On the other hand, capacities and costs are major drivers when Supply Chain Networks are designed, denoting the significant connection between designing warehouses and configurating the related Supply Chain Networks. Thus, this research proposes a novel Mixed Integer Nonlinear Programming formulation to simultaneously optimize the Supply Chain Network Design (i.e., warehouse location and customer assignments) and warehouses design, considering a multi period scenario with multiple products. The proposed formulation is based on a widely studied Inventory-Location modelling structure, in which inventory related decision and costs are integrated into a Facility Location formulation. An application of the proposed model denoted significant benefits when both issues are optimized simultaneously, instead of addressing them based on a traditional hierarchical solution strategy.

■ MC-56

Monday, 12:30-14:00 - Room: Liberty 1.11

Methods & Models in Computational Biology

Stream: Computational Biology, Bioinformatics and Medicine
Invited session
Chair: Leonid Chindelevitch

1 - Mixed integer linear formulation for minimum flow decomposition via column generation
Fernando Hugo Dias, Tuomas Porkamaa, Philine Schiewe

Minimum flow decomposition (MFD) is a classic problem in mathematics and combinatorial optimization, which goal is to find the smallest set of paths that completely decompose a flow. Since this problem and its variants are NP-hard, exact solvers for MFD struggle to scale to large instances and cannot be efficiently generalized for practical applications.

In this work, we present an integer linear programming (ILP) formulation for MFD that tackles the challenge of encoding multiple solution paths by using column generation. With this technique, we can optimize which paths are essential towards an optimal decomposition, eliminating many hurdles that compromise the efficiency of previous models.

Our numerical results demonstrate that this approach has the potential to outperform previous state-of-the-art methods (both existing ILP formulation and algorithmic solutions) and can also be quickly and efficiently adapted to various practical variants, such as incorporating subpaths or minimizing flow errors. In comparison, while competing exact methods often struggle to optimally solve large instances, and heuristic methods may return suboptimal solutions, our findings provide a newer and more efficient tool for addressing larger instances and different variants of these problems without compromising performance and optimality.

2 - Evaluation of Minimal Cut Sets in Biological Systems Modeled by Petri Nets
Agnieszka Rybarczyk, Marcin Radom, Piotr Formanowicz

Biological systems are complex networks of interactions that define their structure and function. To understand these systems, Petri nets are widely used, enabling both structural representation and analysis of biological processes. A key approach in this context is identifying minimal cut sets (MCSs), which help determine how disabling specific processes affects system behavior. While algorithms exist for finding MCSs, assessing their quality remains challenging, as some may unintentionally disrupt essential components. To address this, we proposed two evaluation methodologies: (1) analyzing t-invariants to identify structural dependencies and (2) assessing the impact on potentially starved transitions to capture dynamic network behavior. The effectiveness of the proposed methodologies is demonstrated through selected case studies.

3 - ReverseGWAS: a GWAS variant with a novel reformulation of MINLPs as MILPs
Leonid Chindelevitch, Asa Hedman, Dmitri Bichko, Daniel Ziemek

We developed a variant of genome-wide association studies (GWAS) involving multiple phenotypes, where the phenotypic architecture can be described by a logical combination of individual phenotypes, such as a CNF or a DNF formula. Since brute-force enumeration of such logical combinations is impractical, we leverage mixed-integer optimisation, whose objective, however, is generally non-linear; for example, we may wish to optimise Fisher exact p-values.

We successfully reformulate these MINLPs as MILPs in three steps. First, we leverage a binary search to constrain the objective both above and below. Second, we use a fast (but not well-known) Imai-Iri algorithm to express this constraint with a piecewise linear function guaranteed to have the fewest segments possible. Lastly, we test the feasibility of the resulting MILP.

We successfully tested our approach, called ReverseGWAS, on large-scale genomic data (over 300,000 genomic variants in over 300,000 individuals in UK Biobank) to identify promising combination phenotypes, and replicated those in an independent cohort, FinnGen. The approach scales extremely well with both autoimmune traits as well as ICD10 codes being used as phenotypes.

In summary, our approach provides a scalable way to translate MINLPs with non-linear objective function into MILPs. Our method includes the Imai-Iri algorithm implemented both as standalone R code as well as fast C++ code, available via the rgwas package at github.com/Leonardini.

■ MC-57

Monday, 12:30-14:00 - Room: Liberty 1.12

Mathematical Models and UAV Applications

Stream: Transportation
Invited session
Chair: Cláudio Fabiano Motta Toledo
Chair: Alf Kimms

1 - The Truck-Drone Hurdle Relay Problem in Euclidean Space
Christin Münch, Alf Kimms, Fabian Wilschewski

We present a mixed-integer linear program (MILP) for the Truck-Drone Hurdle Relay Problem in Euclidean space, which is particularly relevant in the context of disaster relief. In this problem, a drone is tasked with the delivery of relief supplies in a disaster-stricken area, while being supported by trucks along its way with transportation and battery exchanges. Trucks and drone need to work together, as the partially damaged road network prevents the trucks from reaching the destination, and as the distance from the depot to the destination is far too great for the drone to cover in one flight. We abstain from the common assumption in truck-drone delivery that vehicles operate on a graph and use a geometric approach with drone trajectory planning instead. Furthermore, we consider the following aspects: i) obstacles with which the drone must not collide, ii) continuously formulated roads, so that the drone can be launched and recovered from any position along the roads, iii) a service time for the battery exchange, and iv) a drone energy consumption dependent on velocity. The objective is for the drone to deliver the relief supplies as fast as possible.

2 - A Two Stage eVTOL Location and Demand Optimization for Urban Air Mobility
Gideon Gottschalg, Arne Strauss

In recent years, the number of electrical vertical take-off and landing vehicle (eVTOL) designs and start-ups has significantly increased. Operators promise to reduce both road congestion due to increasing urban traffic and emissions compared to combustion vehicles.

However, operators face several challenges during the piloting and implementation of an eVTOL service. Besides regulatory and safety concerns, one key question is how to implement a profitable operation of a fleet of eVTOLs given uncertain customer adoption. The investment decision reflects the choice of the number and location of vertiports, as well as the number of vehicles.

In this work, we propose a risk-averse two-stage newsvendor optimization model for an eVTOL airport shuttle service as an application of eVTOLs in urban area mobility. In the first stage, a strategic decision on the number of eVTOLs and number and location of vertiports in the urban area and at the airport site must be made under uncertain

demand. In the second stage, the operational phase of the chosen vertiport configuration is optimized. We use an optimal learning framework to evaluate the expected performance of different first-stage decisions. We test our model in a case study with real-world data from a European airport.

3 - Mathematical Models and Solution Approaches for UAV Path Planning
Cláudio Fabiano Motta Toledo

We present some mathematical models that describe and solve path-planning problems for UAVs. The models consider convex and non-convex regions for dealing with obstacle avoidance, stay-in areas, and handling the risk of collisions. Therefore, mixed integer nonlinear programs, mixed integer linear programs, or the combination of linear programming models with other methods can help to solve the path planning problem.

4 - A Data-Driven Bi-Objective Optimization Framework for Vertiport Placement in Urban Air Mobility
Zhirong Zhang, Yong Fang, Qixiu Cheng

Strategic vertiport placement is critical to the successful implementation of Urban Air Mobility (UAM), influencing network efficiency and accessibility. However, existing approaches predominantly rely on demand models with static assumptions, limiting applicability to dynamic urban scenarios. To address this, we propose a data-driven optimization framework that leverages ground transportation data to optimize UAM vertiport placement. The model integrates key constraints, including eVTOL cruise speeds, charging limitations, vertiport capacity, and inter-vertiport distance, ensuring alignment with urban mobility patterns and infrastructure feasibility. Candidate locations are first generated using a weighted k-means clustering approach to capture spatial demand patterns. A bi-objective optimization model then derives Pareto-optimal solutions balancing total cost and service coverage. To enhance adaptability, a dynamic resource allocation mechanism integrates real-time eVTOL fleet states into the optimization loop, enabling adaptive vertiport capacity allocation during peak demand periods. Additionally, a threshold-driven iterative strategy refines candidate configurations based on historical performance, improving solution quality and computational efficiency. A case study in San Francisco validates the model's effectiveness in optimizing vertiport placement, achieving a balance between cost efficiency and service coverage.

■ MC-58

Monday, 12:30-14:00 - Room: Liberty 1.13

Electric Vehicles

Stream: Vehicle Routing and Logistics
Invited session
Chair: Finn Vehlhaber

1 - Optimization of allocation and operation of charging stations to realize middle-mile logistics by electric vehicles
Yuta Tsutsumi, Katsuya Sakai, Hiroshi Morita

While electric Vehicles (EVs) are increasingly being used for last-mile deliveries from distribution centers to customers, their use is limited for middle-mile deliveries between distribution centers due to their shorter cruising range compared to gasoline-powered vehicles. This study develops a large-scale charging station deployment model for the use of EVs for middle-mile delivery. By optimizing the operational cost of EVs and the installation cost of chargers, the trade-off between infrastructure investment and vehicle charging cost will be discussed.

2 - A Hybrid Metaheuristic and Column Generation Approach for Efficient Urban Electric Vehicle Routing
Yutong Qi

With digital transformation and growing environmental awareness, electric vehicles have become a key part of urban mobility, offering great potential for reducing carbon emissions and boosting energy efficiency. However, battery limitations and charging constraints make efficient route planning a major challenge in large-scale operations. To tackle this, we propose a novel approach that combines a hybrid metaheuristic with column generation techniques to optimize electric vehicle routing. Our method uses an adaptive neighborhood adjustment operator to capture dynamic routing changes, replacing conventional fixed local search methods. We also employ column generation to decompose the problem into master and sub-problems, generating only the necessary candidate routes and using dual information for local refinement. Moreover, a dynamic candidate set is maintained by continuously adding new solutions and removing redundancies, which helps ensure diversity and stability. Experiments with real-world data from Chinese cities show that our approach not only improves solution accuracy and stability but also reduces computation time. This makes it an efficient and practical optimization pathway for urban electric vehicle dispatch.

3 - Fleet Emission Reduction Through Optimized Introduction of Electric Aircraft
Finn Vehlhaber, Mauro Salazar

Numerous manufacturers around the world have announced electric aircraft models to be released in the upcoming decade and several commuter airlines have signed letters of intent to buy some of these initially small planes to integrate them into their daily operations. These aircraft will replace conventional commuter planes and reduce fleet emissions, but the typical pace for phasing them in is rather slow. Still, with adapted fleet assignment schemes that take the type of propulsion into account, significant reductions may be obtained, even for small proportions of electric aircraft in the fleet. In our paper we propose an adapted fleet assignment problem that considers availability of charging infrastructure at the served airports, as well as flight characteristics, to optimally assign the share of electric aircraft in the fleet to flights in order to minimize the fleet emissions. The framework includes battery constraints to ensure routes to be feasible, and enables partial recharging depending on local conditions and flight requirements. We apply our framework to the flight schedule of a commuter airline that operates around 250 daily flights and analyze different boundary conditions for existence of charging infrastructure and number of electric planes in the fleet. Results show that already a small share of electric aircraft can make a large difference in fleet emissions and the infrastructure plays a large role in facilitating these savings.

4 - A Matheuristic Method for Heterogeneous Electric Vehicle Routing Problem with Load Dependent Discharging
Ismail Gokay Dogan

Electric vehicles (EVs) are a transformative asset in logistics and transportation, and aid to improve sustainability. Their use requires effective route planning methods that consider range limitations and charging decisions. The Heterogeneous Fleet Electric Vehicle Routing Problem with Load Dependent Discharging (HFEVRP-LD) optimises routing and charging decisions for a fleet of EVs with varying acquisition costs, energy consumption rates, battery capacities, and load capacities. The problem considers time windows, service durations, and a load-dependent energy consumption model. The objective is to minimise the total cost of vehicle acquisition and energy consumption. This study proposes a matheuristic that combines Adaptive Large Neighborhood Search (ALNS) with an exact method to solve HFEVRP-LD. The ALNS explores diverse neighborhoods through multiple destroy-repair mechanisms, and employs an exact approach to repair charging and vehicle selection decisions. Results of computational experiments on benchmark instances demonstrate the effectiveness of the proposed method.

■ MC-59

Monday, 12:30-14:00 - Room: Liberty 1.14

Freight Transportation and Logistics

Stream: Transportation
Invited session
Chair: Javier Durán-Micco

1 - The Dynamic Multi-Objective Driver Dispatching Problem in Full Truck Load Transport
Neslihan Cevik, Albert Schrotenboer, Tom van Woensel

The logistics sector faces driver shortages and has significant pressure for lower emissions, demanding more advanced dispatch strategies that balance driver satisfaction and sustainability in fleet management. We propose a dynamic, multi-objective framework that processes real-time data. At each decision point, newly revealed requests, each with pickup and delivery windows, vehicle requirements, and driver needs are matched with available drivers. Requests are grouped into feasible sequences, distinguishing between urgent and flexible orders. At each decision point, we combine a Markov Decision Process with a Mixed-Integer Programming (MIP) model. The MIP optimizes operational cost, emissions, and driver well-being by pairing drivers to orders, guided by metrics such as distance from home base, time-window adherence, and regulated work-hour limits. Recognizing the complexity of large state and action spaces, we employ a Cost Function Approximation in the MDP to maintain an anticipation of future outcomes. This dynamic assignment avoids shortsighted decisions—such as overloading drivers or creating inefficient subtours—and balances distance, emissions, and driver satisfaction. Preliminary tests show improvements in cost-efficiency, emission reduction, and driver satisfaction, emphasizing the importance of integrating operational, environmental, and human factors in modern logistics.

2 - Trucks Allocation in Logistics Service Providers' Depots within a Synchromodal Transport Network: A Bayesian Optimization Approach
Shafagh Alaei Jordehi, Sasan Amini, Koen Mommens

Effective management of resources is a significant challenge in the logistics and freight transport sector. This gets more challenging within synchromodal transport systems, which are characterized by high levels of uncertainty due to real-time decision-making. A primary goal in these inherently flexible systems is to optimize the allocation of truck fleets across depots to enhance operational efficiency and maximize profitability. In this work, we propose a Bayesian optimization approach to optimize the truck-depot allocation strategy for logistics service providers in a synchromodal network in order to maximize their profit. This approach minimizes the need for extensive simulation runs to identify the optimal solution. Instead, it efficiently explores and exploits the decision space, converging to the best outcome within a limited computational budget. The findings underscore the effectiveness of this approach in improving decision-making within a synchromodal transport network, offering a robust and computationally efficient solution for truck allocation problems. This study advances the literature by tackling the vehicle allocation problem in synchromodal networks and by integrating advanced optimization techniques with the concept of synchromodality. In doing so, it supports the development of more resilient and efficient freight transport systems.

3 - Service network design with uncertainty: A simulation-optimization approach
Javier Durán-Micco, Bilge Atasoy

In this study, we address the Service Network Design (SND) problem from the perspective of a logistics service provider operating within a multimodal network. The goal is to solve this tactical problem while incorporating information and feedback from the operational level. To achieve this, in addition to the typical capacity planning decisions in SND, we also account for uncertain travel times, routing decisions for a fleet of trucks, and dynamic reaction and re-planning to face disruptions. As such, we propose an approach that explores the interactions between tactical and operational decisions. Specifically, we present a simulation-optimization approach capable of handling all these factors. We employ a simulated annealing algorithm to optimize capacity planning, while an agent-based simulation model is used to estimate costs by capturing uncertainties and dynamic decision making. Since simulations are time-consuming, we introduce a surrogate function, trained on simulation data, to estimate costs efficiently. An adaptive learning technique further refines predictions during optimization, also using the simulation model. The method is tested using benchmark instances from the literature. Preliminary results indicate that our adaptive methods achieve strong performance while significantly reducing computational time. Future work will focus on refining models to better reflect real-world conditions and incorporating dynamic interactions between logistics actors.

4 - Online Container Allocation and Dynamic Rebalancing with Deep Reinforcement Learning
Emre Kara, Layla Martin, Mehrdad Mohammadi, Willem van Jaarsveld

Containerized transportation plays a vital role in global trade, and a substantial part of its cost comes from empty container movements. As global trade is imbalanced, regional container shortages and surpluses occur and logistics service providers (LSPs) inevitably reposition empty containers to avoid losing sales. Therefore, efficient container fleet management is needed to balance out this waste and service quality. Container fleet management typically focuses on repositionings between stocks. However, efficient container allocations from right stocks to the right orders solve, or at least alleviate the problem proactively. Additionally, LSPs operate diverse fleets to accommodate varying order requirements. Consequently, a container qualifies for various order types, while an order accommodates different types of container. Hence, allocating the right type of container to the right order is another challenge of the problem. Lastly, customer orders are revealed over time shortly before they must be fulfilled, which makes the problem online optimization. In this study, we model the container allocation problem as an MDP and solve it with DRL. We test the PPO algorithm with simulation experiments based on an industrial partner's use case and benchmark its performance against their heuristic policy. Through this research, we aim to demonstrate the efficiency of DRL algorithms in optimizing container allocation decisions in terms of operational costs and service levels.

■ MC-61

Monday, 12:30-14:00 - Room: Maurice Keyworth G.31

Advances in behavioral decision analysis 2

Stream: Behavioural OR
Invited session
Chair: Gilberto Montibeller

1 - Anchoring bias in the tradeoff procedure within Multi-Attribute Value Theory
Geqie Sun, Maarten Kroesen, Jafar Rezaei

Eliciting the weights of attributes is one of the key steps in multi-attribute decision-making methods. The weights represent the relative importance, contribution, or influence of the attributes in forming a decision. There exist various weight elicitation methods, each with different assumptions and procedures, though most fail to account for the effect of cognitive bias in their procedures. This study examines anchoring bias, a well-known cognitive bias, in the weight elicitation step (the Tradeoff procedure) of multi-attribute value theory (MAVT). We developed three hypotheses: (i) Using the most important (best) attribute to construct the indifference pairs in the Tradeoff procedure leads to higher weights for the best and worst attributes

and lower weights for the other attributes, (ii) Using the least important (worst) attribute to construct the indifference pairs in the Tradeoff procedure leads to lower weights for the best and worst attributes and higher weights for the other attributes, (iii) Using both best and worst attributes to construct the indifference pairs (i.e., the Best-Worst Tradeoff (BWT) method), mitigates anchoring bias. To test the hypotheses, we conducted an experiment by designing a questionnaire based on the MAVT methodology and collected data from 336 participants for a decision problem. The findings indicate that anchoring bias has a significant impact on the Tradeoff procedure, and that the BWT is effective in reducing this bias.

2 - Multi-criteria decision-making for others: How anchoring effects change based on who guides the interaction
Maura Halstead, Manuel López-Ibáñez, George Farmer, Paul Warren

A person can use their own or someone else's preferences to make multi-criteria decisions. Consider interactive Goal Programming (IGP), where the person uses a goal to find solutions. They are expected to continuously change this goal based on the solutions found until they find their most preferred solution (MPS). A person could use IGP with their own or a client's goals. Despite this common occurrence, we currently do not know how the preference source would influence such decision-making processes.

IGP begins with an initial goal and solution that the person should review to make subsequent decisions. This process resembles anchoring from the psychology of judgment of decision-making, where an initial number can influence the person's next decision even if they are unrelated. In previous behavioral experiments, we have found robust evidence that anchoring occurs in IGP. This research focuses on preference sources and how they could alter anchoring behavior. In a behavioral experiment with 128 participants, we found evidence of IGP anchoring when participants used their own or client preferences. Furthermore, against expectations, we found that participants anchored more when they used their client's preferences. These findings suggest that preference source is an important consideration when designing and implementing methods.

3 - Use of heuristics in pairwise multicriteria choice tasks: An experimental study
Jyrki Wallenius, Eeva Vilkkumaa, Matias Kivikangas, Pekka Malo, Kalyanmoy Deb, Konstantinos Katsikopoulos

There is evidence that people use heuristics in decision-making that are somewhere between non-compensatory (such as Take The Best = TTB) and compensatory (such as tallying). Examples of such heuristics include the Take-Two heuristic, in which decisions are made based on two most salient pieces of information; and a threshold heuristic, in which information is gathered until the evidence supporting a given alternative exceeds some threshold.

Against this background, we study the following research questions:

1. What is the "fit" of different heuristics and their variations to available data? 2. How do these heuristics depend on the number of criteria? 3. How do these heuristics depend on the time spent on the task (i.e., learning)?

To address these questions, we use data from an experiment in which 48 subjects made altogether 5,670 pairwise choices between multicriteria decision alternatives (product bundles) so that the number of criteria ranged between 2-10. In addition to the subjects' choices, we have gathered process data through questionnaires and eye-tracking measures. We use these data to study whether the outcomes as well as the process data align with TTB, tallying, Take-Two, and threshold heuristics. We also study, whether this alignment depends on the number of criteria and the time spent on the task. We propose novel ways of operationalizing Take-Two and threshold heuristics in the context of multicriteria decision making.

4 - Time preferences in repetitive choices
Pelin Gulum Tas, Yousef Maknoon, Gilberto Montibeller, Jafar Rezaei

Research on time preference often relies on behavioral experiments where participants make single-time intertemporal choices (a present versus a future outcome), from which their discount rates are calculated and interpreted. Real-world decisions unfold dynamically, shaped by repeated choices and long-term considerations, requiring decision-makers to broaden their perspective. To capture this dynamic nature, we designed an experiment with two types of scenarios: one framed as a single-time choice, as commonly studied in the literature, and the other as a repetitive choice with the aim of promoting holistic thinking. In total, 277 participants were randomly assigned to either a gain or loss version of these scenarios, completing four conditions that varied by decision type (single-time versus repetitive) and outcome magnitude (small versus big). Results indicate that extending the evaluation environment and motivating individuals to consider the decision repetition lead to choices favoring long-term benefits over immediate outcomes. Participants exhibited lower discount rates in repetitive scenarios than in single-time ones, suggesting that discounting behavior is, at least, partially influenced by the setting in which participants are asked to perform intertemporal trade-offs. These findings have important implications for facilitators when helping individuals make informed choices by reducing present bias and for researchers investigating factors that shape time preferences.

Monday, 14:30-16:00

■ MD-01

Monday, 14:30-16:00 - Room: Great Hall

Álvaro Cartea

Stream: Keynotes
Keynote session
Chair: Rita D'Ecclesia

1 - Unintended Consequences of Artificial Intelligence in Financial Markets
Álvaro Cartea

Abstract: How can artificial intelligence and learning algorithms affect the integrity of market? We discuss three lines of research:

1. Spoofing and quote-based manipulation. Market making learning algorithms will find optimal strategies that manipulate the limit order book. Manipulation occurs to induce mean reversion in inventory to an optimal level and to execute round-trip trades with limit orders at a higher probability than was otherwise likely to occur; spoofing is a special case when the market maker prefers that manipulative limit orders are not filled.

2. Market making. We show that algorithms can tacitly collude to extract rents and we show that that tick size (coarseness of price grid) in the limit order book matters: a large tick size obstructs competition, while a smaller tick size lowers trading costs for liquidity takers, but slows the speed of convergence to an equilibrium.

3. Breaking anonymity in a limit order book. Empirically, we find that liquidity providers use excessively large limit orders to break the anonymity of limit orders by signaling themselves to other liquidity providers. Importantly, we find that liquidity providers respond differently to signaled limit orders. Specifically, they avoid trading with each other and focus on picking-off soft flow from retail limit orders. We use a model of the limit order book to show that signaling occurs in a collusive equilibrium. In equilibrium, signaling occurs so that colluding firms can identity each other in an anonymous book to avoid sniping each other. This allows colluding firms to share profitable flow from retail limit orders.

■ MD-03

Monday, 14:30-16:00 - Room: Esther Simpson 1.01

EPOCG

Stream: EURO Prize for OR for the Common Good
Award Competition session
Chair: Claudia D'Ambrosio

1 - Optimising the Biorefinery Supply Chain: A GIS-Based Multi-Objective Approach for Sustainable Bioenergy Production
Maryam Roudneshin, *Amanda Sosa*

The global push towards renewable energy sources is crucial for combating climate change and ensuring energy security. This research presents an innovative supply chain model that enables the efficient and sustainable utilization of agricultural waste for bioenergy production. This contributes to a circular economy by reducing waste, minimizing carbon emissions, and promoting energy independence. The methodology has been tested using real-world data from Ireland and can be adapted to other regions facing similar challenges in agricultural waste management and bioenergy planning. This study integrates multi-objective optimization, Geographic Information Systems (GIS), and economic modeling to develop a robust decision-support system for policymakers, farmers, and energy producers. By combining spatial data analysis with advanced mathematical modeling, an approach have been designed that balances economic viability, environmental sustainability, and logistical feasibility.

2 - Driving Sustainability: How Operations Research Supports Zero-Emission Bus Fleet Decisions
Sophie Parragh, *Elisabeth Gaar*, *Xenia Haslinger*

The "avoid - shift - improve" framework and the European Clean Vehicles Directive set the path for improving the efficiency and ultimately decarbonizing the transport sector. While electric buses have already been adopted in several cities, regional bus lines pose additional challenges due to the potentially longer distances they have to travel. In this work, we modeled and solved the multi-depot electric vehicle scheduling problem (MDEVSP), lexicographically minimizing the size of the bus fleet, the number of charging stops, and the total energy consumed, while maintaining a given timetable. We developed a graph representation, which allows partial charging without explicitly relying on time variables and derive 3-index and 2-index mixed-integer linear programming formulations for the MDEVSP. While the 3-index model can be solved by an off-the-shelf solver directly, the 2-index model relies on an exponential number of constraints, separated in a cutting plane fashion. Our research has been carried out within the collaborative research project "Zero Emission Mobility Salzburg (ZEMoS)" and provided decision support for the local public transport authority in the tendering of line-based contracts with zero-emission vehicles in two pilot regions in the country of Salzburg. The main decisions concerned the type of zero-emission technology and the size of the bus fleet. The first battery electric buses are now already in operation. Our results were also used as input to total cost of ownership computations by one of our project partners, and they serve as the basis for solution approaches for the multiple line, heterogeneous fleet MDEVSP to evaluate bus concepts for entire pilot regions.

■ MD-04

Monday, 14:30-16:00 - Room: Rupert Beckett LT

EJOR: policy, facts and highlights in stream OR Journals

Stream: OR Journals
Invited session
Chair: Roman Slowinski

1 - Bias and Fairness in Credit Scoring: Challenges, Trade-offs, and Business Impact
Stefan Lessmann

Algorithmic decision-making is reshaping credit risk assessment. Machine learning (ML)-based scorecards promise unprecedented predictive power but raise critical concerns about fairness, reliability, and bias. This talk synthesizes insights from recent credit scoring research. We examine how biases—ranging from algorithmic discrimination to selection bias—can undermine the effectiveness of ML-driven credit scoring systems and explore strategies to mitigate these risks.

First, we examine fair lending, assessing the adequacy of statistical fairness criteria and evaluating algorithmic options for incorporating fairness goals in scorecard development. We demonstrate that while fairness and profitability often seem at odds, multiple fairness criteria can be satisfied simultaneously without significant decreases in predictive accuracy and cost. However, we also show how established practices in algorithmic fairness research may severely underestimate the true degree of discrimination.

Second, we address the sampling bias problem arising from using labeled data from previously accepted clients. By introducing bias-aware training and evaluation techniques, we show how ML models can mitigate the adverse effects of selection bias, improving both predictive

accuracy and profitability. Our empirical findings highlight that addressing bias at the scorecard evaluation stage holds greater potential than training-time adjustments, which prevail in the literature.

Through these discussions, we emphasize that the effectiveness of ML-based risk prediction systems hinges on a comprehensive understanding of the decision problem and its operational context. Biases from algorithmic discrimination, sampling issues, or unintended model behavior can undermine system effectiveness and must be addressed with targeted interventions. Mitigating bias requires balancing fairness, predictive performance, and business impact. Researchers and system developers must go beyond predictive accuracy and holistically assess ML-based credit scoring models, ensuring alignment with institutional goals, regulatory expectations, and ethical standards.

2 - Consensus reaching process in large-scale group decision making based on bounded confidence and social network
Yanhong Li

Group decision making (GDM) consists of a group of experts to make the satisfactory decision, it plays a vital impact on people's activities. In GDM, Different experts often express different opinions, and if they fail to reach a consensus, it often leads to decision failure and affects the results of the decision. Consensus reaching process (CRP) is a dynamic and interactive method used to reach a group decision. Now that social networks and mobile internet are prominent features in daily life, more experts are able to take participate in decision making in the network and their opinions are influenced by others in the decision-making process. Therefore, how to use the difference of opinions and the relationships between experts to promote the consensus is an important issue. When the number of experts participating in the decision-making process is over 20, it involves large-scale group decision-making (LSGDM). In these cases, there are the following issues: (1) Existing studies may ignore experts' unique knowledge background, interests and social relations. As a key factor in information aggregation, it is more reasonable to use experts' social network relations to determine the weight. (2) When experts do not reach a consensus, previous studies usually assume that the suggestions generated by the feedback mechanism will always be accepted by experts. However, providing feedback does not mean that experts will fully accept different suggestions. If the suggestions generated by the feedback mechanism are far from the experts' opinions, the experts will tend to reject the suggestions rather than adjust the opinions. In addition, the known group consensus model ignores the trust relationship between experts, so it can not directly guide the group decision-making behavior under the social network. (3) How to make full use of the trust relationship and opinion similarity of experts to improve the decision-making efficiency in LSGDM. Motivated by the challenge to overcome the above limitations, we assume that the experts tent to accept advice from others they trust and the experts tend to accept advice if the distances between these opinions and their own opinions are less than or equal to a certain confidence value. Therefore, we proposed a CRP approach in LSGDM based on bounded confidence and social network. The approach studied group consensus from social network relationships and differences in opinions and builds the feedback mechanism to help experts reach a consensus. The main contributions and novelties were obtained as follows: (1) A fast unfolding algorithm based on the social relationships between experts is applied to divide the large-scale into the small sub-clusters, which can improve decision efficiency; (2) An algorithm for social network analysis is proposed to determine the weights of experts; (3) A new feedback mechanism based on bounded confidence and social network is designed to promote experts reach a consensus. Compared to the existing methods, the approach directly considers the social relationships between experts and bounded confidence. Thus, it avoids to consider the factors that affect the decision-making results only from social networks or bounded confidence. We also compare our results with different methods using qualitative and quantitative analyses. The simulation analyses are used to show the efficiency of the proposed consensus reaching model approach, the results show that when the social network relationship of experts is static, the degree of experts adhering to their own opinions and bounded confidence in others' opinions will affect the decision-making results.

3 - Policy and facts about the European Journal of Operational Research (EJOR)
Roman Slowinski, Emanuele Borgonovo, José Fernando Oliveira, Steffen Rebennack, Ruud Teunter, Mike Yearworth

The session starts with two presentations done by authors of representative and highly cited papers published recently in EJOR. They represent two categories: Innovative Application of OR, and Theory & Methodology. Some further research developments and practical implications that followed these publications will be given by their authors. Then, the editors of EJOR will explain their editorial policy and will give some current characteristics of the journal. They will also describe their approach to evaluation and selection of articles and will point out topics of OR that recently raised the highest interest. In the last part of the session, the editors will answer some general questions from the audience.

■ MD-07

Monday, 14:30-16:00 - Room: Clarendon GR.01

Extensions of the Resource-Constrained Project Scheduling Problem

Stream: Scheduling and Project Management
Invited session
Chair: *Zdenek Hanzalek*
Chair: *Antonin Novak*
Chair: *Vilem Heinz*

1 - Bicriteria Resource-Constrained Project Scheduling to Minimize Makespan and Total Energy Cost
Antonin Novak, Jan Mandik, Zdenek Hanzalek

As a reaction to rising energy demand, energy utility companies in industrialized countries have begun implementing a so-called Time-of-Use (TOU) energy pricing. TOU pricing helps balance daily energy consumption by introducing variable energy prices, e.g., for every hour, which creates an opportunity for cost savings by shifting the primary energy consumption to off-peak intervals.

The presented work focuses on extending the Resource-Constrained Project Scheduling Problem (RCPSP) from an energy-awareness perspective. We assume a model of production in which a single manufacturing step represents an energy-intense operation (e.g., steel hardening in a furnace). Further, we assume that the energy-intense resource can operate in several states, corresponding, for example, to processing or standby modes. The resource can transition between its states, respecting the time dynamics and energy consumption for transitions and staying in these states. Thus, the switching between the states of the energy-intense resource is part of the optimization problem.

The objective of the problem is to minimize the total energy costs considering both the TOU pricing and power-saving states of the resource. We treat the problem as a bicriteria scheduling problem with parameter alpha, which allows balancing the project makespan and the total energy cost (TEC) objective. For this problem, Constraint Programming (CP) and Integer Linear Programming (ILP) models are investigated.

2 - Accelerating Constraint Programming Using OptalCP Solver: Results on Jobshop and RCPSP
Zdenek Hanzalek, Vilem Heinz, Petr Vilím, Simon Zvara, Vit Knobloch

This presentation discusses the application of reinforcement learning (RL) and metaheuristic algorithms to enhance the performance of the constraint programming (CP) solver OptalCP. Building on our previous research, we propose an extension of an RL framework originally based on the Multi-Armed Bandit algorithm used to select promising branching decisions (branches) in the search tree. In this work, instead of precomputing all branches at the start, branches are computed on-the-go by neural network within a REINFORCE algorithm. This enables dynamic adaptation of branching decisions based on the current search tree context. Meanwhile, metaheuristic algorithms integrated to

the solver through communication interface, enhance its ability to identify promising solutions faster and more efficiently, providing both solutions and bounds which can be utilized by the solver. The combined goal of these approaches is twofold: reinforcement learning primarily improves the solver's ability to reach the optimal solution sooner, while metaheuristics focus on delivering high-quality solutions within practical time limits. While our approach is demonstrated using OptalCP, it is applicable to any CP solver that employs branch-based algorithms for optimal solution search, is sufficiently open to allow code modifications, and provides an interface for real-time interaction with external algorithms.

3 - Designing of efficient project portfolios
Petr Fiala

In an accelerating economic world, projects become tools for promoting multiple objectives of the organization. Project portfolio is set of all projects that are implemented in the organization at a time. Projects in the project portfolio are interconnected by priorities, dependences, and organization's resources utilization. Using sophisticated quantitative tools becomes a significant competitive advantage for project portfolio management. We propose a new approach for project portfolio designing based on a systemic combination of Data Envelopment Analysis (DEA) and De Novo optimization approach. Possible projects are characterized by sets of inputs and outputs, where inputs are resources for project realisation and outputs measure multiple objectives of the organisation The DEA is an appropriate approach to select efficient projects. The organisation has its total resources in limited quantities. It is possible to buy the resources at given prices. A total available budget is a restriction on project portfolio. De Novo optimization is an approach for designing efficient systems by reshaping the feasible set. The proposed combination of DEA a De Novo approaches ensures solving of the efficient project portfolio designing problem. The proposed concept provides designing of optimal project portfolio by given budget. Possible extensions of the problem are formulated and discussed. These extensions include restricted weights, goal restrictions, and time dependent budget.

4 - Online Delay Detection and Resource Allocation in Projects Using Reinforcement Learning
Inkyung Sung

This study proposes a Reinforcement Learning (RL)-based model for project delay management by dynamically detecting deviations from expected progress, estimated through a learning curve model. The model identifies potential delays in real time and allocates additional resources to critical tasks when necessary to accelerate project completion. With RL's adaptive decision-making capabilities, the proposed approach ensures timely project delivery while effectively managing resource availability and the time-cost trade-off.

■ MD-08

Monday, 14:30-16:00 - Room: Clarendon SR 2.08

Methodological developments in PROMETHEE methods

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Yves De Smet
Chair: *Alexandre Flachs*
Chair: *Boris Coquelet*

1 - Ranking construction based on crisp or valued outranking relation
Jerzy Łukaszewicz, Milosz Kadzinski

The outranking relation constructed by the ELECTRE or PROMETHEE methods, widely used in Multiple Criteria Decision Aiding, is intransitive. Therefore, to support the solution of ranking and choice problems, the existing approaches apply some exploitation procedures to impose order on the set of alternatives. Examples include the distillation procedures incorporated in ELECTRE III or Net Flow Score techniques encapsulated in PROMETHEE I and II. We propose novel exploitation methods for constructing complete or partial ranking. While both need to satisfy the transitivity property, the former assumes that all pairs of alternatives are comparable, while the latter tolerates incomparability relations. The proposed approaches are based on mathematical programming. They exploit either a valued relation that captures the preference degrees or a crisp relation consisting of binary statements. The methods minimize the distance between the constructed ranking and the input relation for all pairs of alternatives. The intensity of the divergence for a given pair of alternatives depends on the nature of the two relations, input and output, in question. Alternatively, our aim can be understood as the maximization of support for the relations that are preserved in the obtained ranking. We demonstrate the use of proposed methods in illustrative case studies. We also experimentally compare their results with those returned by the state-of-the-art methods.

2 - Assessing the ranking quality of the PROMETHEE II method
Boris Coquelet, Gilles Dejaegere, Yves De Smet

PROMETHEE methods belong to the family of multicriteria outranking methods. They have been applied for the last forty years in many applications including finance, environmental management, health care, etc. Their successful application is based on their simplicity and the existence of user-friendly software such as PROMCAL, Decision Lab 2000, Visual PROMETHEE or D-SIGHT. These methods are based on the computation flow scores to generate partial or complete rankings of the alternatives. Researchers have recently investigated the net flow scores' properties to characterise or justify the obtained rankings. In addition, a special focus has been given to the influence of third alternatives in the case of PROMETHEE II. In this contribution, following the idea of the consistency ratio developed in the Analytical Hierarchy Process, we propose an indicator to evaluate the quality of the PROMETHEE II algorithm's ranking. This will be derived from an objective function proven to be optimised while computing net flow scores. The indicator will provide a tool for the decision-maker to assess his confidence in the algorithm's ranking. This is illustrated on real data sets.

3 - A study on first ranked alternatives in Promethee methods
Alexandre Flachs, Yves De Smet

Promethee methods are a family of outranking methods from multiple criteria decision aid. These have been used in many practical applications and have been subject to multiple methodological extensions. Among Promethee methods, Promethee I and II allows building partial and complete rankings of the alternatives based on their evaluations regarding each criterion, using the positive, negative, and net flow scores. In the multiple criteria choice problem, a decision maker is given a set of alternatives evaluated regarding multiple conflicting criteria and is expected to select a subset of best alternatives corresponding to his/her preferences. One way to solve the choice problem is to build one or multiple rankings (depending on various instances of the preference parameters) of the alternatives and to choose the best subset by analyzing the obtained result. One can for example be interested in all alternatives that could be ranked first, with at least one instance of the method parameters. In this work we investigate under which conditions an alternative can be ranked first in a Promethee II ranking. Such questions were already raised in the context of Robust Ordinal Regression (ROR) with the concepts of possible and necessary ranks of an alternative. This contribution aims at being complementary to ROR by analyzing parameters requirements for an alternative to be ranked first, and draw conclusions on the expressivity of Promethee methods in terms of DM preferences.

4 - Extensions of PROMETHEE to multicriteria clustering: recent developments
Yves De Smet

PROMETHEE belongs to the family of so-called outranking multicriteria methods. They have been initiated and developed by Prof. Jean-Pierre Brans since the 80s. For the last fourty years, a number of researchers have contributed to its methodological developments and applications to real problems. These cover finance, health care, environmental management, logistics and transportation, education, sports, etc. The successful application of PROMETHEE is certainly due to its simplicity and the existence of user-friendly software such as PROMCALC, Decision Lab 2000, Visual PROMETHEE and D-SIGHT.

PROMETHEE has initially been developed for (partial or complete) ranking problems. Later, additional tools have been proposed like, for instance, GAIA for the descriptive problematic or PROMETHEE V for portfolio selection problems. Following this trend, J. Figueira, Y. De Smet and J.P. Brans proposed, in 2004, a first extension of PROMETHEE for sorting and clustering problems. This initial contribution has led to the development of different algorithms for sorting and clustering.

The aim of this presentation is to present recent advances in multicriteria clustering methods based on the PROMETHEE methodology. After a brief summary of existing procedures, we will focus on related research questions such as the development of partition quality indicators, the integration of clusters size constraints or the DUAL multicriteria problem.

■ MD-09

Monday, 14:30-16:00 - Room: Clarendon SR 2.01

Green Investment on Capital Market

Stream: OR in Finance and Insurance
Invited session
Chair: Rosella Castellano

1 - ESG Business Diversification and Investment Performance
Rei Yamamoto, Akifumi Isogai, Masatoshi Nozaki

ESG investment has attracted attention in recent years, but various problems have been pointed out with the ESG scores. We focus on ESG revenue data −an alternative data that has become available in recent years− and discuss its potential to solve the problem of the ESG scores. We propose ESG business diversification as a new ESG investment measure to evaluate the proactivity of ESG activities and verify its effectiveness in the US and European markets. The results show that portfolios with high ESG business diversification achieve higher returns that cannot be explained by standard risk factors in the US market.

2 - Sustainability portfolio investing in the presence of the risk-free asset
Janusz Miroforidis, Przemysław Juszczuk, Ignacy Kaliszewski

In the financial research community, the need to consider more aspects than return and risk, such as dividends, liquidity, and social responsibility, was noticed early. In particular, the popularity of socially responsible investment has considerably increased over the past several decades. To measure how much social responsibility is accounted for investments, combinations of environmental, social, and governance factors, the ESG index, are assigned to assets. Therefore, incorporating the portfolio ESG index into the classic Markowitz model is natural, and such extensions are present in the literature. However, in these tri-criteria models, the existence of the risk-free asset is not considered. We fill this intriguing gap by proposing a procedure to select a portfolio in the presence of the risk-free asset for the tri-criteria model. We illustrate the operation of this procedure on real data.

3 - Not all glitters but at least is green
Rita D'Ecclesia, Kevyn Stefanelli

In this paper we use the FTSE Russell Green Revenues 2.0 data model, a quantitative, balance sheet-based metric aligned with the EU Taxonomy, together with other available sustainability metrics (ESG ratings) to identify social responsible investments and build High Green Revenue (GR) and Zero GR stock portfolios within the Climate Policy Relevant Sectors (CPRS) using data from 2013 to 2023. We aim to investigate the greenium analyzing the performance of High Green Revenues portfolio vs Zero Green revenues,building a Green Minus Brown (GMB) factor. The results show that High GR portfolios outperform their brown counterparts only in some sub-periods, precisely during periods of market instability, but overall we do not find a preference of investors for sustainable investments. The greenium varies within each business sector, highlighting the need for sector-specific considerations. The significant misalignment between GR-based and other widely used metrics stresses the necessity of a unified and trustworthy framework for classifying a sustainable investment.

4 - Asymmetric Tail Dependence for Climate Risk
Davide Lauria

This study presents a new class of concordance and tail dependence measures based on surface integrals. Measures of tail dependence between random variables aim to numerically quantify the degree of association between their extreme realizations. Existing tail dependence coefficients (TDCs) are based on an asymptotic analysis of relevant conditional probabilities, and do not provide a complete framework in which to compare extreme dependence between two random variables. In fact, for many important classes of bivariate distributions, these coefficients take on non-informative boundary values. We propose a new approach by first considering global measures based on the surface area of the conditional cumulative probability in copula space. The measures could be approached by cumulating probability on either the lower left or upper right domain of the copula space, and offer the novel perspective of being able to differentiate asymmetric dependence with respect to direction of conditioning.

■ MD-10

Monday, 14:30-16:00 - Room: Clarendon SR 1.06

Integrated Healthcare Timetabling Competition III

Stream: Automated Timetabling
Invited session
Chair: Andrea Schaerf

1 - A Multi-Neighborhood Simulated Annealing Approach for Solving the Integrated Healthcare Timetabling Problem
Eugenia Zanazzo, Sara Ceschia, Roberto Maria Rosati, Andrea Schaerf, Pieter Smet, Greet Vanden Berghe

In this talk, we present our Multi-Neighborhood Simulated Annealing approach to solving the newly proposed Integrated Healthcare Timetabling Problem. The solver is designed in a fully integrated manner, meaning that at any time during the search, any aspect of a patient's stay or nurse assignment can be modified. The search space is structured to exclude infeasible patient assignments while allowing the violation of certain hard constraints to improve connectivity and facilitate traversal. To efficiently explore this space, we defined five partially overlapping neighborhoods: four operate on variables related to different aspects of a patient's stay, including their admission schedule, assigned operating theater, and recovery room, while the fifth focuses on nurse assignments. The search process begins from a randomly generated solution and progresses through a series of random moves. These moves are selected by first selecting the neighborhood based

on pre-tuned probabilities and then randomly choosing a move within that neighborhood. The selected move is evaluated and executed if it satisfies the SA acceptance criterion. To ensure a meaningful comparison between our results and those reported by the IHTC-2024 finalists, we set a 600-second time limit for the solver and performed parameter tuning exclusively on the publicly available dataset. Our results closely align with those of the IHTC-2024 finalists, demonstrating the effectiveness of our approach.

2 - Tackling the IHTC with mixed-integer programming, constraint programming and simulated annealing
Matthias Walter, Daniela Guericke, Rolf van der Hulst, Asal Karimpour, Ieke Schrader

The integrated healthcare timetabling competition 2024 is about developing algorithms for efficiently finding good solutions to a certain timetabling problem using limited computational resources. The problem is about deciding when to admit patients to a hospital, where to carry out their surgery, where to host them and which nurses to assign to their rooms. It is entirely deterministic but involves several hard constraints (such as having patients of different gender not share a room) as well as eight different soft constraints by means of penalties, e.g., for delaying patients, nurse workload excess or having not too many different nurses care for a patient.

In the talk I will explain the approach of Team Twente, which is mainly a hierarchical approach that uses uses mixed-integer programming at different places, as well as constraint programming and simulated annealing. Since mixed-integer programming models for the entire problem are prohibitively large, the starting point shall be the justification of our decomposition strategy. Then, for each level of our decomposition, the relevant models and design decisions and algorithmic adjustments will be explained. On the way we learned some lessons and found some directions for future research that could improve our approach, which will be presented finally.

3 - A multi-neighborhood, lexicographic local search algorithm for the Integrated Healthcare Timetabling Competition 2024
Ahmad Mahir Othman, Marco Chiarandini

The Integrated Healthcare Timetabling Competition 2024 (IHTC-2024) focused on the integration of three decision-making tasks: patient admission scheduling, operating theater planning and nurse-to-room assignment. The algorithm we submitted builds upon the ROAR-NET API specification and consists of a classical local search heuristic that uses multiple, small-scale neighborhood structures to address the different decision tasks and handles hard and soft constraint violations lexicographically.

Efficiency has been the primary guideline for the implementation. The search space is reduced by adopting a solution representation that implicitly satisfies some hard constraints. Patients are restricted to only be admitted on dates and rooms that satisfy the hard constraints affecting them independently from other decisions. Neighboring solutions are assessed incrementally over all neighborhood structures. Finally, Python was replaced by C++ after the first draft of the solver.

The high-level search strategy shares the run time between simulated annealing, first, for exploration and iterated local search, later, for exploitation. To take advantage of the 4-threads made available by the rule of the competition, we selected, offline, a set of four algorithm configurations and schedules by solving optimally a sequence of set covering problems with cardinality constraints. Our entry ranked among the best five out of 32 submissions.

4 - Winner IHTC
Venislav Varbanov

Winner IHTC

■ MD-11

Monday, 14:30-16:00 - Room: Clarendon SR 1.03

Scheduling in healthcare

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Erik Demeulemeester

1 - Reactive-proactive Rescheduling in Blood Supply Chain Management
Daniel Santos, Maria Meneses, Ana Barbosa-Povoa

The timely and efficient availability of blood products is crucial in the Blood Supply Chain. However, the inherent uncertainty of blood donations and demand, coupled with various disturbances to planned activities, poses a significant challenge for effective planning and management of this network. To address these challenges, this research introduces a reactive-proactive rescheduling model for Blood Supply Chain management, called Blood-OPE. This model leverages real-time data and known disturbances to adjust the existing master plan by optimizing reactive and proactive measures. The main goal is to maintain high operational performance, that is, the service level provided to demand nodes, while minimizing deviations from the master plan, logistical challenges, in particular, nervousness caused by changing commitments made with third-party organizations, and waste. To demonstrate the model applicability, Blood-OPE is applied to the Portuguese Blood Supply Chain network and quantifies the trade-offs between different rescheduling flexibilities and cost efficiency. The main findings show that rescheduling enhances operational performance, reduces waste, and improves service reliability by meeting safety stock targets. Overall, Blood-OPE can effectively support the operational planning of Blood Supply Chain management networks while maintaining feasibility within the network's requirements, since it is general enough to be applied to most contexts.

2 - Two-stage stochastic programming for scheduling telemedicine appointments
Charlotte Marshall, Daniel Gartner, Geraint Palmer, Paul Harper, Alka Ahuja, Gemma Johns

With telemedicine coming to the forefront during the COVID-19 pandemic, flexibility in terms of modes of care delivery has emerged. In this work we consider the scheduling of patients' appointments via three different modes of delivery: traditional face-to-face, video conferencing platforms, and telephone. Because the length of patients' appointments are subject to stochastic variation and patients may be no-shows, we introduce a two-stage stochastic programming formulation to schedule these appointments. The first stage aims to maximise patient and clinician preferences for delivery mode, while the second stage minimises patient waiting time. We generate test instances that are informed by clinical practice and validate the model using input from our partners, TEC Cymru, within the U.K.'s National Health Service (NHS). The mathematical modelling will provide booking clerks and admin personnel a tool to schedule appointments more efficiently.

3 - Nuclear Medicine Appointment Scheduling
Mei Tuson

This paper describes an approach for assigning nuclear medicine procedures (scan types) for a four-week appointment schedule, using a fixed number of scanning rooms. Some of these procedures require multiple scans on a same scanner, with the stages separated by fixed waiting times. The proposed approach uses a column generation algorithm where the sub-problems construct feasible schedules for a session and the main problem selects the best combination of sessions that satisfy the target demand. The approach is tested on retrospective appointments data from a London University Hospital. Its application at the operational level is further assessed using a discrete event simulation. In addition to assessing the impact of uncertainty on the schedule delivery, the simulation informs lead radiologists at the operational level and administrators at the strategic level on how to map appointments as efficiently as possible.

4 - Multi-scenario simulation-optimization approach for operating room scheduling
Gabriela Pinto Espinosa, Aida Jebali, Erik Demeulemeester

Operating rooms (ORs) are a crucial driver of hospital cost and revenue generation, a key bottleneck in patient care, employ multiple resources and impact several other departments. OR planning and scheduling has been extensively studied in the literature, addressing the complexity arising from inherent uncertainty and resource constraints. Existing approaches include stochastic and robust optimization models. However, they do not fully capture the dynamic behavior of the OR environment and fail to provide comprehensive and reliable solutions. Indeed, the integration of OR planning and scheduling with the consideration of elective and non-elective patients, multiple resources and uncertainties is a very challenging problem that still requires further development. To address it, we propose a multi-stage simulation-optimization approach that combines novel optimization models, heuristics and discrete-event simulation, leveraging the partitioning of surgeries into "more predictable surgeries" and "less predictable surgeries". Based on generated scenarios of non-elective arrivals and surgery and recovery durations, simulation is used to test the feasibility of each daily schedule and to evaluate OR performances (such as waiting time, utilization, and overtime), while iteratively refining solutions. As such, our approach allows for building a reliable schedule that accounts for plausible OR dynamics, sources of uncertainty, resources and objectives.

■ MD-12

Monday, 14:30-16:00 - Room: Clarendon SR 1.02

Flow shop scheduling and line balancing

Stream: Scheduling and Project Management
Invited session
Chair: Joanna Józefowska

1 - Scheduling two-stage processing with job-dependent storage requirements
Yakov Zinder, Joanna Berlińska, Charlie Peter

This talk considers machine scheduling problems where each job consists of two operations that must be processed in a given order. For processing, a job requires an additional resource referred to as a storage space. The storage space required by a job is seized by the job from the start of processing its first operation and is released upon completion of the second operation. This distinguishes the discussed scheduling problems from the most of the literature on resource-constrained scheduling, where the resource is used only during the processing on a machine, i.e. the resource is seized at the start of processing an operation and is released upon completion of that operation. It also distinguishes the considered scheduling problems from the publications on scheduling with a buffer, where the storage space, usually referred to as a buffer, is used only between the completion of the first operation and the beginning of processing the second operation. The storage space is limited and its consumption varies from job to job. At any point in time, the total consumption of the storage space cannot exceed its availability. Research on two-stage processing scheduling with job-dependent storage requirements has been motivated by various applications, including multimedia systems; data gathering in networks; and supply chains of mineral resources. The talk reviews published results and presents new ones, including exact and approximation algorithms, and metaheuristics.

2 - Multi-Objective Distributed Flow Shop Scheduling With Variable Production Speed and Inter-Factory Transportation
Lydia Hilarius, Tristan Becker, Udo Buscher

In a globally integrated economy, production is frequently distributed across multiple factories or production lines, a challenge that is addressed in the Distributed Flow Shop Scheduling Problem (DFSP). The DFSP involves scheduling a set of jobs across multiple distributed flow shop factories, each equipped with identical machine setups. Our study introduces two key extensions to the DFSP: (1) the option to increase machine speed at additional cost, and (2) inter-factory transportation of semi-finished products, incurring transportation costs and delays at the benefit of higher factory utilization. While most existing research focuses on makespan, we consider total tardiness to generate customer-oriented schedules. Our objective is to minimize both total tardiness and cost of transportation and speed increase. To efficiently solve this multi-objective problem, we introduce an iterated greedy algorithm that is tailored to the problem characteristics. Computational experiments demonstrate that our method outperforms conventional mathematical and constraint programming approaches. Our findings quantify the benefits of transportation and machine speed adjustments. We find that the combination of both can lead to synergistic improvements. Further, our results offer valuable insights into the trade-offs between total tardiness and costs for decision makers in distributed manufacturing.

3 - Distributed Permutation Flowshop Scheduling with Tool Transfers: A Novel Approach to Minimize Total Tardiness
Martin Schönheit, Tristan Becker, Rainer Lasch

The increasing frequency of supply chain disruptions due to climate change and political conflicts highlights supply chain vulnerabilities. To mitigate risks, companies diversify production sites, giving rise to the distributed permutation flow shop scheduling problem (DPFSP). In many industries, machines need specialized tools to process specific jobs, creating eligibility constraints. These tools can be cost-intensive or highly specialized, making full redundancy across factories impractical. Therefore, we extend the DFSP by tool availability with the possibility of transferring tools between factories. Transferring tools can enable job processing at otherwise ineligible factories, potentially offering economic and environmental advantages over transporting final products over long distances. To capture the impact of factory location on the assignment of jobs, we minimize total tardiness while considering factory-dependent due dates. In this context, we evaluate the benefits of tool transfers by proposing a network flow-based mixed-integer programming model, a constraint programming formulation, and an iterated greedy algorithm. Through extensive computational experiments, we demonstrate that tool transfers can effectively reduce total tardiness, while also assessing the impact of varying levels of tool redundancy on its minimization.

■ MD-13

Monday, 14:30-16:00 - Room: Clarendon SR 1.01

Pandemics and epidemics

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Esma Gel

1 - Behavioral Interventions Encouraging Telemedicine Adoption in Epidemic Contexts
Zeynep Aksin, Elif Karul, Erhun Ozkan

Telemedicine is an alternative healthcare delivery channel, that offers opportunities to increase access to care by eliminating transportation barriers, enabling earlier appointment times, and mitigating the spread of infection due to respiratory virus epidemics. The infection risk avoidance opportunity provided by telemedicine can be beneficial for healthcare providers in terms of limiting revenue losses and protecting healthcare workers and patients from contracting the virus. We study the possibility of using informational interventions to encourage

telemedicine channel choice during respiratory viral epidemics via behavioral laboratory experiments. We explore multiple informational interventions in a series of studies: infection risk elimination, appointment wait time difference, and convenience messages, all under scenarios that provide an epidemic context. We show that an infection risk elimination message can significantly improve telemedicine channel choice compared to a control with no reminder. A reminder focusing on the convenience aspect of a telemedicine appointment is shown to increase telemedicine choice relative to a control group that receives no reminder. The effectiveness of informational interventions in channel choice is promising, as nudge messages are cost-effective and easy to implement. Our results provide preliminary evidence that nudges can be used to manage patient demand between channels during respiratory virus epidemics or seasonal flu periods.

2 - An Artificial Intelligence and Simulation Framework for Upgrading Capability Management of Radiology Departments in Seasonal Respiratory Diseases
Alexandros Konios, Miguel Ortíz-Barrios, Sajid Siraj

The seasonal escalation of respiratory illnesses, such as influenza and COVID-19, presents recurring challenges in managing critical healthcare resources. In response, Artificial Intelligence (AI) and simulation technologies are increasingly being used to enhance operational readiness, particularly in radiology units. AI systems excel at integrating vast, real-time datasets to predict patient loads and radiology equipment shortages with high precision (Ali, 2024). Simulation-based technologies can further amplify the AI potential by allowing stakeholders to construct digital replicas—or "digital twins"—of radiology systems. These models enable planners to test various policy scenarios, evaluate surge responses, and optimise workflows. By dynamically adjusting to real-world developments, these integrated AI-simulation frameworks provide the agility and foresight required to manage resource-intensive respiratory conditions, transforming reactive responses into proactive cost-efficient healthcare planning. This paper integrates AI and Discrete-Event Simulation (DES) to effectively manage radiology equipment capacity during Respiratory Disease Seasons (RDSs). First, we developed an Xtreme Gradient Boost (XGBoost) to predict the radiology unit requirements considering sociodemographic and clinical factors.

3 - Simulation and Optimization Approaches for Pandemic Response: EpiMORPH
Esma Gel

Epidemiological modeling is a critical tool for understanding the dynamics of pathogen transmission and predicting future outcomes, supporting public health responses. While illustrating the power of modeling in epidemic management, SARS-CoV-2 also highlighted inefficiencies in current modeling practices, with myriad models of varying assumptions, approaches, and quality flooding public forums. One of the main issues is that modeling studies and software are so customized that scientists must often start from scratch to create model-based technologies that address new pathogens or that seek to understand transmission dynamics in new locations. Moving epidemiological modeling from a collection of independent studies towards a more efficient, consensus-building endeavor will require the innovation of tools that accelerate the construction and testing of models, and that facilitates rigorous model comparison. This talk introduces EpiMoRPH (Epidemiological Modeling Resources for Public Health), a groundbreaking tool for advancing epidemiological modeling. It provides a robust framework for rapid model development and evaluation, promoting deeper understanding of epidemic dynamics. EpiMoRPH features an advanced optimization toolkit, empowering public health practitioners to make informed decisions on intervention placements and strategies. We will focus on the latest components of the tool, including its system dynamics modeling and resource allocation optimization capabilities.

■ MD-15

Monday, 14:30-16:00 - Room: Esther Simpson 1.08

Vehicle Routing problems

Stream: Combinatorial Optimization
Invited session
Chair: *Irene Loiseau*
Chair: *Juan José Salazar González*

1 - Optimizing Food Bank Deliveries in Bogotá Colombia
Robert Dell, Sabrina Casucci, Gonzalo Enrique Mejia Delgadillo, Seyed Torabzadeh

We present a vehicle routing problem (VRP) developed for the Banco de Alimentos de Bogotá, a food bank in Bogotá, Colombia, that plays a vital role in alleviating food insecurity in Colombia by supporting approximately 500,000 individuals through a network of 500 agencies distributing food to individuals. Problem characteristics include a dedicated homogenous fleet of vehicles operating from a single depot, agencies with time windows for deliveries, and agencies with differing monthly delivery requirements. We plan daily routes for the dedicated fleet of vehicles over a month that adhere to time window, monthly frequency requirements, and other fleet limits while striving to both minimize vehicle usage and evenly distribute the workload over the month. To help distribute the workload evenly, we iterate between an integer linear program to assign agencies to days and a daily VRP for the fleet of vehicles.

2 - Lane-Level Traffic Flow Estimation with Federated Learning for Urban Vehicle Routing
Chansoo Kim, Sangchul Lee

We propose an integrated approach for lane-level traffic flow estimation for application to the Vehicle Routing Optimization (VRO) problem. Traditional traffic models, based on average flows, fail to capture nonlinear dynamics and bottlenecks at intersections, ramps, and merging areas. To address this, we construct a graph-based lane-level model incorporating network flow constraints. To improve flow estimation, we introduce a deep learning-based auxiliary module, complemented by a stochastic agent-based traffic model to analyze complex lane interactions. The predicted flows serve as key inputs to a Mixed-Integer Programming (MIP) model formulated to solve the VRO problem over a lane-level network. By providing lane-level data, the estimation module enhances the accuracy of decisions within the optimization framework. This model helps determine vehicle routing and allocation under cost functions reflecting actual traffic conditions. We also apply decentralized federated learning to integrate locally trained models across distributed networks. Preliminary simulations on a synthetic complex urban traffic network show approximately 12.3% congestion reduction compared to average flow-based approaches. Sensitivity analyses suggest the scalability under diverse traffic patterns. This study highlights potential of combining AI-assisted estimation with flow optimization to address global issues such as smart cities and autonomous driving, with scalability to multimodal networks.

3 - Models for the Capacitated Vehicle Routing Problem with bounds on each route duration
Juan José Salazar González

In the classical Capacitated Vehicle Routing Problem (CVRP) routing costs and customer demands are given, and a vehicle route is feasible when the total demand of assigned customers does not exceed the vehicle capacity. The aim is to design vehicle routes to visit each customer once and to minimize the sum of routing costs. In this talk, we address a variant of this problem where travel times are also given, and a vehicle route is feasible when its total travel time must fit within a given interval. Despite the large number of applications where the duration of each vehicle route is constrained, the literature on this difficult variant proposes mainly heuristic approaches. We present new MILP formulations for the exact solution and discuss computational results.

■ MD-16

Monday, 14:30-16:00 - Room: Esther Simpson 2.07

Food and Nutrition Security - Vulnerability

Stream: Sustainable Food & Agroforestry
Invited session
Chair: Marleen Balvert

1 - Vulnerability to agricultural export shocks through the global trade network
Polle Dankers, Deniz Besik, Miranda Meuwissen, Joris Wagenaar

The frequency and impact of events disrupting international food trade is rising. For example, the war in the Ukraine has significantly reduced grain exports, while an increasing number of natural hazards cause agricultural losses. These disruptions do not only threaten domestic food security in directly affected countries, but also propagate through global trade networks, affecting other countries as well.

In this research, we assess national vulnerability levels to foreign shocks through trade. Our approach consists of two steps:

First, we construct a model to simulate agricultural production shocks worldwide. This is mainly based on historic data, together with agricultural resilience indicators. These simulated shocks serve as input for our trade model.

Second, we model international trade flows via a spatial price equilibrium (SPE) model, which accommodates transaction costs between various supply and demand markets. SPE can also be used to examine the effects of tariffs, which can be important in the current geopolitical climate.

By integrating these models with real-world data, we estimate the food security vulnerability of countries arising from global trade disruptions. Additionally, the model can show outcomes of different scenarios, e.g., when countries decide to implement protectionist measures, providing valuable insights for policy makers in the global food system.

2 - Anticipatory Action for Floods: A Data-Driven Optimization Framework
Rein Lommerse, Thomas Breugem, Burcu Balcik

Flood occurrences are increasing globally, threatening food security by damaging crops, livestock, and storage facilities. Since 2000, flood-related disasters have risen by 134%, driven by climate change-induced extreme weather. While humanitarian disasters have surged in recent decades, advancements in flood forecasting enable proactive interventions. Such interventions are commonly termed anticipatory actions, an increasingly popular and cost-effective approach to humanitarian aid. We propose a novel framework for optimizing anticipatory actions, leveraging multi-stage stochastic optimization and optimal stopping theory to determine when and how to act. Applying our framework to flood data from the Brahmaputra River in Bangladesh, we demonstrate its effectiveness in enabling timely and efficient interventions, thereby strengthening food security and protecting vulnerable populations from hunger.

3 - "Designing Funding Proposals for Responding to Climate-Induced Disasters under Uncertainty
Janne de Rooij, Burcu Balcik, Joris Wagenaar, Yasemin Merzifonluoglu

Humanitarian organizations face immense challenges in designing effective relief programs, particularly in regions where recurring climate shocks take place. A critical component in the design of such relief programs is the construction of a comprehensive funding proposal, which estimates the necessary funds and ultimately secures the money necessary to execute the relief program. This research aims to assist humanitarian aid organizations with preparing detailed funding proposals for relief operations responding to climate-induced disasters, that address operational feasibilities and uncertainties such as local market and infrastructure conditions during and after the climate-induced disaster. We propose a Mixed- Integer Programming model that advises how to optimally allocate funds across in- kind, cash-based and reserve funding. To account for the uncertain and varying impact of the disaster and associated disruptions, this model incorporates a scenario-based planning, where scenarios represent potential ways in which the disaster can unfold.

■ MD-17

Monday, 14:30-16:00 - Room: Esther Simpson 2.08

Drone Routing

Stream: Combinatorial Optimization
Invited session
Chair: Michel Gendreau

1 - Truck-Drone Arc Covering Problem: Application and Case Study in Disaster Management
Alexander Rave, Pirmin Fontaine

Effective river exploration before, during, or after floods is crucial for civil protection and disaster management, helping to enhance preparedness and even prevent disasters. Traditionally, this process relies on boats, trucks, helicopters, or is sometimes not conducted at all. However, autonomous drones equipped with cameras can significantly improve river monitoring. By integrating a truck with a drone, the drone's operational flexibility increases, overcoming its limited range. Recognizing this potential, the Bavarian Red Cross has equipped a truck with a drone for river coverage.

Inspired by this real-world application, we introduce the Truck-Drone Arc Covering Problem (TD-ACP) to optimize river exploration. We model the TD-ACP as a mixed-integer linear program (MILP) and incorporate valid inequalities that strengthen the formulation, enabling the solution of realistically sized instances to optimality. Our numerical study shows that using drones for river coverage can reduce coverage time by at least 56.3% compared to traditional boat coverage. Additionally, we propose a manual planning heuristic that is easily applicable for practitioners, achieving an average optimality gap of just 4.2%.

2 - On the drone general routing problem with load-dependent costs
Paula Segura, Isaac Plana, Jose Maria Sanchis

Recent advances in drone technology have made it possible for drones to have the capability of capturing images and making deliveries during the same flight. This capability can be very useful, for example, in humanitarian emergencies, where drones can deliver medicine to difficult-to-reach areas and take pictures of disaster-affected zones. However, the payload capacity of drones is still quite limited, and the weight of the cargo being carried significantly affects flight times. In this talk, we present the drone general routing problem with load-dependent costs, where a drone must traverse a set of edges and make a series of deliveries at some vertices of a graph, and both the edge traversal and delivery times depend on the total weight of the drone at that moment. Each time the drone makes a delivery, its weight decreases and, consequently, the traversal time of subsequent edges is reduced. Thus, it may be interesting to serve a vertex with high demand first even if it is far away. The goal here is to minimize the total duration of the drone tour. We propose a formulation for the problem and analyze the associated polyhedron of solutions while introducing families of valid inequalities to strengthen the formulation. We design a branch-and-cut algorithm to solve the problem and perform extensive computational tests on instances with a maximum of 7 deliveries and 96 edges to be traversed.

3 - Close-enough multi-UAV general routing problem for monitoring
Michel Gendreau, Huan Liu, Guohua Wu

We introduce the Close-enough Multi-UAV General Routing Problem (CMUAVGRP), in which homogeneous UAVs perform monitoring tasks involving nodes with disk neighborhoods and edges, aiming to minimize the total travelled distance. A two-phase iterative method is proposed: first, a variable neighborhood descent is designed to generate routes excluding disk neighborhoods in a general routing phase, and, second, a second-order cone programming procedure is developed to optimize representative points for each required node in a close-enough routing phase. The two phases operate iteratively under an adaptive iterated local search framework until termination criteria are met. Extensive experiments demonstrate the efficiency of this two-phase algorithm and the superiority of disk neighborhoods.

■ MD-18

Monday, 14:30-16:00 - Room: Esther Simpson 2.09

OR for Sustainable Development IV

Stream: OR for Sustainable Development
Invited session
Chair: Sarfaraz Hashemkhani Zolfani

1 - A Biobjective Bin-Location Problem for Recyclable Household Waste Collection: Modeling and Application
Carola Blazquez, Alejandro Fuentes, Pablo A. Miranda

In this paper, a biobjective bin location problem is formulated to design a recycling household waste collection system. The model addresses bin location decisions considering a set of potential sites along with demand zones assignment, and the number of bins to be situated at each location. The biobjective function to be minimized comprises bin purchasing costs and the total distance incurred to transport the waste to the selected bin locations. Each demand zone is modeled by considering a set of fictitious centroids that concentrate waste generation. The model is applied to a set of real-world scenarios of an urban commune in Santiago, Chile. An insightful sensitivity analysis is performed, focused on relevant problem features, such as single versus multi-stream strategy, collection frequency, and Euclidean and roadway network-based distances. Results reveal that increasing the number of centroids of each demand zone provides better solutions while involving higher computational times. Significant managerial and policy-making implications for designing and managing recycling household waste collection systems are discussed.

2 - Remanufacturing strategies for a local OEM and an MNR under policy incentives and technology spillovers
Nannan Wang, Linda Zhang

Nowadays, many multinational remanufacturers (MNRs) have established local remanufacturing facilities in the major markets in their global supply chains. Because of the operations of these facilities, the remanufacturing technologies of MNRs naturally spill over to local Original Equipment Manufacturers (OEMs). This study develops analytical models to examine the strategic interactions between a local OEM and an MNR under varied government policies, including environmental taxes, tariffs, and tax incentives. We first investigate how the policies shape the OEM's decision to adopt remanufacturing and influence the MNR's choice between exporting remanufactured products and setting up local remanufacturing facilities. The results reveal that moderate levels of taxes/tariffs help sustain the availability of both new and remanufactured products in the market, thereby enhancing consumer surplus, whereas extreme values may disrupt market dynamics. Additionally, we study the impact the environmental impact of new product production on policymaking and provide implications for policy design. As suggested by our analysis, when the environmental impact of new product production is high, the policymaker should tax the MNR's products regardless of its location strategies; when the degree of technology spillovers is low and the environmental impact is moderate, the policymaker should subsidize the MNR when it establishes a local remanufacturing facility.

3 - Toward Sustainable Manufacturing Growth in Korea: An Operational Research and Analytics Perspective
Kwang-Jae Kim, Young-Mok Bae, YoungGwan Kim, Ye-won Park

For the past 60 years, Korea's economic growth has been driven by manufacturing, playing a critical role in boosting exports and generating employment. However, the industry now faces significant challenges, including a rigid labor market, hierarchical SME networks, and an aging industrial ecosystem. To ensure sustainable growth, the focus must shift from resource-intensive expansion to high-value, innovation-driven strategies. To address these challenges, the National Academy of Engineering of Korea has proposed K-GIFT (Green and Intelligent Factory for Tomorrow) Valufacturing, a paradigm shift that seeks to reshape Korea's manufacturing sector around sustainability, economic value, and social responsibility. This approach moves beyond traditional efficiency-driven manufacturing to establish a sustainable and value-oriented industrial model. In this talk, we introduce the concept of Valufacturing and its strategic implications. We present recent cases from leading Korean firms that align with this transformation. Specifically, we explore the role of OR and Analytics methodologies that enhance customer value across product design, production, and after-sales service. Finally, we review recent research trends in OR and Analytics in Korea and highlight their role in driving sustainable manufacturing innovation in the Valufacturing era.

■ MD-20

Monday, 14:30-16:00 - Room: Esther Simpson 2.11

Problems on graphs

Stream: Combinatorial Optimization
Invited session
Chair: Ulrich Pferschy

1 - Graph Sparsification to Preserve Connectivity: a GRASP approach
Claude Petit, Alexandru Olteanu, Quentin Perrachon, Marc Sevaux

Sparsifying a graph helps accelerate algorithms that involve any type of computation on its edges. However, this operation alters the properties of the graph, even though it might be important to preserve them. Therefore, it is crucial to have sparsification algorithms that guarantee the maintenance or minimal degradation of certain properties of the original graph.

In this work, we propose to study two greedy graph sparsification algorithms to maximize connectivity for a given number of edges. The original algorithms are deterministic and have a complexity of O(nk) and O(k(n+k)) respectively, where n is the number of nodes and k is the number of edges of the sparsified graph. The variants are inspired by the GRASP metaheuristic, and studying their performance shed light on both the optimality of the original algorithms and potential areas for improvement.

Graph sparsification counts numerous applications, such as in transportation problems or in applications involving Graph Neural Networks (GNNs).

2 - On Satisfying Connectivity Requirements In Digraphs With Arc Operations
Matheus Corrêa, Abilio Lucena

Let D = (V, A) be a directed graph. In many applications, D may lack a desired connectivity property, such as strong connectivity. To address this issue, a single arc operation—such as addition or reversal—can be repeatedly applied to transform D into a digraph D' = (V, A') that satisfies the required connectivity. In this study, we explore various problems that involve modifying a digraph using arc operations to achieve specific connectivity properties. Most of these problems are NP-hard. Consequently, we develop exact algorithms based on well-known optimization techniques, including Branch-and-Cut and Lagrangian Relaxation. Our results indicate that, when used individually, these techniques yield limited success. However, when combined, they enable us to solve all tested instances effectively.

3 - A stable set based branch and bound algorithm for the shortest path problem with conflicts
Bahadir Pamuk, I. Kuban Altinel, Temel Öncan

Combinatorial optimization problems with conflicts, mirroring real-world scenarios in transportation and network design, have gained significant interest. The Shortest Path Problem with Conflicts (SPC) builds upon the classic One-to-many Shortest Path Problem (SP) by introducing conflict constraints, forbidding simultaneous inclusion of specific arc pairs. This renders SPC NP-hard, demanding efficient methodologies. SPC aims to identify a conflict-free Shortest Path Tree, a spanning outtree rooted at a source vertex. Notably, SPC is a specialized instance of the Minimum Cost Flow with Conflicts (MCFC), suggesting that efficient SPC solutions could pave the way for advancements in MCFC. A branch-and-bound approach based on stable sets of the conflict graph addresses SPC, transforming maximal stable sets of a conflict graph into spanning outtrees of original network. The algorithm constructs an extended conflict graph, using conflict relations inherent to SP, to reduce the number of stable sets and feasible solution space. Feasibility branching increases stable set size towards |V(N)|-1 arcs, while optimality branching refines cost by incorporating negative reduced-cost arcs. Circuit prevention is integrated. Lower bounds are computed using Dijkstra's algorithm. A greedy heuristic generates initial stable sets at each search node. A fast infeasibility test with a connectivity check improves solution times. Single-threaded runs are compared with multi-threaded Gurobi solver.

4 - Minimizing Dissatisfaction of an Allocation on a Common Preference Graph
Ulrich Pferschy, Nina Chiarelli, Clément Dallard, Andreas Darmann, Stefan Lendl, Martin Milanic, Peter Mursic

We consider the allocation of indivisible items to agents, when all agents' preferences are expressed by a common directed acyclic graph. The vertices of the graph represent items and an arc (a,b) means that item a is preferred over item b. The dissatisfaction of an agent is measured by the number of non-assigned items which are desired by the agent and for which no more preferred item is given to the agent.

We pursue two different goals of an allocation, either efficiency (measured by the total dissatisfaction over all agents) or fairness (given by the maximum dissatisfaction among agents).

For both problems we study the status of computational complexity and obtain NP-hardness results as well as polynomial time algorithms with respect to different underlying graph structures. Focusing on the number of agents, the problem is rather easy for 2 agents, but becomes NP-hard for at least 3 agents, even on fairly restricted graphs. However, depending on the objective function, we obtain polynomial time algorithms for special graph classes, such as out-stars, out-trees and polytrees. Furthermore, we consider graphs of treewidth two and exploit modular graph decompositions to obtain fixed parameter tractability results.

■ MD-21

Monday, 14:30-16:00 - Room: Esther Simpson 2.12

3D Packing

Stream: Cutting and packing (ESICUP)
Invited session
Chair: António Ramos

1 - Exploiting GPU capabilities for voxel-based approaches to the 3D Irregular Strip Packing Problem
Alessio La Greca, Jonas Tollenaere, Tony Wauters

The 3D Irregular Strip Packing Problem is a generalization of the Strip Packing Problem. Given a three-dimensional container of given width and depth but unconstrained height, the problem involves packing a given set of items into this container so that its total height is minimized. The items are not limited to being convex in shape and can have holes. Heuristic and metaheuristic approaches that tackle the problem require building solutions where no pair of items overlap. There are two methods that are commonly used to handle this constraint: one that explicitly takes into account the items' geometry and another that approximates items into simpler shapes by means of voxels. In this work, we consider the latter. While such approaches have received increasing attention in recent years, there has been a lack of research which considers their scalability on modern GPUs. We therefore propose three different voxelization approaches. The first one makes straightforward use of voxels to check for overlapping. The second builds atop the first by adding a Sparse Voxel Octree data structure. The third approach is based on recent advances and leverages the concept of the No-Fit Voxel. A metaheuristic is also proposed to show the speedup granted by the GPU implementations in terms of number of solutions explored, and to compare their performance. The preliminary results we present will demonstrate the potential of GPU integration into voxel-based algorithms to improve execution times.

2 - 3D Irregular Cutting and Packing in Tokamak Reactor Decommissioning
Yifu Wei, Julia Bennell, Hamish Carr, Ipek Caliskanelli

The fusion reactor is widely regarded as the ideal future source of green energy. However, fusion reactors inevitably generate radioactive waste. Due to regulatory and safety requirements, the waste must be stored in disposal facilities for a certain duration. A key challenge in fusion reactor decommissioning is that the waste from fusion reactor is mostly large construction materials, which needs to be cut into pieces in appropriate sizes, then, packed in specific containers. This involves a trade off between the cutting investment and the packing investment to minimise the overall cost of cutting and packing. This PhD project aims to address a 3D irregular partition and bin packing problem that arises in the fusion reactor decommissioning. At this stage, we primarily focus on solving a 3D irregular bin packing problem while considering additional constraints such as weight, radioactivity, and accessibility. The object shapes are represented using voxels. Based on this representation, we introduce a novel and efficient collision detection method derived from the No-Fit Voxel approach. Subsequently, various novel packing algorithms are tested using reviewed datasets, incorporating different combinations of nesting strategies, and evaluation strategies for object orientations. These packing algorithms are developed based on Integer Linear Programming and a novel Selection of Candidates Heuristic. Finally, we expect to evaluate the best algorithm and the optimised bin designs.

3 - Sequential Packing of Irregular Objects: A Collision-Aware Approach to 3D Placement
António Ramos, Pedro Rocha, Elsa Silva, Fillipe Ribeiro

This work introduces a novel approach to three-dimensional irregular packing with sequential positioning requirements. Unlike traditional methods where all items are placed simultaneously, we address the challenge of avoiding collisions between the positioning device and previously placed objects while maintaining containment and non-overlap constraints. Our two-phase methodology first discretizes object geometries into multiple layers and generates No-Fit Polygons to

ensure collision-free placement. The computation phase then employs a GRASP meta-heuristic to optimize item sequencing and positioning. Computational experiments across diverse test instances demonstrate our approach's effectiveness in generating feasible layouts that satisfy sequential positioning constraints. Results confirm that while sequential positioning requires greater container volume than simultaneous approaches, it offers a viable alternative when reliability and collision avoidance are critical. This research establishes a foundation for addressing geometric packing problems where sequential processing constraints are essential, with particular relevance to additive manufacturing and robotic assembly applications.

4 - Optimal Packing of Irregular Objects Composed by Generalized Spheres
Andreas Fischer, Igor Litvinchev, Tetyana Romanova, Petro Stetsyuk

For modeling the optimal packing of objects composed by generalized spheres, we present non-overlapping and containment conditions. A new composition condition enables translations, rotations and reflections of the irregular objects. The modeling is applicable to special problems, like balance, homothetic, or sparse packing. Different geometrical shapes can be created and treated in the same way through selecting a suitable norm, possibly obtained by the composition of norms. Illustrations for small probems demonstrate the potential of the approach.

■ MD-23

Monday, 14:30-16:00 - Room: Esther Simpson 3.01

OR for Better Africa - OR@Africa 2

Stream: OR for Societal Development
Invited session

Chair: Youssef Diouane
Chair: *Issmail El Hallaoui*
Chair: *Fatima Ezzahra Achamrah*

1 - Enhancing Regularity in the Crew Pairing Problem
Mohamed Faouzi Benammour, Frédéric Quesnel, Francois Soumis

The Crew Pairing Problem (CPP) involves constructing feasible sequences of flights, connections, and rest periods for airline crew while minimizing operational costs and ensuring full flight coverage. However, beyond cost minimization, regularity has become a crucial objective for many airlines, as it enhances operational stability and reduces indirect costs associated with hotel accommodations, transportation logistics, and crew training. Traditional CPP optimization methods primarily focus on cost reduction but often fail to effectively incorporate regularity, as they lack a structured mechanism to balance both objectives.

This study proposes several approaches to enhance regularity in the CPP. The first is a bonus-based approach that identifies pairings with high repetition potential in the initial solution. The CPP is then resolved using a branch-and-price algorithm to encourage the selection of these repeatable pairings. The second approach reoptimizes the initial solution by solving a MIP model that explicitly maximizes regularity. Finally, both approaches are applied sequentially to further enhance regularity while maintaining cost efficiency, forming a hybrid method.

Computational experiments conducted on datasets from a major Asian airline demonstrate the effectiveness of the proposed methods. The results show that they generate highly regular solutions with minimal cost deviations, ensuring practical applicability in airline crew pairing optimization.

2 - Solving a real-world Multi Trips Multi Depots Multi Products Petrol Replenishment problem with time windows and a heterogeneous fleet of tank-trucks
Ayoub Correa

In this paper, we address a real-world replenishments scheduling problem of a network of petrol stations with two types of gasoline by a heterogeneous fleet of tank-trucks from five depots. To solve this complex problem, we propose a graph and a related mathematical model integrating a heterogeneous fleet assignment, compartmented truck loading (stowage) with scheduling and capacitated vehicle routing with time windows and no split delivery. We tested our model on 90 instances based on real world weekly replenishment orders. Even though this exact approach is turned into a good heuristic method by setting a short solution time limit, the results obtained are very satisfactory as several optimal solutions are reached. Our approach is also promising in terms of convergence, scalability, and potential for decomposition. Even though our paper is on a case study from a West African context, it offers some insights on the combination of the two most used distribution policies in the world.

3 - Optimizing Empty ULD Repositioning Using Machine Learning and Optimization Techniques
Ali Barooni, Frédéric Quesnel, Francois Soumis, Daniel Aloise

Effective management of Empty Unit Load Devices (ULDs) repositioning is crucial for optimizing efficiency and reducing costs in aviation. Repositioning empty ULDs is expensive and constrained by limited flight capacity, while high demand variance makes distribution challenging. In this study, we tackle imbalanced ULD distribution across airports by developing a data-driven approach to optimize their movement.

Our approach has two stages. First, we forecast ULD demand per flight using features such as aircraft type and route characteristics. We initially applied regression-based models—including XGBoost and a Zero-Inflated Poisson (ZIP) model—to predict ULD requirements. To boost accuracy, we then incorporated time series techniques using Prophet and other methods to capture temporal dependencies in each airport. Second, we built an optimization model to determine the optimal movement of empty ULDs across the network, ensuring cost-effective repositioning while considering operational constraints.

A key contribution of our work is leveraging real-world airline data to enhance the reliability and relevance of our findings. Although similar optimization methods have been used in container shipping, their application in aviation for ULD management is emerging. Our results offer valuable insights for airlines aiming to reduce empty repositioning costs, improve fleet utilization, and minimize unnecessary transfers through data-driven decision-making.

4 - Impact of Hierarchical Forecasting on Inventory Performance: Case of the Vaccine Supply Chain
Oussema Omri, Mohamed Zied Babai, Nadine Kafa, Bahman Rostami-Tabar, Zied Jemai

Accurate demand forecasts are crucial for effective planning and decision-making in vaccine supply chains (VSCs). However, their hierarchical structure is often overlooked in research and practice. While studies primarily assess the accuracy of hierarchical forecasting methods, their impact on inventory performance remains underexplored. Additionally, despite the proven efficiency of advanced inventory control policies in various supply chains, they are often underutilized in VSCs. This paper empirically analyses the inventory performance of several hierarchical forecasting approaches, including Bottom-Up, Top-Down, Minimum trace reconciliation, and two forecasting methods: Error Trend and Seasonality (ETS) and Auto-Regressive Integrated Moving Average (ARIMA). A periodic reorder-point order-up-to-level policy is considered for the inventory control at different hierarchy levels. The inventory performance is measured in terms of the combined inventory holding volumes and achieved service level efficiency. The data used in the empirical investigation are related to the supply chain of childhood vaccines distributed in Kenya, which has four geographical hierarchy levels: National, region, county, and sub-county. The empirical results show that while the Bottom-Up approach

consistently achieves high forecast accuracy and performs well in inventory management, there are cases where the Top-Down approach results in better inventory efficiency despite its lower forecasting accuracy.

■ MD-24

Monday, 14:30-16:00 - Room: Esther Simpson 3.02

Tutorial: Use of Julia/JuMP for Multi-objective optimization

Stream: Tutorials (and Workshops)
Tutorial session
Chair: Thomas Stidsen

1 - Use of Julia/JuMP for Multi-objective optimization
Xavier Gandibleux

vOptGeneric.jl is a JuMP extension package implemented in Julia for modeling and solving multi-objective linear optimization problems. It was created as part of the ANR/DFG research project vOpt (2015-2019). Inspired by the lessons learned in vOptGeneric, we added first-class support for multi-objective optimization problems to JuMP and MathOptInterface. In addition, we developed a meta-solver, MultiObjectiveAlgorithms.jl (MOA), which implements a number of algorithms for solving multi-objective optimization problems. The new features and MOA were released in February, 2023. This talk introduces interactively JuMP and MultiObjectiveAlgorithms.

■ MD-25

Monday, 14:30-16:00 - Room: Maurice Keyworth 1.32

Accreditation/certification for OR professionals: the what, why and how

Stream: Making an Impact: The Practitioners' Stream 2
Making an impact session
Chair: Ruth Kaufman

1 - Certifications: the what, why and how of earning professional recognition
Making An Impact, Juan Manuel Garcia Lopez, Alex Burdon, Ruth Kaufman

Certified Analytics Professional? Advanced Data Science Professional? Chartered Scientist? Fellow of the Operational Research Society? Each of these standards provides an independent endorsement of your professional skills and practice in a world where, once you have graduated, there are no commonly agreed rules and regulations about what it means to practice well. But is it right for you?

This session will bring together speakers who can introduce each of the different certifications and accreditations mentioned above, and explore the commonalities and differences, benefits and costs, from the point of view of provider, professional and employer; to help you decide whether one of these is a path you would like to follow, and set you off down that path.

You can find out more in advance of the session, on the various websites: https://certifiedanalytics.org/ https://www.theorsociety.com/ORS/ORS/Membership/Accreditation/ORS-Accreditation.aspx https://sciencecouncil.org/scientists-science-technicians/ https://alliancefordatascienceprofessionals.co.uk/documents/AfDSP_Guidance_June22.pdf

■ MD-26

Monday, 14:30-16:00 - Room: Maurice Keyworth 1.33

Practical skills: knowledge sharing tutorials

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: John Medhurst

1 - Free Text: How to use it
Oscar de Barsy

Learn how to use one of the most common but challenging types of data in any organization.

Free text is everywhere, from incoming emails, user queries and internal comments to sensitive information and client related data. Knowing how to properly leverage the latest technologies to make use of that data effectively is a core tool to manage our data dense world.

In this hands on tutorial, we will study how to use embeddings, the technique at the core of LLMs, to transform free text into numbers. We will look the practical case of classifying a type of incoming message so that they reach the correct team automatically and we'll examine different examples on how this technique can be applied to your own use cases and even give you the opportunity to try out the methods yourself.

2 - Increasing efficiency without costing the world: incorporating sustainable development goals into operational decision-making
Leendert Kok, Lotte Berghman

Operational decision making traditionally focuses on efficiency. By increasing efficiency, companies can reduce the number of routes, kms, working hours, and resources needed for operations, leading to lower operational costs and increased profitability.

In the last decade, there has been growing attention towards other types of KPIs, like the environmental impact of operations. In 2015, the United Nations adopted the 17 Sustainable Development Goals (SDGs) as a universal call to improve health and education, reduce inequality, and spur economic growth, while tackling climate change. These SDGs put a different and much wider focus on operational decision making.

In this workshop, we will review some of these SDGs, present methodologies for including them in operational decision making, and discuss how we as an OR community can contribute to reaching the Sustainable Development Goals.

■ MD-27

Monday, 14:30-16:00 - Room: Maurice Keyworth G.02

Robust optimization - theory and applications

Stream: Stochastic and Robust optimization
Invited session
Chair: Milos Kopa

1 - Solving Decision-Dependent Robust Problems as Bilevel Optimization Problems
Simon Stevens, Henri Lefebvre, Martin Schmidt, Johannes Thürauf

Both bilevel and robust optimization are established fields of mathematical optimization and operations research. However, only until recently, the similarities in their mathematical structure has neither been studied theoretically nor exploited computationally. Based on the recent results by Goerigk et al. (2025), we reformulate a given strictly robust optimization problem with a decision-dependent uncertainty set as an equivalent bilevel optimization problem and then use solution techniques from the latter field to solve the robust problem at hand. If the uncertainty set can be dualized, the respective bilevel techniques to obtain a single-level reformulation are very similar compared to the classic dualization techniques used in robust optimization but lead to larger single-level problems to be solved. Our numerical study shows that this leads to larger computation times but may also slightly improve the dual bound. For the more challenging case of a decision-dependent uncertainty set that cannot be dualized because it is represented as a mixed-integer linear problem, we are not aware of any applicable robust optimization techniques. Fortunately, by exploiting the corresponding bilevel reformulation and recent bilevel solvers, we are able to present the first numerical results for this class of robust problems.

2 - Robust optimization approaches for the Dynamic Airspace Configuration problem
Martina Galeazzo, Luigi De Giovanni, Go Nam Lui, Guglielmo Lulli

Many factors are contributing to raising challenges in Air Traffic Management operations, from extreme and adverse weather conditions to increasing air traffic demand and emerging usages of airspace. In this context, efficiently managing limited airspace capacity while accounting for traffic demand uncertainty is crucial. In this work, we rely on the concepts of sector (a 3D connected portion of the airspace) and capacity, which measures the traffic demand that can be safely monitored within a sector. Our study focuses on configurations, i.e. partitions of the airspace into non-overlapping sectors. Given a pre-determined set of configurations, we aim to determine an optimal and robust configuration plan that effectively absorbs air traffic under demand uncertainty; this problem is known in literature as the Dynamic Airspace Configuration problem. We propose two solution approaches: an Integer Linear Programming (ILP) model and a graph-based formulation using a shortest path algorithm, both accounting for operational constraints on the configuration dynamics. We extend the formulations to account for uncertainty and provide optimal configuration plans that are robust against possible traffic demand variations. We evaluate our robust approach to dynamic airspace configuration on Madrid ACC, considering available configurations and historic traffic data, and present a computational study focusing on the trade-offs between minimizing traffic overflow and robustness.

3 - Strategically Robust Game Theory via Optimal Transport
Dario Paccagnan, Nicolas Lanzetti, Sylvain Fricker, Saverio Bolognani, Florian Dorfler

In many game-theoretic settings, agents are challenged with taking decisions against the uncertain behavior exhibited by others. Often, this uncertainty arises from multiple sources, e.g., incomplete information, limited computation, bounded rationality. While it may be possible to guide the agents' decisions by modeling each source, their joint presence makes this task particularly daunting. Toward this goal, it is natural for agents to seek protection against deviations around the emergent behavior itself, which is ultimately impacted by all the above sources of uncertainty. To do so, we propose that each agent takes decisions in face of the worst-case behavior contained in an ambiguity set of tunable size, centered at the emergent behavior implicitly defined. This gives rise to a novel equilibrium notion, which we call strategically robust equilibrium. Building on its definition we show that, when judiciously operationalized via optimal transport, strategically robust equilibria (i) interpolate between Nash and security strategies; (ii) come at no additional computational cost compared to Nash equilibria; (iii) often lead to better decisions and higher payoffs. Through a variety of experiments including bi-matrix games, congestion games, and Cournot competition, we show that strategic robustness protects against uncertainty in the opponents' behavior and, surprisingly, results in higher equilibrium payoffs - an effect we refer to as coordination via robustification.

4 - Approximating Robust Problems by Uncertainty Sets
Marc Goerigk, André Chassein, Jamie Fairbrother

For robust combinatorial optimization, a central problem ingredient that decides the problem complexity is the type of uncertainty set. Previous research has already discovered modifications to the uncertainty set as a path to derive approximation results by replacing high-cardinality discrete uncertainty sets by low-cardinality sets. In this talk, I discuss possibilities to replace one type of uncertainty set by another type of uncertainty set, including computational challenges of this approach.

■ MD-28

Monday, 14:30-16:00 - Room: Maurice Keyworth 1.03

Human-AI Collaboration and Ethics

Stream: Decision Support Systems
Invited session
Chair: Rudolf Vetschera

1 - Integrated Data-Supported Smart Root Cause and Process Failure Analysis
Mahdi Mokhtarzadeh, Sidharta Gautama, Jorge Rodríguez-Echeverría

In production systems, a frequent disconnection exists between Process Failure Mode and Effects Analysis (pFMEA) and Root Cause Analysis (RCA) during failure analysis, leading to the inefficient utilization of the causal knowledge documented in pFMEA. Furthermore, despite advancements in technology, pFMEA risk analysis has remained subjective and expert-dependent. This study introduces a data-supported integrated pFMEA-RCA framework that combines quantitative data from the production process with pFMEA qualitative expert knowledge to transform traditional static pFMEA into a connected, continuously updated system with autonomous reasoning capabilities. The framework constructs a failure mode tree based on pFMEA information, links quality control data to this tree, and utilizes a Beta-binomial Bayesian approach for updating and inferring from the tree. This improves failure analysis causality and objectivity and effectively bridges the gap between pFMEA and RCA. The framework is validated through a case study, complemented by sensitivity analysis to demonstrate its robustness. Its key benefits include the ability to objectively prioritize critical failure modes and causes, identify overlooked issues and inconsistencies in pFMEA documents, support data-driven decision-making and automated analysis, produce computer-readable and structured pFMEA documents, and evaluate normal and abnormal operating conditions.

2 - Granularity-Driven Post-Correction Model for Digitizing Handwritten Aviation Maintenance Records
Jianwu Xue, Zhaoyang Zhang

This study addresses the critical challenges in digitizing handwritten civil aviation maintenance records through an innovative approach that integrates granularity-aware tokenization with post-recognition correction mechanisms. First, we construct a domain-specific corpus optimized for tokenization by combining web-crawled aviation maintenance terminology with offline collected records, analyzed using WordSmith to establish linguistic patterns, resulting in a 23.6% improvement in labeling consistency. We then develop a correction model embedding tokenization-aware mechanisms within KenLM (statistical) and Transformer (neural) architectures to address seven distinct error categories prevalent in maintenance documentation, including character mis-segmentation and domain-specific terminology errors. Evaluation using engine maintenance records demonstrated that our Transformer-f model achieved a 12.3% accuracy improvement and

18% speed enhancement over baseline approaches. Finally, we implement a system using Spring MVC architecture that integrates recognition modules with granularity-driven correction algorithms and dynamic corpus management capabilities. Field testing across multiple maintenance facilities yields a 94.7% correction accuracy and reduced manual review requirements by 40%. This research provides a practical solution for aviation maintenance digitization that effectively balances accuracy with operational efficiency while maintaining regulatory compliance.

3 - Do you forgive your algorithm? The impact of self-confidence, perceived accuracy, and trust on the use of decision support advice
Maren Suffel, Ayşegül Engin, Rudolf Vetschera

Artificial intelligence (AI) is transforming decision support by enabling faster, more accurate decision-making in tasks such as forecasting, scheduling, and hiring. However, many AI systems lack transparency due to their "black-box" nature, raising concerns about users' ability to understand and trust their outputs. This can impact decision quality, as users must judge when to rely on AI or override its recommendations. Effective human-AI collaboration requires careful judgment, but this process is often influenced by cognitive biases. Overconfidence in one's abilities or uncritical acceptance of AI (overreliance) can undermine collaboration, while rejecting correct AI outputs (underreliance) limits potential benefits. These behaviors are especially relevant in high-stakes environments like air traffic control, where AI-based decision support can reduce delays and fuel consumption. Nonetheless, controllers' expertise remains essential, requiring effective joint human-AI decision-making. This study examines how self-confidence, perceived system accuracy, and trust evolve as participants interact with system recommendations in a simplified air traffic control task. We focus on how users respond to system errors, including how they adapt reliance and recover trust. Initial observations suggest that unexpected AI accuracy drops or shifts in task structure trigger different biases, with some users becoming overly cautious, while others persist in following incorrect advice.

■ MD-29

Monday, 14:30-16:00 - Room: Maurice Keyworth 1.04

Product, Pricing, and Channel Strategies under Market Uncertainty

Stream: Pricing and Revenue Management Innovations
Invited session
Chair: Andreas Soteriou

1 - Opaque Products in a Generalized Market Model
Michelle Mitter, Jochen Gönsch

Opaque products, such as the blind booking services offered by Lufthansa, Wizz Air, and Hotwire, are increasingly common in practice and appear in other industries, such as retail mystery boxes. Within Strategic Operations Management (SOM), analyses of opaque products are often based on Hotelling-type models, where consumer preferences for component products are not independent but inherently linked. This assumption implies that if a consumer values both components equally, she will always face an adjustment cost of 0.5 for each component. However, the model cannot represent consumers who strongly prefer both components and thus experience lower adjustment costs - or those who dislike both, leading to high adjustment costs. We extend this framework to a more general market model where component preferences are independent and uniformly distributed. Using an analytical optimization approach based on Karush-Kuhn-Tucker (KKT) conditions, we show that the choice of market model critically affects both the profitability of opaque products and optimal pricing strategies. In contrast to previous findings, segmentation benefits from opaque selling are less frequent and strongly depend on market characteristics, particularly the degree of horizontal differentiation.

2 - Channel Expansion Decisions in a Dual E-Marketplace
Fatemeh Zand

This paper examines the strategic interactions between supplier encroachment and secondary marketplaces in e-commerce platforms. We study a supply chain where a supplier can sell directly through the platform's agency channel while maintaining wholesale relationships, and the platform operates both new and secondary product marketplaces through trade-in programs. Using a game-theoretic model, we find that supplier encroachment leads to significant secondary market expansion and transforms the platform's reselling strategy. The supplier's encroachment decision is primarily driven by agency channel efficiency, with counter-intuitive patterns emerging at high efficiency levels. Our results reveal that higher reselling and production costs often encourage encroachment, while a larger proportion of replacement customers reduces it

3 - On the antagonistic and synergistic relationship between price promotions and safety stock
Andreas Soteriou, George Hadjinicola, Nyoman Pujawan, Arnaud Lacheret

In today's competitive markets, well-structured operations and supply chains are recognized for their impact on organizational performance. Scholars and practitioners are moving beyond cost-focused views, while real-time data analytics present new challenges and opportunities. Meanwhile, marketing efforts adapt to shorter product life cycles and changing consumer behavior, aiming to enhance value propositions. However, these efforts often operate separately from operations. While the need for marketing-operations coordination is well known, research increasingly emphasizes a deeper integration of these functions.

This paper examines price promotions and their relationship with operational factors. We propose a framework capturing the interplay between price promotions and factors like safety stocks, service levels, inventory costs, and lead time. The framework assumes that higher safety stocks and service levels drive sales growth. The framework can help managers determine when increased safety stocks can replace or complement price promotions in driving sales. When should firms rely on safety stocks, promotions, or a combination of the two? Our work highlights the conflicting and complementary roles of marketing and operations in leveraging price promotions and safety stocks and identifies both the antagonistic and synergistic relationship of the marketing and operations functions, through price promotions and safety stocks, respectively.

■ MD-31

Monday, 14:30-16:00 - Room: Maurice Keyworth 1.06

Optimization under uncertainty in Logistics and Transportation

Stream: Stochastic and Robust optimization
Invited session
Chair: Francesca Maggioni
Chair: Andrea Spinelli

1 - Integrated customer portfolio selection and procurement quantity planning for a supplier
Yasemin Merzifonluoglu, Tijn Fleuren, Joseph Geunes, Renata Sotirov

This paper considers a supplier who offers a customized product to multiple potential customers, each with uncertain demand. The supplier's end items consume common raw materials, which must be ordered far in advance of the selling season due to long procurement lead times. As a result of the customization, each customer negotiates an individual agreement with the supplier, leading to customer-specific prices and loss of goodwill costs in case of unsatisfied demands. The

supplier aims to select a portfolio of customers and a raw material procurement quantity to maximize its expected profit. We formulate the problem based on echelon stockout costs, and establish optimality conditions and bounds for the newsvendor solution. This formulation, moreover, elegantly generalizes the analysis of the so-called selective newsvendor problem to address settings with lost sales and an uncertain spot market price for expediting. As customer requirements are oftentimes interdependent, we further extend our models to handle correlated customer demands. Lastly, we analyze the setting in which capacity can be reserved with the supplier prior to the selling season. Since the resulting models are difficult to solve exactly, we propose conic quadratic programming-based heuristics as well as sampling-based methods. Finally, we demonstrate the remarkable performance of the solutions obtained assuming normally distributed demands even when the true distributions deviate from this assumption.

2 - Recent results on recoverable robust shortest path problem
Marcel Jackiewicz, Adam Kasperski, Pawel Zielinski

The recoverable robust approach is a two-stage approach allowing for better uncertainty mitigation than the, more conservative, robust (single-stage) approach. We examine the recoverable robust version of the shortest path problem. In this version a path is chosen in the first stage, based on the known first stage cost and uncertain second stage cost, and, after the costs are revealed, the path can be modified to some extent to minimize the cost. This problem is known to be strongly NP-hard in general digraphs.

We consider the problem in acyclic digraphs with natural, known from the literature, neighbourhoods. By constructing efficient algorithms for various classes of acyclic digraphs we show that the problem can be solved in polynomial time for interval uncertainty but remains NP-hard for continuous and discrete budgeted uncertainty.

For discrete budget uncertainty, we strengthen the known NP-hard result and show that the problem is hard for the third level of polynomial hierarchy for arc exclusion and the arc symmetric difference neighbourhoods and the inner adversarial problem for these neighbourhoods is hard for the second level of polynomial hierarchy. For continuous case, we present compact MIP formulation and polynomial time algorithm for the problem in arc series-parallel graphs and for the adversarial problem in acyclic digraphs.

3 - Accelerating Large-Scale Stochastic Optimization: The TULIP Approach
Berend Markhorst, Markus Leitner, Joost Berkhout, Alessandro Zocca, Rob van der Mei

Solving large-scale stochastic optimization problems is challenging, especially when uncertainties are represented by a large number of scenarios. To tackle this, we introduce TULIP ("Two-step warm start method Used for solving Large-scale stochastic mixed-Integer Problems"), an efficient approach for solving two-stage stochastic (mixed) integer programs with an exponential number of constraints. TULIP consists of two steps: we first generate a reduced set of representative scenarios and solve the root node of the corresponding integer linear program using a cutting-plane method. The generated constraints are then used to accelerate solving the original problem with the full scenario set in the second phase. We demonstrate the generic effectiveness of this method on two benchmark problems: the Stochastic Capacitated Vehicle Routing Problem and the Two-Stage Stochastic Steiner Forest Problem. In our numerical experiments, we find that TULIP yields significant computational gains compared to solving the problem directly with branch-and-cut.

4 - A Stochastic Electric Vehicle Routing Problem under Uncertain Energy Consumption
Andrea Spinelli, Dario Bezzi, Ola Jabali, Francesca Maggioni

The increasing adoption of Electric Vehicles (EVs) for service and goods distribution has led to the emergence of Electric Vehicle Routing Problems (EVRPs), a class of vehicle routing problems addressing the unique challenges posed by the limited driving range and recharging needs of EVs. While the majority of EVRP variants have assumed a deterministic energy consumption, in this work we focus on the Stochastic Electric Vehicle Routing Problem with a Threshold recourse policy (SEVRP-T), where the uncertainty in energy consumption is considered, and a recourse policy is employed to ensure that EVs recharge at charging stations whenever their state of charge falls below a specified threshold. We formulate the SEVRP-T as a two-stage stochastic mixed-integer second-order cone model, where the first stage determines the sequences of customers to be visited, and the second stage incorporates charging activities. The objective is to minimize the expected total duration of the routes. To cope with the computational complexity of the model, we propose a heuristic based on an Iterated Local Search procedure coupled with a Set Partitioning problem. To further speed up the heuristic, we derive two lower bounds on the corresponding first-stage customer sequences. Furthermore, to handle a large number of energy consumption scenarios, we employ a scenario reduction technique. Extensive computational experiments are conducted to validate the effectiveness of the proposed solution strategy an

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■ MD-32

Monday, 14:30-16:00 - Room: Maurice Keyworth 1.09

Low- and zero-emission solutions for maritime operations-1

Stream: Maritime and Port Logistics
Invited session

Chair: *Kjetil Fagerholt*
Chair: *Peter Schütz*

1 - Fleet renewal and retrofit strategies for decarbonizing offshore logistics
Andreas Ormevik, Marius Bjørke, Camilla Lie, Marte Vingsnes, Kjetil Fagerholt

To achieve the emission reduction targets set by the maritime industry, large investments must be made in renewing and retrofitting the existing fleets in various shipping segments. This work summarizes our work with the strategic supply vessel fleet renewal and retrofit problem (SVFRRP) for guiding the transition towards a greener fleet of platform supply vessels (PSVs) used for offshore oil and gas logistics. Since the future costs of the different relevant fuel types are uncertain, we propose a new two-stage integer stochastic programming model for the SVFRRP.

In each time period of the planning horizon, the model includes strategic decisions to meet the specified emission requirements. Existing vessels might be retrofitted to a new power system, or scrapped, while new vessels can be acquired and introduced to the fleet. Furthermore, the fleet deployment is considered, controlling the use of each vessel in order to fulfill the required cargo demands at each offshore installation serviced by the PSV fleet. We perform an extensive assessment of available fuel technologies for PSVs and use this in computational analyses for two real case studies from the Norwegian oil and gas industry.

We compare the optimal fleet renewal strategies and corresponding costs from different emission reduction trajectories, and the results from the analyses provide valuable insights to the impact of various emission reduction policies to the optimal fleet renewal strategies.

2 - At-Sea Refueling Solution for Transitioning Deep-Sea Fishing to Green Fuels
Mohamed Kais Msakni, Peter Schütz, Johanne Dobbe Flemmen, Daniel Kielland, Simen Busengdal

The transition to low- and zero-emission fuels poses a significant challenge for deep-sea fishing vessels, which operate far from shore for extended durations. These vessels currently depend on high-energy density fuels such as Marine Gas Oil (MGO), whereas alternative green

fuels like hydrogen and ammonia have significantly lower energy densities, limiting operational range. To address this challenge, this paper explores the feasibility of an innovative at-sea refueling system using a fleet of bunkering vessels to maintain uninterrupted fishing operations. The problem is modeled as a mixed-integer programming formulation using a time-space network representation. The model determines the required number of bunkering vessels, their routes, and refueling schedules, ensuring that neither bunkering nor fishing vessels run out of fuel at any time during the planning horizon. Moreover, the model ensures synchronization between bunkering and fishing vessels, allowing refueling operations to take place at the same time and location. The computational study is applied to a case study of Norwegian deep-sea fishing operations, constructed using AIS tracking data from the Barents Sea, where the longest voyages occur. The results provide valuable insights into the viability of at-sea refueling under different fuel scenarios.

3 - Energy efficient tramp shipping
Line Reinhardt, Agnieszka Sivertsen

Tramp shipping is one of three major types of shipping. Here we optimize a supply demand bulk problem with multiple commodities in an effort to reduce the operational cost per shipped commodity weight. A major cost is the energy consumption, thus, by reducing the energy consumption the emissions are reduced accordingly. Clearly the energy should be measured by the amount of cargo shipped as the aim is to ensure efficient shipping. The problem presented is a real-life problem encountered by a company and therefore, the formulation also considers flexible demand (More or Less Owner Option), heterogeneous vessels, draft and start and end point of vessels in the objective. An arc flow and a path flow model are presented and compared and real-life instances with 1 to 4 commodities, 6 to 16 ports and 3 to 7 vessel types are tested. Since the objective is fractional, a parametric algorithm is used to solve the presented models. Results show that solutions can be achieved in reasonable time using the parametric method for the real-life sized instances, however, the path flow model will grow exponentially when the size of the problem grows.

4 - Can rich information decrease anchorage waiting time? A game-theoretic analysis toward sustainable shipping
Ayato Kitadai, Takuya Nakashima, Yudai Tsurusaki, Rei Miratsu, Naoki Mizutani, Nariaki Nishino

This study demonstrates that reducing information incompleteness among ships can deconcentrate port arrival times, lowering greenhouse gas (GHG) emissions without compromising profits. "Sail Fast, Then Wait" (SFTW), a common practice in cargo shipping, exacerbates GHG emissions. While initiatives like the Blue Visby Consortium are making collaborative efforts to address this issue and have shown promising results in the real world, challenges remain. Ships navigate based on profitability within a competitive environment, suggesting the need to complement voluntary initiatives toward broader impact. Although game theory provides a useful framework for balancing profit and cooperation, game-theoretic studies on queuing assume homogeneous players with complete information, which does not align with actual ship navigation. To address these limitations, we formulated ship sailing as a Bayesian game under various information structures. Our results show that in environments with incomplete information, SFTW emerges as the unique equilibrium. Moreover, if any player gains access to the private information of all others, their best-response set expands, allowing for slower and more environmentally friendly actions without adversely affecting others. We further validated our theoretical results with empirical data. Our findings suggest that the prevalence of technologies enabling ships to infer others' private information can effectively reduce SFTW and help mitigate climate change.

■ MD-33

Monday, 14:30-16:00 - Room: Maurice Keyworth 1.31

Algorithms in Decision Modelling

Stream: Decision Analysis
Invited session
Chair: *Ahti Salo*

1 - Using Portfolio Decision Analysis to Select Reinforcement Actions in Infrastructure Networks
Ahti Salo, Joaquin de la Barra, Leevi Olander, Kash Barker

Critical infrastructure networks, such as railway networks, provide essential services whose continuity must be secured. Towards this end, we combine multi-criteria portfolio decision analysis with Probabilistic Risk Assessment (PRA) to construct portfolios of reinforcement actions that contribute cost-efficiently to the attainment of objectives that represent the network's services. Our model admits a range of assumptions about the relative importance of these objectives through incomplete information about the weights associated with the corresponding criteria. It also helps identify which portfolios of reinforcement actions perform best with regard to these objectives at different budget levels. We illustrate our model with a study on the reinforcement of switches at a railway station, which connects several origin-destination pairs with different volumes of planned traffic. If one or more switches are disrupted, some connections may be lost, and the corresponding traffic volume will be affected. We formulate an additive multi-criteria utility function such that the weight of each criterion reflects the planned traffic volume for the corresponding connection. PRA algorithms are used to assess the reliability of these connections. The results help identify the switches where the reinforcement actions should be implemented when the aim is to maximize the station's performance, as measured by the expected enabled traffic volume between the origin-destination pairs.

2 - Adversarial Risk Analysis with Fully Probabilistic Designs for sequential games
Mario Chacón-Falcón, Tatiana Guy, Miroslav Kárný, David Rios Insua

Adversarial risk analysis (ARA) is a decision analytic methodology that informs decision-making when facing intelligent opponents and uncertain outcomes. It enables an analyst to model beliefs about an opponent's utilities, capabilities, probabilities, and the strategic calculations that an opponent employs. A major aplication of ARA is in defend-attack games, mitigating standard common knowledge and common prior assumptions in standard game-theoretic settings. Yet ARA entails very involved adversarial modeling and computations. To mitigate these, we explore here the combination of ARA with fully probabilistic designs (FPD), used in control theory to support an agent's decisions in choosing the decision distribution that is closest to the agent's ideal trajectory. Specifically, we use FPD to model and forecast the opponent's decisions within an ARA setting and present how to handle simple defend-attack template games. We also discuss how to merge ARA and FPD in sequential games to handle reinforcement learning problems under threats.

3 - Investment decisions analysis with prospect theory: evidence from earnings conference calls
Yunze Xie, Jian-Bo Yang, Dong-Ling Xu

As an important medium for providing information to investors, earnings conference calls play an important role in the stock market. Although many scholars have been dedicated to exploring the textual characteristics of conference call, the process and analysis of textual information is insufficient. The textual characteristics are often directly used to analyze the effect on the stock market, but the real feelings of investors towards them are ignored. Especially for the stock market, it is difficult for investors to act completely rationally, as their reactions to information are influenced by individual psychological characteristics. Therefore, I will introduce prospect theory to analyze the textual characteristics of earnings calls and combine these characteristics

based on evidential reasoning model, digging out the information and exploring the real feelings of investors to the greatest degree. Therefore, this research will achieve accurate evaluation of calls by using prospect theory and predict stock returns combined with company financial performance based on interpretable artificial intelligence, and provide support for investor to make decisions on investment.

4 - Enhancing Decision Tree Analysis via Mixed-Integer Linear Programming and Polyhedral Analysis
Mahdi Doostmohammadi, Jitamitra Desai

This study presents a novel mathematical programming approach to decision tree analysis, addressing the limitations of traditional methods such as stochastic dynamic programming. We model decision trees as path-based polynomial programmes and reformulate them into mixed-integer linear programs (MILP), solvable with standard optimization techniques. In order to strengthen the MILP formulation, we apply polyhedral analysis to derive families of strong valid inequalities for the feasible region of the MILP model. These valid inequalities (cutting planes) are integrated into a branch-and-cut framework to solve medium- to large-scale decision tree instances. Preliminary computational results demonstrate the effectiveness of this exact approach in solving decision tree problems.

■ MD-34

Monday, 14:30-16:00 - Room: Michael Sadler LG10

Advancements of OR-analytics in statistics, machine learning and data science 1

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: *Bruno Kamdem*
Chair: *Sadia Samar Ali*
Chair: *Gerhard-Wilhelm Weber*

1 - A cluster impurity-based hybrid resampling for imbalanced classification problems
You-Jin Park

Generally, when a class imbalance problem exists, the classifier tends to become biased towards the majority class and thus the minority class instances are often misclassified to the majority class. And, the overlap problem in class imbalanced data is known as one of the key sources that makes the learning task become difficult or deteriorates the learning performance. Thus, in this research, we develop a cluster impurity-based hybrid resampling technique to improve the classification performance of class imbalanced data with considering both intra-cluster class imbalance and inter-cluster overlap problems. In particular, various clustering methods are employed for identifying the clusters of the instances and the cluster impurity of each instance is obtained for measuring the cluster-overlap degree. Then, the synthetic instances are created and eliminated recursively based on the cluster impurity. To validate the effectiveness of the developed technique, comprehensive experiments have been conducted on forty imbalanced datasets and non-parametric hypothesis tests have been executed to prove the statistical difference in classification performances between the developed technique and other resampling techniques.

2 - An Ensemble-Based Machine Learning Approach to Increase the Robustness of Forecast Combination Weights
Veronika Wachslander, Thomas Setzer

Forecasting economic or business figures is often the basis for corporate planning, and combining individual forecasts by computing their weighted average regularly increases predictive accuracy. A huge amount of literature deals with the determination of beneficial combination weights and one popular approach is the estimation of so-called optimal weights (OW), minimizing the mean squared error on available past data. However, this and other approaches that learn weights from data usually perform worse on unseen data than simply assigning equal weights (EW). The reason can be seen in the typically limited amount of data available for the estimation, so that weights are (over)fit on random structures that often do not occur on new data, in turn leading to strongly misfit weights and high errors. One widely used approach to reduce overfitting is to estimate OW and shrink these towards EW. This technique requires the tuning of a shrinkage hyperparameter, which is subject to uncertainty. Unfortunately, this uncertainty usually also causes higher errors than EW on unseen data in empirical settings. We introduce a machine learning method using subsampling to learn and shrink combination weights. The method aims at reducing overfitting, while still considering generalizable structures in training data by learning more stable weights that should better fit new, unseen data. Experiments with synthetic data show promising results compared to common weighting and tuning strategies.

3 - Analyzing and Visualizing Job Skill Requirements on Job Search Websites
Li-Ching Ma, Cheng-Syuan Lin

The prevalence of the Internet has led to an explosion of data from various sources, often resulting in information overload. Therefore, finding ways to help users efficiently organize and understand vast amounts of information has become an important issue. Visual representations can simplify and aggregate complex information into meaningful patterns, helping people understand their decision-making environment and make better decisions. In human resource management, the job market also presents a large amount of recruitment information every day. When graduating college students are preparing to look for a job, they usually need to spend a lot of time browsing numerous job postings on recruitment websites to understand the abilities and skill requirements for a specific job category. This study proposes a graphical approach for analyzing and visualizing online recruitment information on a two-dimensional plane using mathematical programming optimization and grouping methods. Taking a well-known online job search website in Taiwan as an example, the proposed process and its corresponding results are illustrated. Users can directly see the capabilities, skill requirements, and their relationships for a specific job category on a simple graph. This can help them be better prepared before applying for a job.

4 - Exact and Heuristic Solution Approaches for Clustering with Localized Feature Selection
Cem Iyigün, Sinan Gürel, Gozdenur Buyuk

The complexity of real-world data characterized by excessive number of features poses significant challenges in clustering problems. Incorporating feature selection decisions in clustering is a way to tackle this issue. Clustering with localized feature selection takes into account the fact that, for each cluster, the relevant set of features may be different. Localized feature selection has been in use in many areas of clustering, such as image segmentation, bioinformatics, and recommendation systems. This paper studies a clustering problem that makes joint clustering and localized feature selection decisions The paper presents alternative Second Order Cone Programming models that find exact optimum solutions. Furthermore, it presents a mathematical programming-based heuristic (matheuristics) and a heuristic algorithm for the problem. Finally, the paper compares computational performance of proposed methods.

■ MD-35

Monday, 14:30-16:00 - Room: Michael Sadler LG15

Nonlinear Optimization Algorithms and Applications: 3

Stream: Continuous and mixed-integer nonlinear pro-

gramming: theory and algorithms
Invited session
Chair: *Ya-xiang Yuan*
Chair: *Xin Liu*
Chair: *Cong Sun*
Chair: *Zaikun Zhang*

1 - New gradient methods with quasi-Newton property and quasi-Newton update
Cong Sun

New stepsizes for gradient method are proposed, from the perspective of quasi-Newton property. A unified stepsize update strategy is proposed through quasi-Newton update formulas. The global convergence of the proposed gradient method is proved, with the combination of GLL nonmonotone linesearch. The convergence rate is also analyzed. In numerical experiments, different gradient methods representing different quasi-Newton update strategies are compared. It turns out that the gradient method with BFGS update performs the best. It outperforms the benchmark gradient and conjugate gradient methods in terms of computational cost.

2 - A random active set method for strictly convex quadratic problem with simple bounds
Ran Gu

The active set method aims at finding the correct active set of the optimal solution and it is a powerful method for solving strictly convex quadratic problem with bound constraints. To guarantee the finite step convergence, the existing active set methods all need strict conditions or some additional strategies, which greatly affect the efficiency of the algorithm. In this talk, we propose a random active set method which introduces randomness in the update of active set. We prove that it can converge in finite number of iterations with probability one without extra conditions on the problem or any additional strategies. Numerical experiments show that the algorithm can obtain the correct active set within a few iterations, and it has better efficiency and robustness than the existing methods.

3 - Model-driven and data-driven inverse problems and intelligent computing
Yanfei Wang

Model-driven geophysical inverse problems have played an important role in the field of resource and energy exploration. Taking oil & gas exploration as an example, the basic idea is to establish a geological model and use the model-driven inverse problem-solving method. Based on geophysical data such as seismic waves collected on the surface, the underground geological structure is inverted to accurately infer key information such as the location, thickness and reservoir characteristics of underground oil & gas layers, thereby guiding the rational layout of oil wells and the formulation of mining plans. In recent years, data-driven geophysical inversion and interpretation have attracted a great attention. The basic idea is to directly mine geological rules from the data itself. It can integrate data from different geophysical methods, improving the accuracy and reliability of inversion results. In the exploration of complex geological structures, through data-driven technologies such as machine learning, geological features can be automatically identified, providing more efficient and accurate interpretation results for geophysical applications such as resource exploration and geological disaster prediction. This research takes a special unconventional oil & gas-natural gas hydrate as an example to explore the geophysical inversion modeling and introduce deep-learning methods for interpretation. Finally, the discussion and outlook of this discipline field are presented.

4 - Asymmetric Long-Step Primal-Dual Interior-Point Methods with Dual Centering
Yurii Nesterov

We discuss a new way of development of asymmetric Interior-Point Methods for solving primal-dual problems of Conic Optimization. It is very efficient for problems, where the dual formulation is simpler than the primal one. The problems of this type arise often in Semidefinite Optimization (SDO), for which we propose a new primal-dual method with very attractive computational cost. In this approach, we do not need sophisticated Linear Algebra, restricting ourselves by standard Cholesky factorization. However, our complexity bounds correspond to the best-known polynomial-time results. Moreover, for symmetric cones the bounds automatically depend on the minimal barrier parameter between the primal and the dual feasible sets. We show by SDO-examples that the corresponding gain can be very big. We discuss some classes of SDO-problems, where the complexity bounds are proportional to the square root of the number of linear equality constraints and the computational cost of one iteration is as in Linear Optimization. Our theoretical developments are supported by encouraging numerical testing.

■ MD-38

Monday, 14:30-16:00 - Room: Michael Sadler LG19

(Deep) Reinforcement Learning for Combinatorial Optimization

Stream: Data Science meets Optimization
Invited session
Chair: *Yingqian Zhang*
Chair: *Kevin Tierney*
Chair: *Yaoxin Wu*

1 - Direct action selection for solving the dynamic job shop scheduling problem with deep reinforcement learning
Fynn Martin Gilbert, Kevin Tierney

This study compares hyperheuristic and direct job selection strategies in deep reinforcement learning (DRL) for the dynamic job shop scheduling problem (JSSP). Both hyperheuristics and direct job selection have emerged as prominent action selection mechanisms in DRL for solving JSSPs, particularly in dynamic, uncertain environments that include machine breakdowns or variable processing durations, which better reflect real-world manufacturing challenges. While direct job selection and especially hyperheuristic strategies are widely used in DRL for job shop scheduling, their relative strengths and limitations remain an open question. To explore its relative strengths, we investigate direct job selection as an alternative to hyperheuristic agents for makespan minimization by comparing their performance, training efficiency, and generalizability. We conduct experiments in a discrete event simulation environment, training both DRL approaches across different problem sizes and degrees of variability and flexibility. This comparison highlights the critical role of action selection mechanisms in DRL-based solution procedures for the dynamic JSSP and provides empirical guidelines for designing effective DRL scheduling policies.

2 - Static and Dynamic Policies for Multi-item Service Level Agreements with Finite Review Horizons and Penalty Costs
Tarkan Temizoz, Christina Imdahl, Remco Dijkman, Douniel Lamghari-Idrissi, Willem van Jaarsveld

Service Level Agreements (SLAs) align performance expectations in operations management. In multi-item inventory systems, suppliers aim to meet an aggregate fill rate (AFR) target by using static base-stock policies (BSPs). To set the order-up-to levels, they typically rely on a greedy heuristic (GH), assuming infinite review horizons. However, incorporating finite review horizons, penalty costs for underperformance, and real-time performance feedback can offer cost savings. We propose a two-tier solution framework. The static approach identifies which infinite horizon AFR target, when fed into GH, produces the cost-minimizing BSP for a given SLA. To find this, we present a simulation-based algorithm that generates candidate BSPs and efficiently prunes the search space. The dynamic approach reduces the combinatorial action space to a smaller set of replenishment rules by introducing composite actions, each specifying an order-up-to level for every item in the system. To implement this approach, we train Deep

Reinforcement Learning policies that learn to choose among the composite actions in real-time. In numerical experiments, results show that dynamic policies reduce costs on average 4% relative to the best BSP benchmark while maintaining similar AFR and incurring mostly fewer penalties. We observe that a longer horizon with a higher penalty can lead to lower costs than a shorter horizon with a lower penalty, showing the importance of negotiating for longer review horizons.

3 - Real-time capacity management in on-demand delivery platforms: A reinforcement-learning approach
Gökhan Ceyhan, Pol Arias, Malte Winckler

Just Eat Takeaway.com (JET) manages an on-demand delivery platform characterised by uncertain demand with spatiotemporal patterns and short delivery time targets. A critical component of this system is the real-time capacity management that employs various actions to keep the courier demand and supply in balance in order to maintain a satisfactory and profitable customer service level. We focus on one of the demand-side actions, dynamic delivery areas, which curtails the demand by shrinking the originally planned delivery areas of the restaurants. We model this problem as a sequential decision problem under stochastic demand and develop a reinforcement learning approach to drive these decisions. As our action space is quite large, we do not attempt to train a model to learn those decisions. Instead, we train a model to learn delivery time constraints for different hours of the day and for different zones of the city. We then solve a bi-objective mixed-integer linear program at each decision point to determine the delivery areas of each partner under those learned delivery time constraints. We train our model in a simulation environment and test our approach under different scenarios. We compare our approach against the version where a single delivery time constraint is used throughout the day and across the region. We also compare our approach to the legacy approach where delivery areas are adjusted based on a predefined rule-based system.

4 - Beyond Optimality: Pragmatic AWS Instance Placement with Hexaly Solver
Rubén Ruiz

This paper presents a practical approach to solving the AWS EC2 virtual machine placement problem. We model the problem as a multi-dimensional, multi-objective, heterogeneous vector bin packing Mixed-Integer Linear Program (MILP). The model incorporates all relevant real-world EC2 features. The sheer size of the problem presents serious challenges to commercial mathematical solvers. While optimality is often desired in Operations Research, we need to be pragmatic in the sense that models are, after all, approximations of reality that often rely on estimated input data. We present a SET-based formulation based on Hexaly (formerly LocalSolver) solver. We compare two state-of-the-art mathematical solvers, namely Xpress and Gurobi, with Hexaly, demonstrating workable solutions where mathematical solvers go completely out of scope. Results indicate improvements over existing production placement algorithms. Our findings suggest that this practical modeling approach, which embraces the reality of working with approximate data and accepts near-optimal solutions, provides valuable insights to guide future EC2 instance placement algorithm development.

■ MD-41

Monday, 14:30-16:00 - Room: Newlyn GR.01

Systems Thinking and System Dynamics

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: David Lane

1 - Insights from causal loop diagrams used in real-world applications
Nici Zimmermann

There is growing interest in systems thinking among practitioners, particularly in policy. When applied to the right problem, systems thinking tools can be very powerful and help safeguard against short-sighted decision-making. Yet, recent research highlights a gap in policy practitioners' abilities to select and apply the appropriate systems thinking tools. Misapplication can lead to policy failure and unintended consequences as well as scepticism toward systems thinking. Causal loop diagrams (CLDs) have emerged as a particularly popular systems thinking tool among practitioners due to their ability to visualise system structure. Thus, knowing when and how to use them is particularly powerful. This presentation examines how CLDs can be applied successfully to real-world challenges, focusing on cases with high stakeholder involvement in the domains of natural space quality and construction product performance. The cases highlight how CLDs, combined with other approaches, facilitate the articulation and visualisation of different views on a problem and foster a more systemic and shared understanding. They also demonstrate how CLDs help structure discussions around intervention points, yet without informing on the effects of interventions. By assessing the use of CLDs in applied settings, this presentation contributes to the broader discourse on systems thinking in practice, emphasising CLDs' visual power and the importance of methodological rigour in their effective use.

2 - A decision support system for analysing different growth paths for local food networks
Christine Mendoza Pardo, Christian Fikar

Driven by consumer demand and political will, more and more local and regional networks are emerging to supply the hospitality sector and community catering with locally grown and produced food. Organized in networks, participants can bundle logistics activities, invest together and offer a wider range of products. However, many of these initiatives face operational challenges within their network activities, which is directly linked to the question of how these networks can grow and become a reliable source of local and regional products. To investigate this issue, this paper adopts a system dynamics approach to analyse how different growth strategies affect the system of a local food network. The growth strategies primarily focus on increasing the number of customers versus expanding the product range with their possible impacts on the underlying structures of these networks. Political and economic implications can be derived from the holistic approach, which contribute to the understanding of growth processes within local and regional food networks.

3 - Using co-designed criteria to evaluate the role of participatory systems dynamics in transdisciplinary research: learning from two case studies
Irene Pluchinotta, Simon Vakeva-Baird, Ke (Koko) Zhou, Gemma Moore

Participatory Systems Dynamics (PSD) is increasingly used to deepen our understanding of complex systems to support policy-making; in practice, this often involves collaborating with a range of stakeholders, focusing on understanding the interconnections between various issues, exploring different problem framing, facilitating solutions and fostering continuous learning. This paper explores the role of PSD, focusing on how PSD has been evaluated across different projects, both in the context of climate change and health.

Within the project "Complex Urban Systems for Sustainability and Health", PSD was applied to understand the use of urban natural space and designing strategies, in a case study in London (Thamesmead). The evaluation process focused on the challenges and opportunities of using PSD to co-produce knowledge, build capacity, and foster collaboration in real-world contexts. However, key lessons emerged about the approach to evaluating PSD in multi-stakeholder transdisciplinary projects. These insights are informing the evaluation of a subsequent project - "Policy and Implementation for Climate and Health Equity", allowing for refinement of the evaluation framework and methodology to evaluate PSD. This evaluation approach has evolved and uses co-designed criteria to enhance the feedback and reflexive learning processes within the project via focused evaluation activities.

■ MD-42

Monday, 14:30-16:00 - Room: Newlyn GR.02

Sustainable supply chains I

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: *Ayham Jaaron*

1 - An Integrated Rolling Horizon Approach for Mining Operations Planning with Environmental Considerations
Taha Lakhdari, Ilyas Himmich, Tarik Aouam

In the mining industry, the production of marketable ores involves multiple processes, such as extraction, treatment, transportation, blending, and drying. Blending decisions depend on previous processing options. Ignoring these dependencies can lead to suboptimal solutions, while integrating blending decisions into the supply chain increases planning complexity.

Uncertain demand, short lead times, and prioritized orders lead managers to use substitution strategies, providing products with deviated qualities or delayed delivery. This approach often results in blending rare superior qualities to fulfill less profitable demands, leading to significant production cost losses and valuable resource destruction. These substitution strategies often lead to inefficient asset utilization that results in over-consumption of water and energy due to missed optimization opportunities.

To address these issues, we propose a spatio-temporal decomposition methodology dividing the mining supply chain into Tactical, Operational, and Emergency Levels. These planning levels communicate via an integrated rolling horizon approach, ensuring a continuous information exchange, synchronized mid-, short, and urgent-term purposes, and adapt dynamically to unforeseen events affecting the production system. In real-world phosphate mining applications, this methodology has reduced total costs by 30% and significantly decreased water and energy usage compared to traditional management practices.

2 - Disruptive technologies and internal and external green supply chain management: role of ethical leadership and absorptive capacity
Ayham Jaaron

This study applies disruptive innovation theory and social learning theory coupled with the natural resource-based view to explore the impact of Disruptive Technologies (DTs) on internal and external GSCM, by considering the Absorptive Capacity (AC) as a mediator and Ethical Leadership (EL) as a moderator in the Chinese manufacturing firms. A survey instrument was developed and 435 responses were retrieved following the convenience sampling technique. Data analysis were performed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The results indicate a positive impact of DTs on external and internal GSCM. DTs were also found positively enhancing AC capabilities of supply chains. Similarly, AC was found to positively impact external and internal GSCM. Furthermore, EL moderates the relationships between DTs and internal GSCM, but not between DTs and external GSCM, whereas AC mediates the relationship between DTs and GSCM (internally and externally). The study contributes to natural resource-based view literature by empirically validating that information generation and assimilation through DTs and AC can consequently result in improving supply chains' capabilities relating to meeting GSCM goals internally and externally. More importantly, this study provides theoretical and empirical evidence that EL is an important variable that produces the learning effect among supply chain employees based on the leaders' novel perspectives supported by DTs innovation.

3 - Securing Critical Minerals for UK Net Zero 2050: Supply Risks and Circular Solutions
Richard Jackson

Critical minerals, such as nickel, lithium and rare earths, are those minerals that have both high economic vulnerability and global supply risk. They are vital for decarbonisation technologies, including electric vehicle batteries, wind turbines, and nuclear reactors. Their limited availability and uneven global distribution place significant pressure on supply chains as demand surges for Net Zero solutions. Decision Analysis Services Ltd (DAS) conducted studies for the UK Critical Minerals Intelligence Centre, on behalf of the UK Government Department for Business and Trade, to evaluate the supply risks and future UK mineral demand for electricity grid upgrades and nuclear deployment to meet Net Zero 2050 targets. We applied a bill of materials approach to undertake scenario analysis demand forecasting and assess risks at each stage of the value chain — from mining to refining and components. We have pinpointed bottlenecks, including capacity assessments, production concentration risks, comparisons with future demand, and geopolitical challenges. We also explored the opportunities associated with the circular economy and material substitution to mitigate these risks. The findings now inform government and industry on supply risks and mitigation strategies for aluminium, copper, and nuclear materials essential to decarbonisation.

4 - Practising Systemic Sustainability for the Circular Economy Concept
Miles Weaver, Kamila Pokorna, Renata Osowska, Maxwell Chipulu, Ana Paula Fonseca, Hock Tan

Systems thinking is essential for addressing sustainability challenges & promoting sustainable development. While management approaches like Doughnut Economics & the Circular Economy are rooted in systems thinking, research in this area is limited. Circularity is a concept that can offer depth to Raworth's Doughnut Economics, which emphasises avoiding ecological overshoot & human well-being undershooting to ensure a just and safe space for humanity to thrive within the means of a living planet. This requires replacing linear thinking to recover value through regenerative and restorative design practices & sustainable consumption rather than recycling & energy recovery. Organisations must recognise they cannot waste irresponsibly and transition away from using finite raw materials. We propose the 'Systemic Sustainability' framework (SSF), which integrates traditional systems thinking principles with the need for organisations to engage stakeholders at four levels: oneself, others, nature, & systems that thrive in perpetuity (in line with Raworth's central message). The SSF helps organisations reflect on their purpose, differentiate between value & values judgements, & balance organisational viability with broader impacts. A construction case illustrates how the SAF combined with a boundary critique can be embedded with a soft system methodology to help organisations engage their supply chains in co-creating circular design solutions and policies.

■ MD-43

Monday, 14:30-16:00 - Room: Newlyn GR.07

MIP Solvers

Stream: Software for Optimization
Invited session
Chair: *Stefan Vigerske*

1 - New in FICO Xpress Solver
Michael Perregaard

We will give an overview of the latest enhancements, the newest features, and the most recent performance improvements in the FICO Xpress Solver, with a focus on algorithmic improvements for linear and mixed-integer linear problems.

2 - What's new in Gurobi 12
Michael Winkler

In this presentation, we will give an overview of recent developments within Gurobi 12. In particular, we will talk about performance improvements and the improved global MINLP solver.

3 - Recent Developments in the Cardinal Optimizer
Qi Huangfu

In this talk, we present the recent developments in the Cardinal Optimizer (COPT). We discuss some key techniques that contributed to the performance improvements of our LP and MIP solvers. We will also introduce our latest GPU development experiences.

4 - The SCIP Optimization Suite 10
Stefan Vigerske

In this year, the SCIP Optimization Suite reaches its first double-digit major version number. Starting with an algebraic modeling language, a simplex solver, and a constraint integer programming framework, containing the world's best non-commercial mixed-integer programming solver, it has evolved over the last 20+ years into a swiss army knife for anything where relaxations are subdivided, trimmed, generated dynamically, and eventually solved, be it on embedded, ordinary, or super-computers. The newest iteration brings major updates for the presolving library PaPILO, the generic decomposition solver GCG, and the branch-cut-and-price framework SCIP itself. In this talk, we will give a short overview on the current SCIP Optimization Suite ecosystem and catch a glimpse on the new features contributed by over 15 developers in the newest major release.

■ MD-44

Monday, 14:30-16:00 - Room: Newlyn 1.01

Decentralized energy system integration modelling

Stream: Energy Economics & Management
Invited session
Chair: Russell McKenna

1 - A reproducible method to determine network integration costs of decentralised energy technologies
Sammit Vartak, Wendy Paola Reyes Calle, Russell McKenna

Decentralised energy technologies (DETs) such as solar PV plants, heat pumps, and electric vehicles are deployed locally within electricity distribution networks with limited hosting capacity. Deploying DETs beyond this capacity leads to operational challenges and necessitates network reinforcement, imposing significant additional costs. A major challenge in analysing hosting capacity and reinforcement requirements is the lack of public distribution network data. Previous studies have relied on proprietary data, limiting reproducibility, while geo-referenced synthetic networks, though useful, remain computationally expensive. To address this, we develop typological distribution networks using clustering based on open-source urban morphological data, ensuring reproducibility. Using these networks, we analyse the stochastic deployment of DETs at various capacities and locations. Initial results for a Swiss case study show lower reinforcement requirements for PV but higher for heat pumps, with rural networks having lower hosting capacity than urban ones. Simultaneous deployment increases hosting capacity and creates synergy effects. Combined with regression analysis on reinforcement cost, these results provide the network reinforcement cost per additional kW of DET deployment above hosting capacity. The findings can inform DET deployment policies, help prioritise grid reinforcement, and be directly integrated into energy system models for more accurate decentralised planning.

2 - Multi-Stage Distribution Expansion Planning with Flexible and Controllable Distributed Energy Resources
Alfredo Ernesto Oneto, Blazhe Gjorgiev, Giovanni Sansavini

The ongoing transition to low-carbon energy systems drives the increasing adoption of distributed energy resources (DERs). These DERs include heat pumps (HPs), electric vehicles (EVs), rooftop solar photovoltaic (PV) systems, and battery energy storage systems (BESSs). These technologies affect the operation of power distribution networks (DNs), which were not originally designed to accommodate DERs. Consequently, planning DNs with DER integration requires comprehensive modelling of their flexibility to ensure reliable operation while minimizing capital investments and variable costs. In this context, the distribution expansion planning (DEP) problem provides optimal DN design solutions, minimizing investment and operational costs while meeting service requirements. Existing DEP studies often overlook the flexibility potential of DERs. This work addresses this gap by exploring the mixed-integer multi-stage DEP problem that accounts for DER flexibility provision, allowing for line and transformers expansion and BESS placement. Different levels of DER penetration are considered through the planning horizon to model their rising deployment. Moreover, we leverage the control of HPs, considering the thermal modelling of buildings, flexible EV charging with energy and power bounds, reactive power capabilities of PVs, and BESS operation. We use an open-source dataset of representative DNs in Switzerland, developed in our previous work, to evaluate the proposed approach.

3 - Real-time optimization of distribution electricity network management
Jean Jodeau, Saoussen Abidi, Tristan Basler, Simon Bayle, Nicolas Blandamour, Germain Francois, Paul Javal, Olav Lafourcade, Pierre Mordant, Lucas Selini

The evolution of the role of DSOs, in particular ones involved in Active Network Management, requires strategic changes from historical monitoring and control approaches. DSOs must adapt to manage an increasing number of distributed energy resources, a growing number of planned worksites, while meeting regulatory and quality standards. A first milestone in developing a decision support tool based on optimization and power flow management will be presented. It relies on an optimization model designed to mitigate electrical constraints, enhance network robustness while explicitly taking into account economic efficiency. The resulting optimal set of actions - flexibilities, power limitations, network reconfigurations - follow complex DSO operational rules. A critical aspect of this work has been the collaboration with operators to build upon their knowledge and feedback. This engagement has been instrumental in identifying the several implicit industrial rules and best-practices. Leveraging black-box optimization methods and meta-heuristics, such as local search algorithms, the model provides operators with actionable insights and dispatching's advice. Future developments will focus on incorporating machine learning techniques to enhance convergence times and further optimize decision-making processes. By addressing these challenges and integrating operator expertise, this work supports the efficient operation of distribution networks and improve overall grid reliability

4 - Modeling Robust Energy Systems Under Weather and Nuclear Failure Uncertainties: A Case Study in Northern Europe
Lina Reichenberg, Kamran Forghani, Xiaoming Kan, Fredrik Hedenus

Capacity expansion models used for policy support have increasingly represented both the variability and uncertainty of weather-dependent generation (wind and solar). However, even though nuclear power output is uncertain, as demonstrated, for example, by the performance of the French nuclear power fleet in 2022, its variability and uncertainty has been largely neglected in the literature. This paper presents the first capacity expansion model that considers uncertainty in nuclear power availability. We propose a mathematical framework combining scenario-based stochastic optimization for weather-related uncertainties and data-driven adjustable robust optimization for nuclear failure uncertainties. The robust model captures the on/off behavior of large (1 GW) nuclear units while optimizing nuclear capacity. Due to computational complexity, a heuristic method is developed to solve the model efficiently. We tested the model in a case for Northern Europe with seven nodes and a time resolution of 1250 time steps. Our findings show that nuclear power outages do indeed impose a vulnerability for the energy system if not considered in the planning phase. The proposed model effectively prevents Loss-of-Load (with a 0.6% robustness cost) even under extreme weather-demand-outage scenarios. The robust solutions are characterized by a higher capacity of gas

plants, but, perhaps surprisingly, the nuclear power capacity is barely impacted.

■ MD-46

Monday, 14:30-16:00 - Room: Newlyn 1.07

Planning and operation of power networks

Stream: Energy Economics & Management
Invited session
Chair: *Abdolazim Yaghooti*

1 - Solving non-linear optimal power flows with Artelys Knitro in PowSyBl open-source toolbox
Marvin Stanczak, Hugo Chareyre, Pierre Arvy, Jeanne Archambault, Hadrien Godard, Nicolas Omont

Electrical networks have grown significantly, requiring advanced tools like Optimal Power Flow (OPF) to ensure reliability and efficiency. OPF problems are crucial for determining the most efficient operating conditions of power systems, minimizing costs or emissions while meeting system constraints. These problems are complex due to large-scale optimization, numerous constraints, and mixed variables. The power systems community has focused on enhancing AC modeling of OPF, which involves non-linear and non-convex constraints, making real-world scenarios challenging to solve. PowSyBl is an open-source Java framework for grid modeling and simulation. It simplifies the development of complex software for power system analysis and includes a reusable code base for solving non-linear AC OPF problems. The framework uses the AMPL modeling language and the Artelys Knitro solver for optimization. It allows flexible configuration and the use of slack variables to facilitate convergence in power-imbalanced grids. The PowSyBl community continuously improves the framework, which has supported various research projects, including a divergence analyzer for detecting network parameter inconsistencies. Future perspectives include enhancing and broadening the use of the Artelys Knitro solver within PowSyBl. Recent efforts aim to enable its use in additional processes that benefit from OPF solving. This aligns with Artelys' long-standing research and development on OPF problems.

2 - T&D System Planning: The Perspective of the Transmission Planner
Abdolazim Yaghooti, Gregorio Muñoz-Delgado, José Manuel Arroyo, Javier Contreras

The proliferation of smart grid technologies in distribution systems allows unlocking the ability of distributed energy resources to provide services not only to distribution system operators (DSOs), but also the transmission system operator (TSO). This evolving paradigm calls for the development of new tools accounting for the coupling of transmission and distribution systems. Within this context requiring the joint consideration of both systems, this paper addresses the investment planning problem faced by a TSO. Unlike previous TSO/DSO integrated approaches, the DSO's reaction against the TSO's expansion plans is explicitly modeled while considering that both entities are driven by their own goals. To that end, we propose a novel stochastic bilevel programming framework to deal with this hierarchical decision-making process under uncertainty. As another salient aspect, three different instances are analyzed, each associated with a practical operational scheme for interface nodes and distribution substations. The resulting bilevel programs are handled by a new approach where the upper and lower levels are solved sequentially. In contrast to the standard transformation to a single-level equivalent, the proposed solution technique is suitable for problems lacking convexity in the lower level. Numerical results from two case studies illustrate the performance of the proposed approach.

3 - On the Complexity of the Switch Allocation Problem in Power Distribution Networks
Fábio Usberti, José Federico Vizcaino González, Laura Silva Assis, Celso Cavellucci

The Switch Allocation Problem (SAP) is central to optimizing reliability in power distribution networks, where the strategic placement of sectionalizing switches significantly reduces the expected Energy Not Supplied (ENS). Despite extensive research into SAP and its variants, the fundamental complexity of the Sectionalizing Switch Allocation Problem (SSAP), specifically whether it is NP-hard, remained unresolved. Historically, the SSAP was predominantly addressed through heuristics or exact algorithms based on Integer Linear Programming (ILP), both approaches having limitations. Heuristic methods offer approximate solutions without guaranteeing optimality, whereas previous exact approaches using ILP or dynamic programming (DP) encountered exponential complexity, restricting scalability.

This work conclusively resolves this open complexity question by introducing the first exact polynomial-time dynamic programming algorithm capable of optimally solving SSAP instances efficiently. Our algorithm employs a carefully defined state space and optimality functions tailored for both linear and branched radial networks. By establishing polynomial-time solvability, this research addresses a long-standing open problem in combinatorial optimization for power systems and lays a robust foundation for future advancements in distribution network reliability optimization.

■ MD-47

Monday, 14:30-16:00 - Room: Parkinson B08

Retail Supply Chain Management

Stream: Retail Operations
Invited session
Chair: *Stefan Voigt*

1 - Delivery planning for grocery retail outlets with delivery time constraints
Heinrich Kuhn, Markus Frank, Wen-Shin Tsai, Stefan Voigt

The paper considers the determination of weekly delivery patterns (delivery days) of grocery retail stores and the associated route planning from the distribution center to the stores of the delivery area with multi-compartment vehicles. The problem under consideration includes different assortment classes and store-specific delivery time windows for the respective assortments. This can lead to a situation where a store is supplied with different assortments on the same day, but the respective assortments should be delivered to the store at different times. For example, the dry goods range is requested in the morning and the frozen goods in the afternoon. If both assortment classes are assigned to the same delivery tour of a multi-compartment vehicle, the special situation arises that a store is visited several times during a single tour. Comparable tour planning models have not yet been found in the literature. The paper develops an MIP model and a heuristic solution approach that first defines delivery patterns considering the subsequent delivery planning, and then a decision is made on the daily tour planning. The applicability of the developed model and solution approach is demonstrated using a real example of a large German grocery retailer. The numerical study shows considerable potential for improvement compared to current practice.

2 - Proactive transhipment strategies for an omnichannel retailer with partial-lost sales
Ben Lowery, Anna-Lena Sachs, Idris Eckley, Louise Lloyd

We consider a retailer who operates a complex network of integrated online and offline storefronts, where items can be shipped between them. When an order is unavailable at the store, the customer can choose to have their order delivered to their home from the warehouse

instead. Such a mechanism is useful for stores facing a surge in demand. However, scenarios arise whereby stores suffer from the opposite problem, with little to no demand for products; in these cases, it may be beneficial to proactively redistribute this stock to other stores via transshipment policies.

We expand on previous development of a divergent, periodic-review model with partial lost sales, to allow for lateral transshipments. We evaluate the effectiveness of transshipment policies, both established in the literature and novel, for this setting. We focus on joint replenishment and transshipment decisions, formulating the problem as a Markov Decision Processes. Due to the curse of dimensionality, only small instances are solved to optimality. Therefore, we consider a capped base-stock policy coupled with equalization or expected shortage reduction for transshipments. To allow for more robust decision making, we propose an integrated replenishment and transshipment method. We compare these methods in a numerical study as well as real data by analysing different demand characteristics, determining decision rules as to when including the option of transshipments provides tangible operational benefits.

3 - Do omnichannel grocery customers add value?
Marjolein Buisman, Sander De Leeuw, Arnd Huchzermeier

Prior research in non-grocery retail suggests that omnichannel customers are more valuable than single-channel customers. However, the impact of the adoption of a second (online) channel on customer purchasing behavior in the grocery sector remains unclear. We examine how customers' overall weekly purchases change when they start using the online channel of a grocery retailer. Using a two-way fixed effects model, we compare online adopters to customers who remain in-store only showing that grocery omnichannel customers indeed spend more than single-channel customers. We show that in the week of the first online purchase, total spending, purchase quantity, and the number of distinct categories and items significantly increase, particularly in food products. However, this increase is temporary, with online adopters' purchasing levels eventually converging with those of in-store-only customers. Also, the overall share of online grocery purchases per customer decreases. We further analyze purchasing behavior during the COVID-19 pandemic and find similar trends. Though non-food categories play a more pronounced role, and the effect persists slightly longer, the declining trend is still observed. These insights suggest that while omnichannel customers initially show higher value, their value declines over time, even in times of crisis. Sustaining omnichannel customer engagement over time is thus critical for long-term profitability in grocery retail.

4 - A simulation-driven order dispatcher algorithm for international orders in Trendyol
Mehmet Orhan Yildirim, Mert ParÇaoĞlu, Betül Ahat, Ahmet Çınar, Meltem Sanisoğlu

Efficient international order fulfillment is crucial for e-commerce platforms managing multi-warehouse operations. This study introduces a dispatcher algorithm for Trendyol, engineered to minimize operational costs while satisfying diverse constraints inherent in international logistics. The algorithm considers various business requirements, including item demand, order origin, stock availability, warehouse prioritization, and customs regulations. It optimizes the total operational cost of an order by balancing warehouse expenses and shipping costs while determining whether to consolidate multiple packages. By applying advanced optimization techniques, it evaluates all feasible stock combinations based on predefined cost parameters, selecting the most cost-effective dispatch strategy. Additionally, it ensures efficient stock allocation across global storefronts by integrating warehouse priority mapping, which streamlines package consolidation. To further assess the impact of different policies on dispatch decisions, we developed a simulation framework that measures key business metrics such as unit shares of different warehouses and profit margins. The algorithm results show 5% saving in total operational costs while minimizing the total delivery/order through consolidation. This comprehensive approach enhances fulfillment efficiency, reduces logistic costs, and improves cross-border order accuracy, making it a scalable solution for high-volume e-commerce operations.

■ MD-48

Monday, 14:30-16:00 - Room: Parkinson B09

Applications of Location Methods

Stream: Locational Analysis
Invited session
Chair: *Marta Baldomero-Naranjo*

1 - Addressing Uncertainty in Emerging Economies through Facility Location Modeling
Hasan Nur

Most facility location problem models have focused on applications in advanced economies, with limited attention to the distinct challenges faced by emerging economies. These economies are characterised by rapid economic, social, and political transitions, introducing unique uncertainties such as supply-demand fluctuations, price volatility, infrastructure constraints, accessibility issues, and policy changes. While uncertainties exist in all economies, their frequency, intensity, and impact tend to be greater in emerging economies, posing distinct challenges for modelling. This study presents a case study on determining the optimal locations for Nickel Industrial Parks in Indonesia, a country experiencing a significant nickel industry boom. To address the uncertainty inherent in emerging economies, a stochastic change constraint formulation is developed. Given the growing role of emerging economies in global supply chains and industrial development, this research contributes to a broader understanding of facility location modelling in these contexts, offering practical insights for policymakers and industries navigating complex strategic facility location decisions.

2 - Ordinal Location Problems and Consistent Shortest Paths
Renée Lamsfuß, Kathrin Klamroth, Michael Stiglmayr, Julia Sudhoff

We consider ordinal location problems on graphs, where in addition to the edge length, a category is associated with each edge. We assume that we have two categories to choose from, where one category is strictly preferred over the other. As an example, we consider the safety of an edge and categorize edges as safe (green) and unsafe (red) from the perspective of a cyclist. Although a value function that assigns monetary costs to the categories is not known in general, we can still formulate a biobjective optimization problem using the preference information from the ordering of the categories. We are now not only interested in finding an optimal location, but also require the shortest paths to be consistent. Specifically, a particular decision to choose an efficient customer-to-facility path must align with all other customer-to-facility paths. Speaking of safe and unsafe edges, choosing a longer path over safe edges once induces that choosing a shorter, but unsafe customer-to-facility route is prohibited in the following. In this talk, we introduce a notion of consistency and analyze the solutions in terms of supportedness. We propose an algorithmic approach to construct consistent solutions iteratively and demonstrate it at a medium size instance in the city of Wuppertal, Germany.

3 - The Reliable Capacitated Modular Facility Location Problem
Lea Raubuch, Stefan Lier, Tristan Becker

Modular production concepts provide an increased flexibility in production systems, enabling better adaptation to demand fluctuations and supply chain disruptions. Unlike immobile plant systems that rely on reallocating demand in the event of disruptions, modular systems can flexibly relocate production units between sites. This study investigates the potential of location flexibility in modular production systems for reliable network design in a two-stage stochastic setting. The objective is to minimize the total cost of the production network while meeting customer demand. At the first stage, modules of independent failure probabilities are located at production facilities. At the second stage, the modules can be relocated and demand reassigned

to deal with disruptions. This problem generalizes the capacitated reliable facility location problem (CRFLP). We propose two mathematical formulations: a facility-indexed and module-indexed formulation. We apply scenario reduction techniques to solve these models with data from the chemical industry. Our experiments illustrate the benefits of including relocations and reliability in location decisions of modular production units. Due to the efficient scenario structure, we also apply our module-indexed formulation to CRFLP problem instances. Our formulation significantly reduces the scenario space compared to existing formulations for the CRFLP when an upper bound on facilities is known.

4 - Advancing Firefighter Games: Novel Integer Programming Formulations and the Cost-Value Model
Marta Baldomero-Naranjo, Jörg Kalcsics, Antonio Manuel Rodriguez-Chia, Catriona Wedderburn

In the Classical Firefighter game, a fire breaks out on some vertices of an undirected connected graph at time zero. At each subsequent time step, a fixed number of defenders can protect one vertex each from catching fire. Afterwards, the fire spreads from each burning vertex to every adjacent vertex that is neither burning nor defended. The game ends when the fire can no longer spread. The goal is to find a defence strategy (i.e., the location of defenders) that maximises the number of non-burning (saved) vertices. In this work, we first revisit the classical integer linear programming formulation and then present several improvements for it as well as two new formulations and tighter bounds on the maximal duration of the game.

Moreover, we relax the classical assumptions that all vertices have uniform values and costs, i.e., we allow vertices to have different values and costs for being defended. Furthermore, instead of a fixed number of defenders we are given a defence budget that we can spend each time step to defend the vertices. We call this the Cost-Value Firefighter game. We present three different integer linear programming formulations for the problem, along with a series of inequalities to strengthen the formulations as well as tight bounds on the maximal duration of the game.

■ MD-49

Monday, 14:30-16:00 - Room: Parkinson B10

Social Network Analytics

Stream: Analytics
Invited session
Chair: *Fredy Troncoso*

1 - Identification of Criminal Groups in Networks with Multiple Known Suspects
Fredy Troncoso, Richard Weber, Dimitri Loaiza

Understanding criminal organizations as social networks has led to the development of advanced decision-support tools for criminal investigations. Existing models, such as StPro, have proven effective in identifying criminal associations from a single suspect, using a Steiner tree rooted at the suspect's node. However, when multiple suspects are known, these models require independent executions, leading to an overestimation of network size and an increased rate of false positives. This study introduces K-Suspect, an extension of StPro based on the Linear Rational Association Model (LiRAM), which integrates multiple known suspects in a single execution. By leveraging Steiner tree optimization, K-Suspect constructs a more precise and structured representation of the criminal organization while avoiding redundant connections. The proposed model is applied to real-world data from the Public Prosecutor's Office in Chile. The results demonstrate that K-Suspect reduces false positives and improves computational efficiency, providing a more accurate identification of criminal structures without compromising precision. Its implementation enhances investigative processes, optimizing resource allocation and improving the effectiveness of criminal network detection.

2 - Burglary prediction using graph-based deep learning on crime reporting app data
Carla Vairetti, Sebastian Maldonado, Richard Weber, Joaquín Roa, Ricardo Jara, José Tomás Queirolo

Predictive policing represents a productive avenue of research utilizing analytics to anticipate potential criminal activities. This study aims to develop a learning machine capable of forecasting the occurrence of specific crime types in a given area based on historical data. The main objective of this model is to furnish municipalities and police departments with a tool to deploy patrols and allocate resources efficiently. Data was collected from a Chilean crime report app, encompassing various criminal events and suspicious activities reported by the public. Under the assumption that past reports serve as reliable predictors of future criminal activities, we formulate a classification problem to predict burglary and motor vehicle theft in a designated area. In this study, we adapt graph neural networks (GNNs) to take advantage of the spatial structure of the problem. GNNs excel in predictive tasks involving spatial structures by effectively capturing complex relationships and dependencies between entities. Unlike traditional machine learning methods that treat data as independent points, GNNs leverage connectivity patterns to model spatial correlations. Promising outcomes were achieved using GNNs, as well as conventional statistical and machine learning methods such as logistic regression and gradient boosting. Additionally, we incorporated eXplainable Artificial Intelligence (XAI) techniques to assess the importance of various covariates in the task.

3 - A Data-Driven Approach for Exploring Emotional Guidance Modalities in Social Media during Emergency Events
Xianchen Duan, Yan Xu

This study investigates how the emotional guidance modalities (EGMs) employed by social media figures influence collective emotional responses in parasocial interaction (PSI) networks during emergency events. Social media platforms have created novel interpersonal interaction networks where influential figures can significantly impact public sentiment through various EGMs. This phenomenon becomes particularly significant during emergencies, where emotional disparities among audience groups can further catalyze public sentiment, prevent social consensus and exacerbate uncertainties in complex societal problems. To this end, we propose a novel data-driven approach to (a) establishing a PSI network model using data mining, natural language processing and event graphs to reflect the interactive relationships between influential figures and audiences; (b) identifying EGMs embedded in multimodal user-generated content using large language model and sentiment analysis; (c) assessing the impact of EGMs on emotional responses within PSI networks by creating a knowledge base using psychological behavioral theories and emotion wheel; and (d) developing a BERT-based model for the automated discovery of EGMs and their impact in larger datasets. The results contribute to the understanding of collective emotional dynamics in parasocial contexts through advanced analytics and provide insights for strategic emotion management in emergencies to improve social harmony and governance.

4 - Online Misinformation: A Generation and Propagation Model
Xuan Vinh Doan, Tri-Dung Nguyen

We propose a model of how messages which may contain misinformation are generated and how they impact people's beliefs. The results show the asymptotic convergence of the belief when one receives multiple messages which are generated and delivered sequentially. The decision of whether to verify messages or not is considered. In addition, the role of online platforms in message propagation will be discussed together with sharing actions from users.

■ MD-50

Monday, 14:30-16:00 - Room: Parkinson B11

Variational analysis and equilibria

Stream: Variational analysis, equilibria and nonsmooth optimization
Invited session
Chair: *Francisco Javier Aragón Artacho*

1 - Convex optimization in nonpositively curved geodesic spaces
Adrian Lewis, *Ariel Goodwin*, *Genaro Lopez*, *Adriana Nicolae*

In various disciplines, data sets live in Hadamard spaces: complete metric spaces with nonpositive curvature, meaning that triangles are thinner than their Euclidean analogues. Examples include manifolds like Euclidean space, hyperbolic space, and the cone of positive-definite matrices with the affine-invariant metric. However, models ranging from robotics to phylogenetics involve Hadamard spaces that are not manifolds: one interesting example is the BHV tree space, which is a complex of orthants. Hadamard spaces invite convex optimization techniques, because squared-distance functions to points are strongly convex along geodesics. We might, for example, seek to compute means or minimum enclosing balls for sets of matrices or phylogenetic trees. A fundamental challenge is the lack of any duality theory. Nonetheless, the convex geometry of Hadamard space is rich enough to support practical generalizations of the subgradient method, both in classical and incremental forms, supported by complexity analysis. In the particular case of CAT(0) cubical complexes (like tree space), practical algorithms can also rely on traditional cutting plane techniques. We also discuss the tractability of recognizing weighted means of finite sets in Hadamard spaces.

2 - On the Equivalence between Non-smooth Interval-Valued Vector Optimization Problems and Generalized Vector Variational Inequalities
Priyanka Mishra

This article deals with the study of a class of non-smooth interval-valued vector optimization problem and a class of generalized vector variational inequality with its weak form for interval-valued functions. Using the tools of Mordukhovich subdifferential, we define some new classes of generalized approximate LU-convex functions. These functions are then employed to establish the relations between the solutions of generalized vector variational inequalities and the approximate LU-efficient solutions of the non-smooth interval-valued vector optimization problem. Moreover, we identify the Kuhn-Tucker vector critical points of the considered non-smooth interval-valued vector optimization problem. Under suitable constraint qualification, we establish the equivalence among local approximate LU-efficient points, Kuhn-Tucker vector critical points and the solutions of generalized vector variational inequalities.

3 - Projected solutions for quasi-equilibria
Giancarlo Bigi

The concept of a projected solution for quasi-variational inequalities and generalized Nash equilibrium problems was recently introduced, due to the modeling of deregulated electricity markets where the constraint map is not a self-map. In this talk we show that the projected solutions of a quasi-equilibrium problem correspond to the classical solutions of an auxiliary quasi-equilibrium problem. This can be achieved by doubling the number of variables and adding an appropriate term. In this way algorithms for quasi-equilibria can be exploited for computing projected equilibria through the auxiliary problem. However, its structure does not guarantee the fulfilment of the assumptions required for the convergence of algorithms. In particular, descent and extragradient algorithms need that each feasible point is a fixed point for the constraint map and this not true in the case at hand. Thus, we show that under suitable assumption an ad-hoc choice of parameters allows convergence of the extragradient algorithm without the above requirement. the results of preliminary numerical tests are reported as well.

The talk is based on joint papers with Marco Castellani and Sara Latini

4 - DISM: A Distributed Incremental Subgradient Method for Weakly Supervised Skin Segmentation
Narges Araboljadidi, *Valentina De Simone*

We present a novel Distributed Incremental Subgradient Method (DISM) for Multiple Instance Learning (MIL) applied to skin segmentation. Traditional approaches require labor-intensive pixel-level annotations, while our weakly supervised framework uses only image-level labels, treating images as bags of pixels with binary indicators of skin presence. Our method optimizes the resultant non-smooth, non-convex objective function with an efficient distributed architecture and reduced-synchronization strategies that prevent parallel processing overhead with retained convergence properties. Experiments with the UCI skin segmentation dataset show our method achieving significantly higher accuracy (79.25%) compared to the MATLAB toolbox method with sequential minimal optimization with SVM (59.81%), with 50.3% computational time saved (from 17.38 to 8.64 seconds). This contribution implies how distributed MIL can effectively leverage weak labels to counteract annotation load with greater scalability for large-scale segmentation problems with high accuracy and computational savings.

■ MD-53

Monday, 14:30-16:00 - Room: Liberty Moot Court

New Trends in Game Theory III

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Stefan Nickel*

1 - Linear Equations with Min and Max Operators: Computational Complexity
Ruichen Luo, *Krishnendu Chatterjee*, *Raimundo Saona*, *Jakub Svoboda*

We consider a class of optimization problems defined by a system of linear equations with min and max operators. This class of optimization problems has been studied under restrictive conditions, such as, (C1) the halting or stability condition; (C2) the non-negative coefficients condition; (C3) the sum up to 1 condition; and (C4) the only min or only max oerator condition. Several seminal results in the literature focus on special cases. For example, turn-based stochastic games correspond to conditions C2 and C3; and Markov decision process to conditions C2, C3, and C4. However, the systematic computational complexity study of all the cases has not been explored, which we address in this work. Some highlights of our results are: with conditions C2 and C4, and with conditions C3 and C4, the problem is NP-complete, whereas with condition C1 only, the problem is in UP intersects coUP. Finally, we establish the computational complexity of the decision problem of checking the respective conditions.

(The author list should be in alphabetical order.)

2 - Evolutionary Game Analysis of a Crowd-Sourced Last-Mile Delivery System
Laura Rosa Maria Scrimali

The last-mile crowd-sourcing system has emerged as an innovative transportation management model that reduces logistics costs, enhances delivery speed, and mitigates environmental impact. This study introduces a tripartite evolutionary game model to examine the strategic interactions among logistics providers, independent drivers, and customers in a crowd-sourced last-mile delivery framework. The

model captures key factors influencing decision-making by incorporating penalty and compensation mechanisms, along with two delivery types. Through replicator dynamics, we identify the system's evolutionary stable strategies. Furthermore, numerical simulations provide insights into how critical parameters impact the long-term behavior of each stakeholder group, offering valuable implications for optimizing last-mile logistics.

3 - Incentive Contract Design for Two Dimensional Quality Development with Information Asymmetry
Hongyan Jenny Li

To overcome business challenges such as increasing customer satisfaction and profits, reducing production costs, and meeting sustainability or environmental requirements, the manufacturer needs to improve the product quality continuously. In many cases, collaborating with the supplier to improve the supply product quality is indispensable. However, the manufacturer and the supplier often make decisions based on local information and objectives. Cooperative quality development in supply chains has gained prominence over the past decades but remains challenging due to information asymmetry. In our study, we investigate the incentive contract design problem regarding a two-dimensional quality development in supply chains based on the joint adverse selection and moral hazard models. The two dimensional model considers two types of supplier and also two options on quality improvement efforts. The manufacturer and the supplier face a two-stage quality development game: the manufacturer determines a menu of incentive contract terms in the contracting stage, and the supplier makes decision on whether to conduct quality improvement efforts in the quality development stage. We formulate and analyse the problem under quality audit and quality inspection scheme. The results show that the two-dimensional model provides more flexibility and outperform the uni-dimensional model. The mixed model of adverse selection and moral hazard is formulated and solved in SC context.

4 - On the Optimization of Vectors of Katz-Bonacich's Centralities Related to Nash Equilibria for a Class of Non-Cooperative Network Games
Mauro Passacantando, Giorgio Gnecco, Fabio Raciti

Evaluating the importance or centrality of nodes in a graph is a fundamental issue in network analysis and design. One possible measure of centrality is Katz-Bonacich centrality, which arises in the steady state of a dynamical system involving local communication within an undirected graph and in the pure Nash equilibrium of a non-cooperative game on that graph, whose players are its nodes. In this context, the present paper investigates the connection between the vectors of Katz-Bonacich centralities arising in the deterministic and stochastic cases, respectively, and its consequences for network design and for finding the so-called key player, i.e., a player/node that contributes most to increasing the equilibrium aggregate level in the network. Numerical results and a discussion of possible extensions to other measures of node centrality complement the theoretical analysis.

■ MD-55

Monday, 14:30-16:00 - Room: Liberty 1.09

Network Optimization 4

Stream: Network Optimization
Invited session
Chair: Luís Gouveia

1 - An online column generation framework for segment routing optimization
Jérôme De Boeck

Segment Routing (SR) is an Interior Gateway Protocol that has been developed in the recent years which offers a much larger flexibility than common routing protocols such as the OSPF protocol. This protocol consists in routing requests through the shortest path in a network from the entering to the exiting router. It is technically difficult to modify these paths, which can lead to congestion if a link is on the shortest path between several pairs of routers with high traffic. The SR protocol offers the possibility to add deviations, called segments, that requests must reach before reaching the exiting router. These deviations can be dynamically added when a request enters a network. It has been shown some standard traffic measures can be improved by 40% in a deterministic context.

The main difficulty in handling SR appropriately compared to OSPF lies in the number of routing possibilities that are exponential in the number of segments. Path-based mathematical programs tend to quickly become untractable. We present a column generation algorithm that tackles the issues on large-scale instances. Recent preprocessing techniques for SR are used to work on a reduced-size formulation, speeding up the computation times of the state-of-the-art algorithms. The fast computation times of the column generation algorithm allow to embed it in an online procedure that can take into consideration the real-time demand observed on the network.

2 - Formulations and Branch-and-cut algorithms for the Period Travelling Salesman Problem
Sofia Henriques, Ana Paias

Considering a time horizon with different periods, the Period Travelling Salesman Problem (PTSP) is defined on a directed graph with a depot and n customers, in which each customer has a required number of periods to be visited in. The objective of the PTSP is to assign each client to as many periods as it is required while determining the set of routes, one for each period, with minimum cost. Each route starts and ends at the depot and visits the clients assigned to that specific period only once.

The PTSP combines an assignment and a routing problem in a single problem, making it very difficult to solve to optimality, even for instances with few clients. Most of the works in the literature study heuristic methods for the PTSP, and the few exact methods in the literature only consider two periods in the time horizon, which is insufficient to model many real-life routing problems involving periodicity. We will present different flow-based compact formulations for the PTSP and we will use the concept of projection to derive new ILP formulations with fewer variables but exponentially-sized sets of constraints. Furthermore, we intend to propose new valid inequalities for the PTSP. The conclusions from our theoretical and computational study will be presented for instances with different characteristics.

3 - Formulations and branch-and-cut algorithms for cycle covers with up to p cycles
Francisco Canas, Luís Gouveia

Given a positive integer p and a weighted undirected graph G, we study a problem in which the objective is to find a minimum weight set of up to p elementary cycles partitioning the vertices of G. We study several exponential sized formulations including i) edge variables only; ii) edge and depot variables only; iii) edge, depot and node-depot assignment (NDA) variables only; iv) edge, depot, NDA and edge-depot assignment (EDA) variables, some of which are known from existing works on similar problems. Branch-and-cut algorithms based on many of these formulations are proposed, and computational experiments are conducted to compare the performance of the different algorithms. The computational testing reveals that some of the formulations including edge, depot and NDA or EDA variables produce the best initial lower bounds and that the best computational times are obtained with the algorithms based on formulations including edge and depot variables only. The best performing algorithm (in terms of computational times) is capable of solving several instances with up to 442 nodes for different values of p.

4 - Applying regularized Benders decomposition to efficiently optimize power grid expansion in large-scale energy system models
Lene Marie Grübler, Felix Muesgens

Decarbonizing the European economy requires a substantial increase in renewable energy generation capacities across the continent. As their capacity factors are time and site dependent, the importance of transmission grid expansion on national and international scale rises. Grid expansion projects rely on standardized components. In capacity expansion models of energy systems, investments in grid expansion projects therefore require binary investment decision variables, resulting in complex mixed-integer optimization models to be solved. Complexity of such expansion models is additionally driven by a high number of linking variables on the temporal and spatial scale. To keep such problems computationally tractable and efficiently solvable, we apply regularized Benders decomposition and implement different strategies to handle binary decision variables. Furthermore we explore different variants of modelling operating constraints of power grids by means of optimal power flow constraints and analyze their impact on solving times and solution quality.

■ MD-57

Monday, 14:30-16:00 - Room: Liberty 1.12

Smart mobility: Exploring the Potential of Connected and Autonomous Vehicles

Stream: Transportation
Invited session
Chair: Eloisa Macedo
Chair: *Jorge Bandeira*

1 - Assessing Societal Impacts of Cooperative, Connected, and Automated Mobility (CCAM): The European Common Evaluation Methodology (EU-CEM) for CCAM
Steve O'Hern

Cooperative, Connected, and Automated Mobility (CCAM) promises safer, efficient, and sustainable transport. However, fragmented evaluation practices hinder comparability and policy integration. To address this, the Horizon Europe-funded FAME project developed the European Common Evaluation Methodology (EU-CEM) for CCAM, a standardised framework for assessing CCAM's direct and indirect impacts on users, vehicles, the transport system, and society. The EU-CEM promotes consistency in CCAM impact assessments through structured guidance, a common vocabulary, and best practice examples. It follows key principles such as collaboration, flexibility, and a comply-or-explain approach, allowing adaptability while maintaining transparency. Targeting large-scale CCAM testing but applicable to smaller studies, the EU-CEM focuses on impact assessment of SAE Level 3 automation and above in real-world deployment. It includes standardised performance indicators across 18 impact areas. Six of these focus on wider society: land use, liveability, economic activity and employment, socioeconomics, equity, and sustainability. By providing a harmonised evaluation framework, the EU-CEM enhances the reliability of CCAM impact assessments, supporting policymakers, industry, and researchers. This presentation will introduce the EU-CEM for CCAM methodology, focusing on the guidance for setting up an evaluation and discussing the societal impact areas.

2 - Multi-enabler transportation network design for autonomous trucks with elastic demand
Ebrahim Mohammadi, Marie Schmidt, Rob Zuidwijk

Autonomous truck (AT) transportation has the potential to reduce transportation costs and improve road safety. The successful adoption of this technology relies on key enablers such as refueling stations, emergency maintenance facilities, and transfer hubs. However, the actual demand for ATs may be lower than the nominal demand, as customers may not immediately switch to autonomous transportation. The decision to adopt AT may depend on the cost-benefit it provides to customers, which, in turn, is influenced by network design decisions. In this paper, we investigate the problem of multi-enabler transportation network design for autonomous transportation with elastic demand. We assume that demand for ATs depends on the cost savings it offers to customers, and these savings are directly impacted by network design choices. We develop a mixed-integer mathematical model for locating infrastructure enablers required for long-haul autonomous transportation. To solve the model for larger instances, we developed a Column Generation based heuristic. The model is implemented numerically for benchmark cases, such as the Sioux Falls network, and a sensitivity analysis is conducted for key parameters. Additionally, the findings provide several managerial insights, such as the investment required to achieve specific adoption level.

3 - How CAVs Shape Network Performance and Emissions
Eloisa Macedo, Gonçalo Chaves, Jorge Bandeira

The study explores the synergistic effects of Connected and Automated Vehicles (CAVs) on urban network performance in a mixed-traffic environment with Conventional Vehicles (CVs). Focusing on a complex urban area in Aveiro, Portugal, which includes a university campus, kindergarten, health service, and a roundabout, we simulate introducing CAVs in the network. The impact of varying CAV driving behaviours on CVs and overall network performance is evaluated. For the baseline scenario, real-world traffic data was collected from probe vehicles. The microscopic traffic simulation model PTV VISSIM will be subject to many different interactions with Python code designed to be capable of launching different runs with different specificities in the car-following dynamics and operations. Scenarios included a baseline and mixed traffic with 30% CAV penetration, considering "cautious" and "all-knowing" CAV driving behaviours. Besides speed and acceleration profiles, we evaluate vehicle-specific power, operational mode, estimate pollutant emissions (CO2 and NOx), compute safety distances, and classify traffic flow characteristics. Findings show CAV integration, particularly "cautious", influences CV operations, leading to reduced emissions for light passenger vehicles in some road segments but inducing higher emissions due to congestion in others. Specific CAV behaviours contribute to smoother traffic flow, potentially mitigating congestion and improving safety for vulnerable road users.

■ MD-58

Monday, 14:30-16:00 - Room: Liberty 1.13

Branch-and-Cut

Stream: Vehicle Routing and Logistics
Invited session
Chair: Udo Buscher

1 - A Branch-and-Cut algorithm for the Single Picker Routing Problem with Scattered Storage
Constantin Wildt, Felix Weidinger

E-commerce warehouses enhance order fulfillment efficiency by employing scattered or mixed-shelves storage. By strategically allocating items of the same product to different shelves, the travel distance for picking unpredictable customer orders is minimized. The complexity of the picker routing problem increases due to scattered storage, as it requires an additional selection task regarding which product is picked from which storage position. Although there has been an increasing interest in this field of research in recent years, most solution approaches are facing critical limitations. These include assumptions such as unit demand (where the picker visits only one storage position per product) or constraints to specific warehouse layouts. In this talk, a novel approach is proposed, wherein the Single Picker Routing Problem with Scattered Storage (SPRP-SS) is solved optimally by using a Branch-and-Cut algorithm. Unlike previous methods, this approach allows for arbitrary warehouse layouts, multiple depots, and covers the varying demand case. To this end, valid inequalities and corresponding separation algorithms are developed either by adapting existing procedures from related routing problems or by creating new procedures tailor-made for the SPRP-SS. The algorithm's performance is evaluated, testing its effectiveness on both rectangular problem instances as

well as on newly designed instances featuring a non-rectangular warehouse setting with multiple depots.

2 - Branch-and-Cut methods for the Vehicle Routing Problem with Stochastic Demands
Caio Tomazella, Pedro Munari, Reinaldo Morabito

The Vehicle Routing Problem with Stochastic Demands (VRPSD) involves optimizing the routes of a fleet of vehicles to fulfill customer demands while minimising traveling costs. Demand is uncertain, and is modeled using discrete positive values that are realised when the vehicle arrives at the customer. If demand exceeds the vehicle's load, a replenishment trip is required to fulfill the remaining demand, incurring additional expected recourse costs. These recourse costs, which must be considered in the objective function, are calculated through recursive equations. We propose a novel Mixed Integer Programming (MIP) formulation that linearises the recursive equations, allowing us to solve VRPSD instances to optimality using general purpose MIP solvers. Based on this formulation, we developed variants of the Branch-and-Cut method, using both simpler and more sophisticated separation algorithms for the expected recourse costs constraints. We also present Branch-and-Cut methods that employ combinatorial Benders cuts, which are based on the separate computation of the recourse costs. A computational experimentation was performed to assess the efficiency of the proposed methods, and to evaluate how the developed enhancements improve the method's convergence.

3 - Branch-and-cut approaches for a Two-Echelon Vehicle Routing Problem with Porters
Suheyb Erdemci, David Lai, Carlos Lamas-Fernandez, Antonio Martinez Sykora

Vehicles used in logistics, such as trucks and vans, face a range of challenges, including limited kerbside availability, traffic congestion, air and noise pollution, and city regulations (e.g., ULEZ in London). As a result, there is an increasing reliance on alternative delivery methods for last-mile operations, such as porters, bikes, and drones. In this work, we present a two-echelon vehicle routing problem with porters that captures the real-life operational requirements. In the first echelon, goods are transported from the depot to intermediate depots, referred to as micro-consolidation points. Porters then handle the final delivery to customers on foot in the second echelon. The porter routes are subject to constraints related to weight, volume, and maximum distance. Since porters are allowed to revisit micro-consolidation points to resupply, synchronizing these operations becomes a complex challenge. We propose two new exponential-size MILP formulations to model this structure and introduce separation algorithms to manage the exponentially sized constraints. We conduct experiments to compare the performance of the formulations and the proposed separation algorithms. To support our experiments, we introduce a new benchmark dataset of realistic instances to evaluate the scalability and performance of the proposed approaches. Managerial insights are derived by analyzing the effects of parcel sizes and porter types.

4 - A branch-and-cut algorithm for vehicle routing problems with three-dimensional loading constraints
Udo Buscher, Felix Tamke, Florian Linß, Leopold Kuttner

This study presents a new branch-and-cut algorithm based on infeasible path elimination for the three-dimensional loading capacitated vehicle routing problem (3L-CVRP) with different loading problem variants. A key observation is that a previously infeasible route may become feasible when adding a new customer if previously violated support constraints in the loading subproblem can now be satisfied. We refer to this as the incremental feasibility property. Consequently, infeasible path definitions vary across different 3L-CVRP variants, and we introduce variant-specific lifting steps to strengthen infeasible path inequalities. To determine route feasibility, we employ a flexible constraint programming model that solves the loading subproblem exactly. An extreme point-based packing heuristic reduces time-consuming calls to the exact loading algorithm. Furthermore, we introduce a start solution procedure and periodically combine memorized feasible routes using a set-partitioning-based heuristic to generate improved upper bounds. A comprehensive computational study on well-known benchmark instances demonstrates the substantial performance improvements achieved through these algorithmic enhancements. As a result, we prove the optimality of numerous best-known heuristic solutions for the first time and establish new optimal and best-known solutions for many instances.

■ MD-59

Monday, 14:30-16:00 - Room: Liberty 1.14

Transport system and land use

Stream: Transportation
Invited session
Chair: *Polina Maglevannaia*

1 - Optimal location of healthcare facilities based on equity
Antonio Basile, Mariano Gallo

The location of healthcare facilities in a large territory, such as a region, is a decision that has a significant social and economic impact. The choice of the optimal location can be achieved by considering various objectives. This paper proposes an optimisation model that maximises equity, based on measures of accessibility. It is assumed that resources are available for the construction of new healthcare facilities and/or the expansion of existing ones in a regional territory, with the objective of rebalancing equity for residents. This paper proposes a methodology for calculating accessibility to healthcare facilities that takes into account both the generalised cost of travel and the capacity of facilities. The capacity of the facilities is calculated as a function of the beds available in each specialisation and the incidence of the pathology requiring admission to that specialisation. The generalised cost is calculated on the basis of a transport supply model. The optimisation model maximises the equity of the distribution of healthcare facilities across the territory. The proposed methodology is applied to the case study of the Campania Region.

2 - An Integrated Framework for Population Synthesis and Activity Scheduling for Transportation Microsimulation
Polina Maglevannaia, Branislav Pejak, Sanja Brdar, Oskar Marko, Vladimir Crnojević, Nikola Obrenović

Urban transportation planning requires detailed insights into both socio-demographic composition and travel behavior. Yet, many regions rely on limited, aggregated, and outdated data, undermining accurate modeling. Our work addresses this challenge by proposing an integrated framework that generates high-fidelity synthetic households, individuals, and detailed daily travel schedules. Using an advanced MCMC-based one-step sampling approach, we synthesize populations that reproduce the joint distribution of key household and individual attributes, relying solely on aggregated census and survey records. The synthesized population serves as a critical input for an activity-based model, which simulates activities based on discrete choice models that account for individual preferences, time constraints, spatial, and modal characteristics. The integration of population synthesis and activity-based modeling overcomes data limitations and ensures consistency in capturing both marginal and joint distributions accurately reflecting the characteristics of real-life populations. By doing so, our framework enhances the behavioral realism of subsequent agent-based microsimulations and enables reliable evaluations of planned transportation infrastructure changes, such as traffic rerouting and pedestrian zone creation. Developed within the UDENE project, our approach offers a powerful, data-driven tool for sustainable urban planning and decision-making in data-constrained environments.

■ MD-60

Monday, 14:30-16:00 - Room: Western LT

DEA methodological developments I

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: Helena Brozova

1 - What's the Efficient Team Size Using DEA Approach
Helena Brozova, Lucie Chytilová

Optimal SME team size depends not only on team goals and function but also on SMEs' efficiency. From the first perspective, it is crucial to know who a team member is. From the second perspective, SMEs' efficiency is essential. One broadly used method for efficiency analysis, mainly in the cases of natural, not financial, data, is Data Envelope Analysis (DEA). Therefore, this contribution aims to use a specific modification of the DEA model to estimate an efficient team size. This modification is based on the DEA model for optimal allocation of certain dual-role factors. The modified model assumes that the input or output factors are constrained by lower and upper bounds determined by the quantities of these factors for all DMUs in the first step. The procedure for identifying efficient values of the selected factors for all units follows in repeated steps, adjusting the bounds of the desired size of selected factors (inputs or outputs). The process concludes when all DMUs are efficient or sufficiently efficient according to the context of decision-making. In our contribution, we want to show how to find the (almost) efficient size team of analysed SMEs considering the minimum number of employees from the managerial point of view.

2 - DEA models for citation performance evaluation of ORMS journals
Josef Jablonsky

Performance and citation impact of scientific journals are measured by traditional metrics such as impact factor, article influence score, journal citation indicator, and others. While the impact factor is based on the total number of citations and does not reflect the quality of journals cited, the article influence score considers the past importance of the citing journals. This paper aims at the analysis the possibility of measuring the performance of journals by data envelopment analysis (DEA) models and propose a new DEA based citation performance metrics for ranking of a set of journals. We applied traditional radial and slack-based measure DEA models with weight restrictions where the outputs of the models are the citation counts from Q1 to Q4 categories, and other journals. This basic model is extended by considering the impact factor of the journals from the previous year as one of the inputs of the model. The results of the study are illustrated in the set of 80 journals from the Web of Science category Operations Research and Management Science (ORMS). The dataset for the study was obtained from the Journal Citation Reports in the period from 2017 until 2022. The relative efficiency scores and the ranking of journals obtained by the models are compared with traditional metrics, Academic Journal Guide 2021 classification and the results of other similar studies.

3 - Decarbonization under Cap-and-Trade Regulation: An Integrated Slack-Based DDF Model with a Shapley Value Approach
Elnaz Azadi, Ali Emrouznejad, Xun Zhou

In many industries, carbon emissions are an unavoidable byproduct of producing final goods, reflecting an intrinsic trade-off embedded within production processes. Recognizing this inherent relationship, the directional distance function (DDF) model has emerged as a prominent tool within the data envelopment analysis (DEA) framework to measure efficiency improvements. This model enables decision-makers to simultaneously pursue undesirable output reductions and desirable output expansions in chosen directions. Building on this model, we propose a novel Slack-Based Measure Directional Distance Function (SBM-DDF) model within a cap-and-trade system to reallocate emission allowances across multiple stages of a networked supply chain. The model facilitates an iterative, market-oriented mechanism for controlling and reducing carbon emissions, while enabling flexibility and adaptability through carbon permit trading. The model reallocates emission allowances across different stages within a network supply chain structure, ensuring that each stage adheres to a predefined emission cap. This reallocation identifies whether emission permits should be curtailed or made available for trade. Individual stages within decision-making units (DMUs) can then sell surplus emission permits to their peer stages across different DMUs seeking additional allowances. The study further examines whether the coalition of DMUs in the carbon permit trading market facilitates a gradual reduction in emission

4 - A new RDM-based EAT Model for efficiency analysis of non-homogeneous units with negative Data
Anjali Naik, Ananya Sharma, Harshit Joshi, Aparna Mehra

A new Data Envelopment Analysis (DEA) model is introduced in this paper to evaluate the efficiency of non-homogenous decision-making units (DMUs) with negative input-output data. We propose RDM-based convex DEA and Free Disposal Hull (FDH) models, specifically designed to handle negative data scenarios. The DEA and FDH models frequently exhibit overfitting; therefore, we employ the Efficiency Analysis Tree (EAT) method as an alternative. This method utilizes regression trees to identify production frontiers while adhering to microeconomic principles such as free disposability. The traditional EAT method caters to homogeneous DMUs, making it unsuitable for non-homogeneous scenarios. We suggest a new RDM-based EAT model for non-homogeneous DMUs for nonconvex technology and an RDM-based CEAT model for convex technology. The new RDM-based EAT and CEAT models for non-homogeneous units are compared with the RDM-based FDH and RDM-based convex DEA models for non-homogeneous DMUs, respectively. Additionally, we apply statistical tests to assess model differences, finding statistically significant variations among them. Furthermore, simulations conducted on randomly generated datasets examine performance trends across different conditions, including negative values.

■ MD-61

Monday, 14:30-16:00 - Room: Maurice Keyworth G.31

Behaviour in group decision making

Stream: Behavioural OR
Invited session
Chair: Femke Bekius
Chair: Hubert Korzilius

1 - Group diversity and facilitated modelling
L. Alberto Franco, Etienne Rouwette

Given the increasing diversity of the workforce, groups that use facilitated modelling (FM) are inevitably composed of members with different social and knowledge characteristics. The accumulated research evidence in the social sciences shows that group diversity can have both synergetic and disruptive effects on group functioning. Synergy comes from the elaboration of information, knowledge and perspectives instigated by diversity; disruption is linked to the tensions that may arise between dissimilar group members, which hinders elaboration. The FM literature is relatively silent about group diversity, and in this talk we examine the extent to FM can help diverse groups realise their synergetic potential. Furthermore, we argue that the claimed benefits of FM substantially depend on the degree to which the operational researcher is able to predict the dominance of intra- versus inter-group behaviours engendered by diversity. We end with some testable research propositions, and their implications for practice and education

2 - Methodological adaptivity and design choices to support decision-making in a citizen participation program
Hubert Korzilius, *Femke Bekius*, *Mats ter Horst*

Despite good intentions, top-down projects to increase the quality of living in cities often fail. Therefore, citizen participation in decision-making is increasingly applied, but knowledge about how to organize and design citizen participation in decision-making is scarce. We show experiences of ongoing action research in a city-wide neighborhood program, where citizens work together with professionals and municipality officials on decision-making in interventions to promote quality of living. We adapted the methodological approach to fit a running process and the needs of the participants. Our system's approach combined Group Model Building and Multi-Criteria Decision Analyses in multiple group sessions. Several methodological issues played a role, such as the dynamics between stakeholders showing the need for a stakeholder analysis beforehand; multiple data sources and participants missing sessions, which queried model comprehensiveness; and a high degree of interrelated leverages (e.g., language skills, self-reliance, citizen meetings) make it difficult to develop interventions. In the presentation, we show how these methodological issues were addressed and present considerations in the design of these interventions supporting the decision-making process to increase citizens' commitment and sense of ownership, to eventually implement change.

3 - Intervention design supporting inclusion and transparency in a strategic alliance within Dutch infrastructure
Jonan Raaijmakers, *Femke Bekius*, *Vincent De Gooyert*, *Etienne Rouwette*

More organisations are seeking openness in their strategizing processes. In Dutch infrastructure this trend is pursued in more interorganizational strategizing, in which we have found during empirical research based on 55 interviews that three paradoxical tensions arise: collective-autonomy, collective sensemaking-usability, and strategizing-operation. Based on our earlier conceptual research on what operational research (OR) can contribute to these open strategizing processes and our empirical research on the paradoxical tensions, we have formulated an intervention design that addresses these paradoxical tensions based on the characteristics that OR can contribute. We will present our intervention design that includes OR methods within visioning and adaptive frameworks to address the paradoxical tensions of interorganizational strategizing in Dutch infrastructure using OR. The intervention design aims to integrate perceptions and knowledge of broad stakeholder groups within small group workshops. The intervention design will be iterated through the use of six sub-cases of strategizing within the strategic alliance to evaluate the intervention design. Finally, we will present our preliminary results of the intervention process focussing on the design itself, on the interplay of the interaction of inclusion as suggested by open strategizing with small group OR workshops, and the evaluation of the experienced paradoxical tensions by participants within our intervention design.

4 - Navigating complexity in sustainable mobility transition with integrated group model building and process mapping methods
Mats ter Horst, *Peraphan Jittrapirom*, *Femke Bekius*

Transitioning to a zero-emission rail system is a complex process that involves stakeholders from various organizations and expert-driven strategies. For this sustainable transition to succeed, it is essential for decision-makers to have a shared understanding of the problem (system knowledge), common goals (target knowledge), and clear pathways for implementing the transition (transitional knowledge). In this study, we utilized a participative model-building method in Group Model Building (GMB) and complemented it with process mapping (PM) to integrate diverse perspectives among key stakeholders and create flowcharts outlining a potential pathway for a zero-emission rail project in Gelderland Province, Netherlands. This novel approach facilitated dialogue among stakeholders, captured the project's complexity using a qualitative model, and supported action plan development. By combining PM with GMB, we formulated a shared understanding of the transition, defined tasks, assigned responsibilities, and established a timeline to achieve the goals identified during the GMB process, thus addressing often-neglected aspects of implementing GMB session outcomes. Our findings demonstrate how this integrated process can promote the development of a shared understanding and pathways for a sustainable mobility transition.

Monday, 16:30-17:30

■ ME-01

Monday, 16:30-17:30 - Room: Great Hall

David Simchi-Levi

Stream: Plenaries
Plenary session
Chair: *Rina Schneur*

1 - Reinventing Operations Management's Research and Practice with Data Science
David Simchi-Levi

In this talk we show how data-driven research fosters the development of new engineering and scientific methods that explain, predict, and change behavior. We report on a few projects with online and brick-and-mortar retailers where we combine machine learning, optimization and econometrics techniques to improve business performance.

Monday, 17:40-18:40

■ MF-01

Monday, 17:40-18:40 - Room: Great Hall

Elevator-Pitches on the 50th Anniversary Articles

Stream: EURO Journals 50th Anniversary
Invited session
Chair: *Anita Schöbel*

1 - 50 years of EURO: short overviews of published papers on the history of major areas of OR
Euro

This is a series of short talks on a selection of recent accepted papers in EURO journals covering 50 years of history of developments and future directions in a range of areas of OR. Each short talk will be given by one or more authors of these papers.

The elevator pitches will present the following accepted papers:

Fifty Years of Vehicle Routing: Insights into the History and the Future

Fifty Years of Power Systems Optimization

Fifty Years of Data Envelopment Analysis

Fifty Years of Multi-Objective Optimization and Decision-Making: From Mathematical Programming to Evolutionary Computation

Fifty Years of Operational Research Applied to Healthcare

Fifty Years of Inventory Research from a Forecasting Perspective

Fifty Years of Mixed-Integer Nonlinear and Disjunctive Programming

Fifty Years of Decision Analysis in Operational Research: A Review

Fifty Years of Soft Operational Research: The Enduring Focus on Legitimacy, Meaningfulness and Performativity

Last Fifty Years of Integer Linear Programming: A Focus on Recent Practical Advances

Fifty Years of Multiple Criteria Decision Analysis: From Classical Methods to Robust Ordinal Regression

Fifty Years of Maintenance Optimization: Reflections and Perspectives

Fifty Years of Metaheuristics

Fifty Years of Portfolio Optimisation

Fifty Years of Research in Scheduling - Theory and Applications

50 years of behavioral models for transportation and logistics

50 years of Operations Research in Public Transport

Tuesday, 8:30-10:00

■ TA-01

Tuesday, 8:30-10:00 - Room: Great Hall

Joanna Sułkowska

Stream: Keynotes
Keynote session
Chair: Marta Szachniuk

1 - Topology in Biological Matter: New Ways to Use Entanglement in Structural Biology
Joanna Sulkowska

We have been aware of the existence of knotted and slipknotted proteins for over 30 years; however, the potential of entanglement in proteins has not been fully explored. From the perspective of chemistry and soft condensed matter, it is known that knots can perform various functions, such as increasing thermal or mechanical strength. During this lecture, I will show that the vast majority of knotted proteins have the simplest type of knot, and that the presence of knots is not preferred in any of the three domains—Bacteria, Eukaryota, or Archaea. Moreover, there is no organism without at least one knotted protein. Recent advances in machine learning methods in structural biology have opened up new perspectives for protein analysis and prediction. I will demonstrate how machine learning techniques can be used to incorporate knotting into structural biology, enabling the design of fit-for-purpose new proteins that enhance or manipulate protein activity. Additionally, I will discuss extensions toward the design of robust polymer-knotted-protein hybrid materials.

■ TA-03

Tuesday, 8:30-10:00 - Room: Esther Simpson 1.01

Young Women 4OR - 1

Stream: WISDOM - Women in OR
Invited session
Chair: Annunziata Esposito Amideo

1 - My Research Path in Operations Research for a Sustainable Future
Ozlem Mahmutogullari

With a strong passion for mathematics and solving real-world problems, I have been working in Operations Research, focusing on combinatorial optimization problems in the context of sustainable transportation and alternative energy systems. My research integrates mixed-integer programming and decision-making under uncertainty to design networks to serve the demand for goods or energy. Through mathematical modeling and algorithm development, I aim to bridge the gap between theoretical advances and practical applications, contributing to a more sustainable and data-driven future. Currently, as a postdoctoral researcher at Eindhoven University of Technology, I am working on supply chain design challenges to support the integration of an alternative technology into chemical processes. My PhD research at KU Leuven involved the development of exact solution methods for inventory routing and facility location problems with applications in road transportation, taking into account environmental and financial concerns. In the future, I would like to further explore the optimization of the production of renewable electricity and alternative fuels and the design of efficient infrastructures for their deployment. I aim to contribute academically and practically by collaborating with researchers and industry partners to develop innovative solutions for sustainable mobility and energy transition.

2 - Carbon Capture, Utilization, and Storage (CCUS) under Capacity Constraints: Help or Hindrance in Supply Chain Decarbonization?
Xiaoyan Xu

Carbon capture, utilization, and storage (CCUS) is a critical decarbonization technology for the oil and gas (O&G) industry. By implementing CCUS, carbon emissions can be captured, stored, and later reused for enhanced oil recovery (EOR). However, investing in CCUS presents challenges, primarily due to the mismatch between carbon capture capacity and demand. This paper introduces a two-period model for an O&G system that includes one O&G manufacturer and one CCUS provider. We analyze how CCUS capacity affects optimal operational decisions and investment strategies in this system. Our findings reveal that CCUS enables net-zero emissions and enhances profitability for both entities within the O&G system, even when high-emission products are produced. However, these benefits diminish when production costs are low. Furthermore, the results highlight optimal CCUS strategies under varying product cost conditions: For low-cost products (e.g., asphalt, petroleum coke), partnering with a CCUS provider with higher capacity improves profits and social welfare. Conversely, for high-cost products (e.g., gasoline), collaboration with CCUS providers enhances the manufacturer's profitability through a high EOR rate but does not improve social welfare.

3 - A Primer on Bilevel Optimization Under Uncertainty
Yasmine Beck

Bilevel optimization is a rather young but very active sub-field of mathematical optimization. The main reason is that bilevel optimization problems can serve as a powerful tool for modeling hierarchical decision-making processes, which arise in various real-world applications such as in critical infrastructure defense, transportation, or energy. However, the nested structure of bilevel problems makes them intrinsically hard to solve—even if all parameters of the problem are exactly known. Further challenges arise if problems under uncertainty are considered. In this talk, we give an overview of the class of bilevel problems under uncertainty. We discuss how techniques from stochastic and robust optimization can be used to address uncertainties. Moreover, we highlight that the sources of uncertainty in bilevel optimization are much richer compared to classic, i.e., single-level, problems since not only the problem data but also the (observation of the) decisions of the two players can be subject to uncertainty.

4 - Optimization models for Group Counterfactual Analysis: an overview
Jasone Ramírez-Ayerbe

Machine Learning models are increasingly being used in high-stakes decision-making environments such as healthcare, finance, or law. Many of these models are black-boxes and therefore do not explain how they arrive at decisions in a way humans can understand. Counterfactual analysis has proven to be a powerful tool in the growing field of Explainable Artificial Intelligence. In Supervised Classification, the goal is to associate with each record a counterfactual explanation: an instance that is close - according to a given metric- to the record and whose probability of being classified in the positive class (a "good class") by a given classifier is high. Finding counterfactual explanations is equivalent to solving an optimization model, the structure of which will depend on several ingredients. This talk will illustrate several such models, including when dealing with a group of instances, functional data, or when applied to benchmarking models.

■ TA-04

Tuesday, 8:30-10:00 - Room: Rupert Beckett LT

Journal of Simulation. Computer Modelling and Simulation

Stream: OR Journals
Invited session
Chair: Navonil Mustafee

Chair: *Claudia Szabo*
Chair: *Charles Macal*
Chair: *Enlu Zhou*

1 - Simulation Optimisation for Clinical Trial Design
Luke Rhodes-Leader, Matthew Darlington, Tom Parke, Peter Jacko

The design of complex clinical trials, particularly those that involve multi-stage analyses, can be a complicated task. It includes considerations on several operating characteristics such as the number of participants (trial size) and statistical properties such as the type-I and type-II error rates. The trial configurations involve multiple parameters, including trial sizes, number of interim analyses, each analysis' significance level, and stopping thresholds for success/futility. To evaluate these metrics and explore the configurations, a stochastic simulation is often needed. To get an accurate evaluation of a configuration (needed to ensure a trial meets regulatory standards) requires the simulation to be run many times (approximately 100,000), which may take several hours, for each simulation scenario. By exploring and altering the parameters, one can find a trial configuration with good performance. Current practice can be trial and error, learning from the designer's experience and the output of the simulation model. This is time consuming. This talk will discuss a project aiming to build a simulation optimisation approach to make the searching for optimal designs more systematic and efficient. In particular, Bayesian Optimisation was applied, with some adaptations to handle application specific considerations, such as stochastic constraints on the type-I error. The results suggest able to identify good solutions much more quickly than the usual approach.

2 - Enhancing Humanitarian Supply Chain Resilience: A Hybrid Simulation Approach to Managing Geopolitical and Economic Risks
Seyed Mojtaba Sajadi, SeyedMohammadReza Ayazi, Oscar Rodriguez-Espindola, Pavel Albores

In an increasingly interconnected and volatile global environment, humanitarian organizations face mounting challenges due to geopolitical and economic risks. Conflicts such as the invasion of Ukraine and the crisis in Palestine have highlighted the vulnerabilities of supply chains, particularly those supporting humanitarian operations. This study examines the impact of political and economic disruptions on the supply chain performance of international charities. A hybrid simulation model is developed to analyze the operational challenges faced by a humanitarian organization delivering aid across politically unstable regions. The model evaluates the effects of supply chain disruptions and explores strategies to enhance flexibility and resilience. By testing various scenarios, this research identifies optimal configurations for humanitarian supply chains to maintain service continuity under adverse conditions. The key contributions of this study are threefold: (1) it introduces a simulation-based framework for analyzing humanitarian supply chain risks, (2) it investigates strategies to embed flexibility in humanitarian logistics, and (3) it evaluates the interplay between local and global supply dependencies in crisis-prone environments. The findings provide valuable insights for decision-makers in NGOs and humanitarian agencies, enabling more effective risk mitigation strategies in volatile geopolitical landscapes.

3 - Multi-fidelity modelling and optimisation for long-term public sector capacity planning
Graham Burgess, Luke Rhodes-Leader, Dave Worthington, Rob Shone, Dashi Singham

In long-term capacity planning, public sector organisations must meet the public need over time with tight financial budgets. Examples of such problems arise in housing, healthcare and prisons. The overall aim of this research is to investigate a multi-fidelity, integer-ordered simulation optimisation approach to long-term public sector capacity planning problems. To this end, we study a problem in housing. Here, decision makers must split their resources between emergency shelter and permanent social housing to alleviate homelessness. We present three models of differing fidelity for the homeless care system in California, USA. These are a fluid model, an analytical queueing model and a discrete-event simulation model. We then propose and solve a deterministic optimisation problem based on the fluid model. Using policy-based shape constraints, we minimise unsheltered homelessness while planning for long-term relief to the system via permanent housing. We then discuss ongoing work on multi-fidelity, integer-ordered simulation optimisation.

4 - A Decision-making Framework for the Valorisation of the Water Cycle through Industrial Symbioses
Navonil Mustafee, Otto Chen, Lydia Vamvakeridou-Lyroudia, Albert Chen, Slobodan Djordjevic, Dragan Savic

The reuse of recycled water can help address water scarcity and promote sustainability. Industrial symbiosis (InSym) can further this goal by leveraging geographic proximity and developing solutions that allow, for example, the exchange of recycled water among businesses. However, InSym decision-making is complex as it involves multiple agents representing different stakeholder groups and displaying non-linear interacting behaviours. OR techniques can capture such dynamic and emergent behaviour and help assess the feasibility of InSym formation. For example, MCDA can evaluate conflicting criteria in decision-making problems, and simulation can model the operational processes, emergence and non-linear system feedback using approaches such as DES, ABS and SD. We present an OR framework that combines MCDA with a hybrid simulation model (DES, ABS and SD) to support InSym decision-making; we apply the framework to a greenhouse case study based in the De Volt region of The Netherlands, where a cooperative comprising greenhouse businesses is proposed, intending to invest in a central wastewater treatment plant and confront challenges on stricter national regulations on wastewater discharge and water deficit during dry seasons. The challenges reveal the urgent need for better water reuse and the deployment of OR tools to assess InSym formation and its long-term sustainability. This research was funded by the EU Horizon 2020 ULTIMATE project.

5 - Discrete Event Simulation for Perishable Inventory Management in Human Milk Banking
Marta Staff, Navonil Mustafee

Human Milk Banks play an important role in providing pasteurised donor human milk (DHM) to infants in neonatal care and community settings. Being perishable, DHM requires effective inventory management to ensure optimal utilisation, minimise waste, and meet demand from both settings. Balancing supply, storage, and allocation decisions is a challenge due to variable supply and uncertain demand. Extending a previously developed conceptual model, this study applies Discrete Event Simulation (DES) to model DHM inventory dynamics, focusing on bottling choices, batch handling, and allocation strategies. DES is well suited for capturing system variability and decision-making processes, allowing exploration of different inventory management policies. The study examines two classes of DHM products, where hospital demand requires smaller bottles, with a more costly production process than for larger bottles used for community allocation. Substitution is unidirectional, meaning hospital-grade DHM may be repurposed, but community-grade DHM cannot be redirected back. By varying supply and demand levels, we determined scenarios where enhanced perishable inventory management techniques, such as batch splitting and early redirection to the community, provide operational benefits. Both donor supply and hospital neonatal unit demand are statistically modelled using distributions fitted to real-world data, allowing for a realistic evaluation of inventory strategies in human milk banking.

■ TA-07

Tuesday, 8:30-10:00 - Room: Clarendon GR.01

Scheduling models and algorithms II

Stream: Scheduling and Project Management
Invited session

Chair: *Erik Demeulemeester*
Chair: *Alessandro Agnetis*

1 - Optimization models and algorithms for sustainable crop planning and scheduling
Paolo Detti, Mario Benini, Luca Nerozzi

Sustainable agriculture is crucial for long-term food security and environmental health, addressing challenges such as resource depletion, biodiversity loss, and climate change. However, it also presents new challenges for farmers, who find long-term crop planning increasingly difficult due to constraints like resource management, environmental regulations, and climate variability. In this work, we present decision models and optimization algorithms designed to support farmers by solving multi-period crop rotation planning problems, with the objective of maximizing the profit, taking into account sustainability regulations and sustainable agronomic practices. In such problems, the rotation of different crop types over a plot of land affects the yield and the profit of each crop, and crop rotation benefits and rewards coming from sustainability regulations must be considered. We propose an arc-flow Integer Linear Programming model and a matheuristic algorithm, based on column generation, to efficiently solve the problem. An optimal dynamic programming algorithm for a special case and a complexity analysis of the pricing problems are also provided. An extensive experimental study using real-world data from Italian farms and the sustainability regulations of the European Union's Common Agricultural Policy is presented. The numerical results demonstrate the effectiveness of our proposed methods in optimizing crop rotation while ensuring compliance with sustainability constraints.

2 - Learning-augmented algorithms for robust scheduling
Thomas Lidbetter, Spyros Angelopoulos, Konstantinos Panagiotou

We consider the classic single machine scheduling problem of minimizing some weighted sum of completion times of a set of jobs with given processing times. If the weights are unknown, the problem of finding a randomized scheduled to minimize the worst-case sum of completion times can be viewed as a zero-sum game between a Hider, who hides a target in one of a finite set of boxes with search times, and a Searcher who looks in the boxes one-by-one with the aim of minimizing the expected time to find the target. We consider this game in a learning-augmented setting, where a potentially erroneous prediction is given about the weights of the jobs (or location of the target). We establish tight tradeoffs between "consistency" of a policy (that is, the worst-case sum of completion times if the prediction is correct) and the "robustness" (that is, the worst-case sum of completion times regardless of the correctness of the prediction). We extend our results to the case of unreliable scheduling, where there is a given probability that when the machine attempts to process a job, it is unsuccessful.

3 - A Surgery Scheduling Problem Solved by Branch and Price Enhanced by Machine Learning
Přemysl Šůcha, Broos Maenhout, Pavlína Koutecká

This paper presents an operating room scheduling problem solved by the branch-and-price algorithm enhanced by machine learning. When branch and price is applied to large real-world problems, the problem is often decomposed into many subproblems with still non-negligible computational complexity. Since pricing problems often consume the majority of CPU time, we introduce a machine learning-based ranker that strategically guides the search for new columns in the column generation process. The solution to the master problem is analyzed by the ranker, which then suggests an order for solving the pricing problems to prioritize those with the potential to improve the master problem the most. This prioritization mechanism is essential for speeding up the column generation process since, by identifying new columns early in the process, we can terminate the search procedure sooner. Furthermore, our technique shows applicability to all nodes of the branching tree, making it a valuable tool for solving a wide range of optimization problems. We demonstrate the usefulness of this approach in the challenging domain of operating room scheduling. Experimental evaluations underscore the effectiveness of the developed algorithm, which consistently outperforms traditional search strategies in terms of time, number of pricing problems solved, nodes searched in the branch tree, and column generation iterations performed.

■ TA-08

Tuesday, 8:30-10:00 - Room: Clarendon SR 2.08

Hierarchical MCDA and MCDA in circular economy

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Milosz Kadzinski
Chair: *Nikos Tsotsolas*

1 - Hierarchical Dominance-based Rough Set Approach for Evaluating Omnichannel Retailing Strategies
Weronika Mrozek, Milosz Kadzinski, Mladen Stamenković, Aleksa Dokić

We consider Dominance-based Rough Set Approach (DRSA) incorporating criteria hierarchy. The method enables the partial disaggregation of a base set of criteria into multiple levels, ranging from specific to general. The classification for a given node in the hierarchy is derived based on the outcomes attained or observed only for its child nodes. This approach is advantageous from both structuring and data processing perspectives. We applied the method to a dataset of 74 Serbian retailers' multichannel marketing integration, comprising 17 criteria organized into four hierarchical groups. We compared it against the classical DRSA with a flat criteria structure, using two rule induction algorithms, DOMLEM and DOMApriori, alongside two classification schemes — standard and score-based. The hierarchical DRSA demonstrated competitive accuracy in cross-validation, with the combination of DOMLEM and standard classification yielding the best performance. The results suggest that the inconsistency in top-level criteria values may impact classification quality. However, further improvements in data preprocessing could enhance the method's accuracy, making hierarchical DRSA a promising tool for addressing decision problems with complex criteria structures.

2 - Companies' maturity to use Open Data: A Hierarchical Multi-Criteria Evaluation Model
Mirjana Kljajić Borštnar, Staša Blatnik, Uroš Rajkovič, Gregor Lenart, Marjeta Marolt, Andreja Pucihar

Governments have invested significant resources in opening their data for public to promote transparency, innovation and digital transformation. Although the provision of high-quality open data is evidenced by indices such as the Open Data Maturity Report and the OURdata Index, adoption by companies remains limited. In this study, we develop a multi-criteria evaluation model using the hierarchical multi-attribute decision method DEX to assess companies' readiness to use open data. A systematic literature review identified driving and inhibiting factors, which were refined through a facilitated brainstorming session with 16 domain experts using innovative software and generative AI. This process generated 260 ideas, which were categorized into 11 groups and prioritized through voting. Based on these findings, we constructed a hierarchical tree with 53 attributes, assigned qualitative domain values for each attribute and developed utility functions in the form of expert rules. The model was first evaluated on 10 Slovenian companies and later implemented as an online automated assessment tool. The analysis of the assessments of 50 SMEs shows that the hierarchical multi-attribute decision modelling improves the understanding of companies' readiness to use open data and thus provides valuable feedback for policy makers in developing effective strategies and support measures.

3 - Research on Multi-criteria Decision-making of Zero-Defect Intelligent Manufacturing from the Perspective of Circular Economy
Chu-Lun Hsieh

To achieve the net-zero transformation goal in 2050, zero-defect smart manufacturing is an innovative manufacturing model and is regarded as an essential way to improve production efficiency and energy efficiency and achieve net-zero carbon emissions. In his book "How to Avoid Climate Disaster," Bill Gates put forward the perspective of "Innovation to Zero," emphasizing that without continuous innovation, the goal of net-zero emissions cannot be achieved. The manufacturing industry is striving to attain zero-defect smart manufacturing. The concept of "innovation to zero" has been transformed into a business and production model aimed at reducing the impact on the natural environment. When making decisions, the manufacturing industry must carefully assess its effects on society and society. The impact of the natural environment and integration of the sustainable perspectives of zero-waste resource recycling and material flow cost accounting into the strategy of zero-defect smart production. This research aims to use multi-criteria decision analysis and decision laboratory analysis from the circular economy perspective to comprehensively evaluate and integrate zero-defect smart manufacturing and net-zero carbon emission strategies and establish an optimal decision-making model, which will help the manufacturing industry achieve sustainable manufacturing goals.

4 - Towards a DSS for Selecting Sustainable Construction Materials Using Multi-Criteria Models
Nikos Tsotsolas, Athanasios Spyridakos, Isaak Vryzidis

In recent years, the construction industry has highlighted the increased need to improve resource efficiency, reduce waste and increase value through the selection of sustainable construction materials. Given that fact that waste materials from construction and demolition activities make up over a third of all waste in the EU, the reuse of materials from existing buildings to supply new construction and renovation projects has the potential to reduce demolition waste, as well as demand for primary (non-recycled) materials and greenhouse gas emissions. The basic concept of sustainable building construction and retrofitting is to maximize value and minimize cost by achieving a balance between social, economic, technical and environmental aspects. As part of a research project, a DSS is being developed that will address decisions related to the selection of the optimal construction materials per project, based on life cycle assessment (LCA), life cycle costing (LCC) and social assessment (S-LCA) criteria. The DSS integrates two MCDA methods, namely WAP and Stochastic UTAdis. Through the application of these methods, the grading (value) will be elicited and the classification of the materials will be produced. This documented information could be included, in accordance with EU guidelines, in the Digital Passport of Building Materials, which will act as a tool to enhance transparency and sustainability in the construction industry.

■ TA-09

Tuesday, 8:30-10:00 - Room: Clarendon SR 2.01

Statistical methods for finance

Stream: OR in Finance and Insurance
Invited session
Chair: Giulia Rotundo

1 - Synthetic networks generation and technology innovation
Giulia Rotundo

This work elaborates on the role of assortative mixing in broadcasting technology diffusion. The role of assortativity intra-firm networks for firms' innovation performance has been widely studied. The classic definition of assortativity through the Pearson correlation coefficient among the degrees of the nodes at the end of each edge captures the linear dependencies among the degrees of the connected nodes. This paper aims at pushing forward the concept of assortative mixing allowing for non linear dependencies. In order to achieve this task, the marginal distributions are fixed as the most detected from the empirical data sets and networks are generated for meeting an assigned joint distribution. The approach is different from the classic configuration model and its extensions which allow to build a network with a target level of correlation. The structure of the network impacts on the diffusion of technologies. Actually, the possibility to generate networks with specific properties allows to have a null model for investigating the role of topological structures in specific problems.

2 - Edge-clustering coefficient in directed networks
Giorgio Rizzini, Rosanna Grassi

Clustering coefficient, that describes the triadic relations between nodes, is one of the most important structural indicators in network theory. Although many works are devoted to study the issue by a vertex perspective, a study by the point of view of the edge has not analysed enough. The aim of this work is to provide a new edge-clustering coefficient for unweighted directed networks, in line with the local clustering coefficient for nodes. We define the edge-clustering coefficient as the ratio between the actual triangles to which an edge belongs and all potential ones, that is, all triangles an edge could belong to. This coefficient captures the importance of the edges forming triadic relations among nodes highlighting the relevance of an edge within the network. We propose a closed-form formula to compute the edge-clustering coefficient based on the degrees of the edge endpoints. The extension of the coefficient to the directed case allows considering also the direction of the edges so that we are able to analyse different patterns of triangles constructed on each link. In this way, it is also possible to assess the strategic role of each edge in the transmission of any kind of relevant information. A detailed numerical analysis based on simulated and real networks shows how the proposal could provide meaningful insights into capturing at local level the topological structure of the network.

3 - Organizational ambidexterity and financial performance in hotel industry
Sebastian Ion Ceptureanu

This paper examines the effects of organizational ambidexterity on financial performance in hotel industry. Due to the relative lack of validated understanding of the organizational ambidexterity effects on financial performance, it contributes to the development of theory explaining this interaction and its effects. The results provide new insights on the role of exploratory and exploitative activities of Romanian hotels.

4 - Dcc-mgarch and wavelet coherence analysis in exploring the contagion effect between cryptocurrencies and fiat currencies
Tea Šestanović, Josip Arneric, Klara Luketa

This paper investigates the phenomenon of financial contagion between cryptocurrencies (Bitcoin, Ethereum) and fiat currencies (USD, EUR, GBP). Dynamic Conditional Correlation (DCC) Multivariate Generalized Autoregressive Conditional Heteroscedasticity (MGARCH) model is estimated for each pair of currencies, i.e. crypto vs fiat, since it provides time-varying conditional correlations based on which the properties of currencies as diversifiers, hedge or safe heaven can be examined. Kolmogorov-Smirnov (KS) test is used to investigate the contagion effect by comparing the distribution of conditional correlations in pre-crisis and crisis period. However, source of contagion can not be extracted from these methods. Therefore, wavelet coherence analysis (WCA) is used to elaborate on the lead-lag relationship between the pairs of currencies. The results show that before the pandemic, Bitcoin and Ethereum had a weak negative correlation with USD, acting as a hedge, while during the pandemic, they become safer havens. Correlation with EUR remains close to zero, positioning them as a hedge. In relation to GBP, they exhibited weak positive correlations, making them diversifiers. KS tests revealed the dominance of the crisis over the pre-crisis period for the pairs EUR-ETH, GBP-BTC, and GBP-ETH, indicating the presence of contagion. WCA confirms the correlations between cryptocurrencies and fiat currencies, enabling the lead-lag relationship analysis for each period.

■ TA-11

Tuesday, 8:30-10:00 - Room: Clarendon SR 1.03

Home Health Care

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Antonio Martinez Sykora*

1 - Integrated Planning of Home Healthcare with Multi-functional Medical Staff and Heterogeneous Demand
Wei-Ting Chen, Kuancheng Huang, Wan-Lin Lu, Chung-Yu Chen

As the senior population rapidly increases, the demand for home healthcare (HHC) is rising. HHC integrates medical resources into patients' homes, allowing them to receive care in a familiar environment while reducing the inconvenience of traveling to a medical facility. This study focuses on the staff assignment and routing problems in home healthcare, aiming to minimize the total workload of the multi-functional medical team. Based on the integrated home medical care plan promoted by the National Health Insurance Administration, medical institutions connect different professionals according to patient needs. Therefore, this study considers the scheduling and resource limitations of different professionals, as well as the diverse needs and care continuity of patients, to develop a mathematical model. Compared to previous research, this paper considers multiple professions in an HHC team while the requirements of visit and continuity for each profession are various. The proposed model plans patient assignments, scheduling, and visit routes across various time periods to improve service efficiency. Given the decreased efficiency of exact methods in solving larger-scale problems, the study adopts a tabu search algorithm to enhance solving efficiency. Numerical tests show that the designed algorithm effectively solves problems in both small and large-scale scenarios, with significantly reduced computation time compared to exact methods, demonstrating its potential and reliabilit

2 - Integrating IoMT and Multi-Objective Optimisation for Efficient Expert Allocation in Home Health Care
Seyedamirhossein Salehiamiri, Richard Allmendinger, Arijit De

The increasing ageing population has demanded more investment in different healthcare sectors, especially the home healthcare area. However, more experts are leaving the industry since the current situation offers less flexibility for nurses, more pressurised roles, and riskier conditions for patients. Meanwhile, newly developed health care systems, such as the Internet of Medical Things and wearable devices, can help automate tasks such as recording and storing real-time patient data and performing necessary care where possible. This paper addresses the problem of allocating experts to patients considering time windows, the expert's skill level, and the service menu, considering multiple objectives. The primary objective is to minimise the total service menu, while the second objective maximises the fairness of the distribution of the most complex tasks; finally, the third objective minimises the total service time for the patients with the highest risk levels. The proposed approach employs two solution approaches, the epsilon-constraint and the multi-objective evolutionary algorithm based on decomposition. The results from different scenarios indicate the decrease in patients visit time and balance in the expert's workload across the home health care industry.

3 - Resilient Home Healthcare Planning during Disruptions with Interagency Collaboration
Mahla Tayarani Zare, Dhananjay Thiruvady, Mahdi Bashiri, Benny Tjahjono

Demand for Home healthcare (HHC) services has increased due to an aging population. Disruptions like disasters can interrupt HHC care continuity, placing vulnerable groups' conditions at risk. Resilient HHC planning is vital for recovery from disruptions; without it, agencies risk losing patients to hospitals, causing financial losses and higher hospitalizations. A two-stage stochastic model for resilient HHC planning is developed, integrating pre- and post-disruption phases with agency collaboration, unlike existing studies focusing solely on post-disruption without collaboration. In the first stage, agencies hire on-call temporary caregivers before disruptions under patients' uncertainty. The second stage optimizes daily caregiver routing and scheduling, integrating full-time, temporary, and shared caregivers whose availability remains uncertain until each day. The objective function minimises costs and over-qualification time, which is the time caregivers spend on tasks below their expertise. It ensures skilled caregivers are available for critical cases of other agencies, even if it incurs higher costs. Small instances are solved using Gurobi, while a heuristic algorithm is developed to handle large instances efficiently. Numerical analysis shows that caregiver sharing between agencies increases the total number of patients visited compared to the classic HHC models. The effectiveness of the proposed model is tested under disruptions with greater uncertainty.

4 - A flexible mathematical model for Home Health Care Problems
Carlos Lamas-Fernandez, Consuelo Parreño-Torres, Miguel Reula Martín, Antonio Martinez Sykora

In the health and social care sectors it is common for some specialized teams to travel to patients homes to provide care. These teams are typically made up of by a number of staff members with varying skills, starting locations and working hours. Patients require different types of care, during specific time windows, and may have special requirements, such as needing two staff members, or multiple visits with some sort of temporal dependency between them. Since teams need to decide which staff member will visit each patient, as well as the routes they will take to do so, this kind of planning problem is known in the literature as the Home Health Care Routing and Scheduling Problem (HHCRSP). We introduce a new mixed integer linear programming formulation for the HHCRSP that extends previous models. Our formulation can readily be adapted to address more specific variants in the scientific literature, proving a larger number of optimal solutions and stronger lower bounds on benchmark instances using the same computational framework. We further propose an instance generator for producing scenarios that closely resemble those of the National Health Service in the United Kingdom.

■ TA-12

Tuesday, 8:30-10:00 - Room: Clarendon SR 1.02

Scheduling Approaches for Complex Manufacturing Systems

Stream: Scheduling and Project Management
Invited session
Chair: *Lars Moench*

1 - Genetic Programming for Solving Flexible Flow Shop Scheduling Problems with Maximal Time Lags
Daniel Schorn, Lars Moench

A scheduling problem for a two-stage flexible flow shop with maximal time lags between consecutive operations motivated by semiconductor manufacturing is considered. The jobs have unequal ready times and both initial and inter-stage time lags. The total weighted tardiness is the performance measure. A heuristic scheduling framework using genetic programming (GP) to automatically discover priority indices is proposed. Computational experiments are carried out on randomly generated problem instances. The results are compared with the ones of a reference heuristic based on a biased random key genetic algorithm combined with a backtracking procedure and a MILP-based decomposition approach. The results show that high-quality schedules are obtained in a short amount of computing time using the GP approach.

2 - Solving Flexible Flow Shop Scheduling Problems with Parallel Batching and Maximal Time Lags
Jens Rocholl, Lars Moench

Maximal time lags between consecutive process steps are important process restrictions in semiconductor manufacturing. A scheduling problem for a flexible flow shop with parallel batching, time lags, and the objective to minimize total weighted tardiness is considered. Jobs refer to different products, and only jobs of the same product may be grouped together in a batch. A constructive heuristic computing a schedule by successively inserting operations and making batching decisions on the fly while avoiding time lag violations is presented. The heuristic is integrated into a biased random key genetic algorithm. In addition, a decomposition approach is presented where subsets of jobs are iteratively assigned to batches and machines according to solutions to a mixed integer linear programming formulation. The performance of the procedures is assessed by means of computational experiments with randomly generated problem instances. The metaheuristic outperforms the decomposition approach.

3 - Scheduling Parallel Stress Test Machines in Semiconductor Reliability Laboratories: Exact and Heuristic Approaches
Jessica Hautz, Lars Moench

A parallel machine scheduling problem motivated by stress test machines in semiconductor reliability laboratories is considered. The jobs have unequal sizes and ready times, and belong to incompatible job families. Jobs of the same family can be processed simultaneously on a machine if the sum of their sizes does not exceed the machine's capacity. In contrast to conventional p-batching machines, the machines can be interrupted to start new jobs and have to be interrupted to unload completed ones, requiring conditioning times to restore the necessary stress conditions. The machines are unavailable during conditioning periods, and jobs that were preempted are resumable after conditioning. The performance measures are the makespan and the total (weighted) completion time. Mixed-integer linear programming and constraint programming models are established. A constructive heuristic and metaheuristics are designed. Computational experiments on randomly generated instances demonstrate good performance in terms of solution quality and time.

■ TA-13

Tuesday, 8:30-10:00 - Room: Clarendon SR 1.01

Appointment scheduling

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Alex Kuiper*

1 - Outpatient Department Appointment Scheduling: A Semi-Open Queuing Network Model
Mahua Banerjee, Ashutosh Sarkar

Hospital Outpatient Departments (OPDs) traditionally provide advance appointments for doctor consultations, ensuring service predictability, reduced waiting times and increased resource utilization. However, they also accept walk-in patients to protect against cancellations and no-shows. In this context, OM researchers have extensively studied various policies for scheduling walk-in patients. The parameters used to design these policies are - patient arrival sequence, caseload, consultation time, and patient waiting time. This study considers the case of the OPD of a multi-specialty hospital that offers both advance appointments as well as walk-ins with a few additional characteristics such as patients with multiple consultations and patients with appointments arriving late. These pose a challenge for the OPD manager to determine the extent of buffer to be built between consecutive appointments and the way to schedule late arrivals and walk-in patients. In this study, the complexities of the above decision environment are modeled as a semi-open queuing network (SOQN) model. The model evaluates the effectiveness of several scheduling policies and determines the optimal buffer time between appointments. Subsequently the model simulates the collected test data from the hospital, and it is observed that the effectiveness of the scheduling policies is greatly influenced by factors such as, caseload, service time variability, and prioritization of different patient classes.

2 - Online Multi-appointment Scheduling for Outpatient Examinations with Genetic Programming
Zhang Huan, Yang Wang, Lihui Zeng, Li Luo

Centralized appointment platforms in hospitals enable patients to submit requests online and receive immediate allocations of date and time slots, significantly enhancing convenience and operational efficiency. However, existing multi-appointment scheduling algorithms predominantly rely on simplistic dispatching rules, which are short-sighted and fail to effectively balance patients' dual needs for reduced waiting times and fewer visits. To address this limitation, we introduce a novel online multi-appointment scheduling problem (OMASP) and develop a genetic programming (GP) algorithm to evolve high-quality dispatching rules. Our proposed GP algorithm integrates two key components: a multi-fidelity simulation evaluator to filter out underperforming rules, and a feature selection to enhance the interpretability of the evolved rules. Leveraging real-world data from a partner hospital, we design simulation scenarios that capture the distributions of the number of patient examinations and daily request arrival rates. Experimental results demonstrate that our GP-based method achieves an average improvement of 20.16% over the existing appointment dispatching rules.

3 - Appointment Scheduling across Patient Groups with Varied No-Show Rates
Qihao Wu, Yong-Hong Kuo, Haolin Feng, Yiwu Jia

The disparity of equity in access to healthcare services could be attributed to scheduling preferences for avoiding appointment no-shows, which are found to be relevant to ethnic, racial, and socioeconomic characteristics. Our study aims to design appointment scheduling (AS) schemes that address equity issues and evaluate how patient-group information affects both schedule efficiency and equity in access to medical appointment services (i.e., fairness). In our problem, appointment requests come in gradually, requiring the scheduler to account for stochasticity and patient group-dependent no-show rates. We propose AS schemes that come with different levels of procedural fairness, and each proposed scheme leads to a Markov Decision Process (MDP). By deploying dynamic programming for a manageable-scale problem and reinforcement learning for the large-scale problem in practice, our experiments reveal consistent managerial insights. The Group-Aware Scheme (GAS) that fully leverages patient category information achieves the highest utility. The Semi-Aware Scheme (SAS), which utilizes only the group information from the existing schedule when making decisions regarding upcoming requests without needing the group identity of those requests, performs exceptionally well under specific operational environments characterized by patients' show-up rates. This finding suggests that SAS can offer a competitive alternative to GAS and simultaneously achieve efficiency and perceived fairness.

4 - Appointment Scheduling with Updates: An Exact and Optimal Approach
Alex Kuiper, Roshan Mahes

Traditionally, appointment schedules have been determined by minimizing a specific cost function consisting of clients' waiting times and server idling. Under stochastic service times, this intra-day problem is predominantly studied in a static sense, assuming that a schedule—after determined—is fixed. Technological advancements now enable real-time communication with clients during the day. Using such channels allows for updating appointment schedules on the fly, for example, by postponing appointments in case of overcrowding. Yet, while its promise is clear, sending updates at the wrong moments, or too many, may be ineffective or unrealistic, potentially causing client confusion and frustration.

Within optimal appointment scheduling, three rescheduling paradigms are introduced that facilitate updating during the day: via arrivals, the timeline, or the waiting room. Each of these demands its own dynamic programming formulation, but they all yield significant savings over static scheduling. Furthermore, the more updates there are, the better the performance becomes, albeit with diminishing returns. Incorporating additional enrichments extends the applicability of the methodology: the inclusion of no-shows, overtime, and grace periods to account for clients underway.

Sending updates enables the scheduler to exert control during the session, which improves the utilization of the scheduled resource. For the first two paradigms,

■ TA-15

Tuesday, 8:30-10:00 - Room: Esther Simpson 1.08

Heuristic Search 1

Stream: Combinatorial Optimization
Invited session
Chair: Rafael Marti

1 - A Heuristic Approach for the Periodic Vehicle Routing Problem with Driver Consistency
Marc Benito-Marimon, Manuel Laguna, Anna Martínez-Gavara, Rafael Marti

This paper addresses the Periodic Vehicle Routing Problem with Driver Consistency (PVRP-DC), a critical extension of classical routing problems that incorporates both temporal planning and driver assignment consistency constraints. While traditional vehicle routing focuses primarily on cost minimization, the PVRP-DC acknowledges the significant operational benefits of maintaining consistent driver-customer relationships across multiple visits within a planning horizon. Despite its practical relevance in last-mile logistics, this variant has received limited attention in the optimization literature . We propose a novel heuristic method for efficiently solving the PVRP-DC, which extends the standard Periodic Vehicle Routing Problem by ensuring that the same driver visits a customer across all scheduled service days. Our approach balances the computational complexity of simultaneously optimizing visit day combinations, route construction, and driver assignments while maintaining consistency constraints. Through computational experiments on benchmark instances, we show that our heuristic produces high-quality solutions within reasonable computational times. Additionally it compares favorably with the previous exact method in terms of scalability. The results indicate significant potential for practical implementation in dynamic last-mile delivery operations where both routing efficiency and service consistency are essential performance metrics.

2 - Leveraging Fourier Analysis for Instance Characterization in Permutation-Based Combinatorial Optimization Problems
Leticia Hernando, Xabier Benavides, Anne Elorza, Maialen Beristain, Josu Ceberio, Jose A. Lozano

The Fourier transform provides an alternative perspective for addressing permutation-based combinatorial optimization problems (COPs) beyond their conventional instance representation. However, its high computational cost limits practical applications to small problem sizes. To overcome this limitation, this work explores how insights from Fourier coefficients can be leveraged to analyze instance properties without explicitly computing them. Using the Linear Ordering Problem as a foundation, we establish direct connections between instance characteristics and the properties of their Fourier coefficients. Building on these results, we extend the approach by decomposing instances within a broader class of problems—the Multi-dimensional Quadratic Assignment Problems—relating their structure to problem complexity. Additionally, we highlight a connection between the information embedded in Fourier coefficients and the patterns observed in solution rankings of COPs. In particular, we examine the intersection of the Linear Ordering Problem and the Traveling Salesperson Problem through the lens of solution rankings. To illustrate the practical implications of these theoretical findings, we generate instances of permutation-based COPs with varying complexity and solution ranking properties. Furthermore, we analyze how different metaheuristics perform across these diverse instances. The ultimate goal is to develop a taxonomy of problem instances based on algorithmic performance.

3 - A Matheuristic Framework for the k-Group p-Dispersion Problem
Anna Martínez-Gavara, Antonio Rodriguez Uguina, Manuel Laguna

Forming diverse, balanced teams is essential for effective decision-making in fields such as workforce management, consulting, and interdisciplinary research, among others. This talk introduces the k-Group p-dispersion Problem ((k,p)-GDP), a novel extension of the classical p-dispersion problem (p-DP). The (k,p)-GDP seeks to form k teams of p individuals while maximizing intra-team dispersion, ensuring that diversity is achieved and distributed across multiple teams, an aspect often overlooked in traditional models. Given the computational complexity of the problem, we propose an advanced solution methodology that integrates Integer Programming formulations with heuristic techniques. Specifically, we develop a novel matheuristic based on the Biased Greedy Randomized Adaptive Search Procedure (B-GRASP) to efficiently handle large-scale instances. This talk will present key findings from extensive computational experiments, highlighting the effectiveness of our approach in generating high-quality diverse teams. Finally, we will explore open challenges and future research directions in diversity maximization and combinatorial optimization.

4 - GRASP WITH PATH RELINKING. An analytical review
Rafael Marti, Manuel Laguna, Anna Martínez-Gavara, Sergio Pérez-Peló, Mauricio Resende

This is a comprehensive review of the Greedy Randomized Adaptive Search Procedure (GRASP) metaheuristic and its hybridization with Path Relinking (PR). GRASP with PR has become a widely adopted approach for solving hard optimization problems since its proposal in 1999. The talk covers the historical development of GRASP with PR and its theoretical foundations, as well as recent advances in its implementation and application. It identifies the design questions that are still open in the scientific literature. The experimental part applies advanced PR implementations on two well-known combinatorial optimization problems, linear ordering and max-cut, in an effort to answer these open questions. The talk also explores the hybridization of PR and other metaheuristics, such as tabu search, scatter search, and random-keys genetic algorithms.

■ TA-16

Tuesday, 8:30-10:00 - Room: Esther Simpson 2.07

Food and Nutrition Security - Crops and menus

Stream: Sustainable Food & Agroforestry
Invited session
Chair: J.c. Gerdessen

1 - Optimizing local diets while considering seasonality of ingredients
Maike van Rooijen, Francisco Martos-Barrachina, Laura Delgado Antequera

Food miles account for nearly 20% of global food emissions. Therefore, prioritizing the use of local foods is an opportunity to reduce the environmental impact of our food system. Besides decreasing environmental impact there is a need for nutritious and affordable diets. Formulating these diets is challenging due to the conflicting nature of

the objectives. Mathematical programming has proven to be an effective method to find these diets. However, current studies usually propose one meal plan, overlooking seasonal ingredient availability. This study develops a mixed-integer meal planning model which considers seasonality of ingredients, costs, and nutritional value. Andalucia is taken as a case study. Our findings demonstrate that increasing local food is feasible without compromising nutritional adequacy. This meal planning framework offers an approach to reduce food miles while improving the palatability of dietary recommendations.

2 - Towards a sustainable supply of underutilized cereals and beans to improve micronutrient supply in China
Yijun Li, J.c. Gerdessen, Wopke van der Werf, Anneleen Kuijsten, Sander De Leeuw, Wen-Feng Cong, Shenggen Fan, Tjeerd Jan Stomph

Rice and wheat provide the bulk of calories in Chinese diets. However, the food products based on these cereals are low in most macro- and micronutrients. Greater use of nutrient-rich underutilized cereals and beans (UCBs) (e.g., millet, sorghum, beans) could improve nutrition. Moreover, due to less intensive cultivation methods, these food crops have generally lower environmental impact. Here, we explore how reallocating rice and wheat areas to UCBs could balance nutrient supply and improve environmental sustainability in China. Using multi-objective optimization, we found that reallocating rice and wheat areas to UCBs would improve the nutrient supply of iron by 23%-52%, of dietary fiber by 11%-46%, while selenium had only small gains (1%-4%) across the tested scenarios. The combined strategy of reallocating areas and increasing the use of unrefined rice and wheat led to the greatest improvements in the supply of all nutrients analyzed. To achieve these benefits, 7.2 million hectares of rice and 0.3 million hectares of wheat areas would be reallocated to sorghum (+4.6 million ha), millet (+2.1 million ha), and beans (+0.9 million ha), primarily in Northeast China and Inner Mongolia. Reallocating areas among crops and promoting healthier diets with more UCBs and whole grains would unlock the potential of UCBs to improve human nutrition and environmental sustainability.

3 - Portfolio Optimization in Crop Breeding
Paul Deuker, Marleen Balvert, Juan Vera, Jacob van Etten

In many non-Western regions, agricultural yields can be as low as 10% of those in Europe due to extreme climate variability and heightened biotic and abiotic stresses. Traditional breeding methods, which typically optimize for single traits like yield, fall short in addressing the multifaceted challenges imposed by such uncertain environments, leaving farmers exposed to significant economic risks.

We introduce a two-stage stochastic programming framework that integrates breeding and planting decisions to manage environmental uncertainty. In the first stage, our model determines optimal breeding strategies that balance the trade-off between broad adaptation—ensuring resilience across diverse conditions—and specific adaptation—maximizing yield under particular environmental scenarios. Once uncertainties are resolved in the second stage, the model guides planting decisions, selecting crop varieties from a diversified portfolio tailored to the realized conditions.

By capturing the interplay between breeding and planting, our approach aims to minimize yield volatility and economic losses while enhancing the overall efficiency of breeding programs. This framework aims to provide a robust decision-support tool that helps farmers and breeders navigate variable agricultural environments, with the goal to contribute to more stable and sustainable food production systems.

■ TA-17

Tuesday, 8:30-10:00 - Room: Esther Simpson 2.08

Modeling and competitive analysis in routing and covering problems

Stream: Combinatorial Optimization
Invited session
Chair: Erwin Pesch
Chair: *Alena Otto*
Chair: *Sven Mallach*

1 - Effective compact formulation for the Pickup-and-Delivery Problem with Time Windows and Transshipment
Luis Rocha, Alena Otto

The pickup-and-delivery problem with time windows (PDPTW) and transshipments (PDPT) is a generalization of the vehicle routing problem (VRP). Unlike VRP, where deliveries are made to a central depot, PDPTW treats the delivery address of a customer request as an input, allowing it to be any node in the network. Applications include ridesharing, where passenger requests with predefined pickup and drop-off points are assigned to shared vehicles and same-day deliveries, such as food or retail item deliveries from specific restaurants or shops. In all these applications, each request is associated with a time window. To meet time constraints and reduce costs, logistics companies increasingly consider transshipments as in the PDPT, where a request can be transferred between vehicles. We design a compact mixed-integer linear program (MILP) for PDPT. A compact formulation removes the vehicle index to eliminate much of the inherent model symmetry. Compact formulations are valuable due to their ease of implementation in off-the-shelf solvers, and adaptability to problem extensions. We build on existing compact formulations for related problem classes and develop novel strengthened inequalities. Our model significantly outperforms state-of-the-art model formulations, solving 89% of benchmark instances. It achieves a 90% and 52% reduction in run time for instances with up to 15 and 30 requests, respectively. Our model also significantly outperforms existing MILPs for the PDPTW.

2 - Online approaches for the drone-supported distribution of relief in disaster areas
Marie Schmidt, Alena Otto

We study the problem of providing emergency supplies in disaster areas by a tandem of truck and drone. In the basic problem version, we assume that we are given a number of potential demand points. Upon visiting a potential demand point by either vehicle, we learn whether there is indeed demand for relief goods in the respective node. In that case a visit by truck is necessary to deliver the required goods. We propose a routing strategy for truck and drone and are able to prove that it has a competitive ratio of 2 if the truck is faster than the drone and 1+alpha if the drone is faster, where alpha denotes the ratio of truck and drone speed. Furthermore, for some values of alpha, we are able to show that the proposed strategy is optimal in the sense that no other strategy can achieve a better competitive ratio. After studying the basic problem variant, we transfer our ideas to problem extensions.

3 - The Maximum k-Vertex Cover Problem: Polyhedral Structure, Valid Inequalities, and Computational Enhancements
Shengjie Chen, Yu-Hong Dai

The maximum k-vertex cover (Max k-VC) problem is a fundamental combinatorial optimization problem that seeks to select at most k vertices in an edge-weighted undirected graph G to maximize the total weight of covered edges. In this paper, we study the polytope associated with an integer programming (IP) formulation of the Max k-VC problem. Some insightful polyhedral properties of the polytope are established. In particular, we demonstrate that certain facet-defining inequalities for the polytope can be derived from those for the projected and low-dimensional polytopes obtained by restricting G to its

subgraphs in the associated IP formulation. Exploiting this structural property, we introduce three families of strong valid inequalities based on different subgraph structures, including odd cycles, cliques, and (generalized) stars. We further characterize the necessary and sufficient conditions for these inequalities to be facet-defining and investigate the corresponding separation problems. Finally, we integrate the proposed valid inequalities as cutting planes into the branch-and-bound framework of the IP solver CPLEX. Extensive computational experiments demonstrate the effectiveness of these inequalities in improving solution quality and efficiency, providing both theoretical insights and practical enhancements for solving the Max k-VC problem.

4 - Integer Programming Formulations for the Target Visitation Problem - Revisited
Sven Mallach

The target visitation problem asks for a permutation (or tour) of target locations such that the difference between a reward expressing pairwise relative ordering preferences and the traveling distance is maximum. It can thus be seen as a combination of the traveling salesman problem and the linear ordering problem, or likewise as a generalization of the traveling salesman problem with precedences. In 2015, Hildenbrandt proposed according integer programming formulations along with polyhedral investigations. In this work, we extend and slightly revise some of these results, we highlight relations to betweenness and quadratic linear ordering problems, and we give some impressions about the computational performance obtained with the most promising integer programming models.

■ TA-20

Tuesday, 8:30-10:00 - Room: Esther Simpson 2.11

Applications of combinatorial optimisation in industry and services 1

Stream: Combinatorial Optimization
Invited session
Chair: *Adriana Cherri*
Chair: *José Fernando Oliveira*
Chair: *Deisemara Ferreira*

1 - Optimising Operating Theatre Scheduling in a Brazilian Public Hospital Using Mixed Integer Linear Programming
João Paulo Francisco da Silva, Lucas Ribeiro Bortoletto, Rafael Crivellari Saliba Schouery, Edilson Arruda

Efficient operating theatre scheduling is essential for optimising hospital resources and ensuring organized sessions of medical procedures. This process involves scheduling time blocks for each operating theatre over a planning period and allocating them to medical specialities, while considering constraints such as medical team availability and theatre compatibility. In this work, we model operating theatre scheduling as an optimization problem and apply Mixed Integer Linear Programming (MILP) techniques to improve theatre utilisation and enable medical teams to operate more patients. Our case study focuses on the University of Campinas' Clinical Hospital, a regional high-complexity centre of excellence that serves a population of around 5 million people. Additional challenges include transplant surgeries, priority surgeries and scarcity of anaesthetists. To address these complexities, we develop a hierarchical multi-objective optimisation model that incorporates packing and knapsack-based constraints and can be solved efficient with an open-source MILP solver. This study includes a pilot implementation of the model within the hospital setting for validation and refinement. Preliminary results indicate that the model is able to not only replicate the schedules produced manually by a highly experienced staff member, but also improve the utilisation of the surgical centre with respect to the current practice.

2 - Multi-Appointment Scheduling with Patient Transportation
Yang Wang, Junpeng Wang, Yaohui Guo, Abraham Punnen

This paper addresses a novel multi-appointment scheduling problem with patient transportation (MASPT), where each patient requires a series of diagnostic tests and transportation operations across hospital departments under limited resource availability. The problem involves assigning each diagnostic test to a specific machine and each transportation operation to a designated resource, while determining their start times to minimize total patient waiting time. To tackle this problem, we formulate Mixed-Integer Linear Programming (MILP) and Constraint Programming (CP) models and develop a two-individual based path-relinking (TIPR) algorithm. The TIPR algorithm incorporates three key innovations: (1) a novel encoding-decoding scheme that efficiently transforms a permutation list into a feasible schedule, (2) a backward swap-based local search strategy that leverages decoded information to enhance search efficiency, and (3) a forward swap-based path-relinking mechanism to promote solution diversity. Using real-world hospital data, we generate test instances with diverse structures and sizes to evaluate the proposed approaches. Experimental results demonstrate that the TIPR algorithm outperforms both MILP and CP models, as well as existing hospital scheduling practices. Furthermore, our findings reveal that while increasing transportation resources improves scheduling performance, the marginal benefit diminishes once a certain resource threshold is reached.

3 - Lot-Sizing and Scheduling problem in the Beverage Industry: Challenges, Classification, and Future Directions
Deisemara Ferreira, Víctor Mario Noble-Ramos, Douglas Alem, Reinaldo Morabito

This research presents a comprehensive literature review on lot-sizing and scheduling (L&S) problem in the beverage industry, highlighting its unique challenges and production characteristics. Unlike general manufacturing, beverage production involves two interdependent stages, synchronization constraints, and perishability concerns that complicate planning and scheduling decisions. We introduce a novel classification framework that systematically categorizes L&S approaches tailored to beverage manufacturing. Our review covers over 38 studies on soft drinks, fruit-based beverages, beer, and yogurt, identifying key trends, research gaps, and future directions. We emphasize the need for addressing machine maintenance, data uncertainty, and the potential role of emerging. This study provides valuable insights for researchers and practitioners aiming to enhance production efficiency in the beverage sector.

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■ TA-23

Tuesday, 8:30-10:00 - Room: Esther Simpson 3.01

Community OR

Stream: OR for Societal Development
Invited session
Chair: *Olabode Adewoye*
Chair: *Jinal Parikh*

1 - Transformation of a Rural Settlement in Lagos, Nigeria using a Community Operational Research Approach
Olabode Adewoye

Community Operational Research (COR) is the branch of OR that addresses community-based issues such as community development planning; disaster preparedness and response; healthcare access, quality, and improvement; poverty reduction strategies; education access, and quality; social network analysis for community mobilization; and participatory decision-making processes within marginalized communities, etc., using analytical methods. In this work, most of the issues described in COR above were used to transform a rural settlement. The community was divided into Areas, Zones, and Central for ease of administration. Each Zone is headed by a Chairman and the decision-making organ of the Zone is made up of the chairmen of the areas. The Central Authority (CA) is headed by the Central Community Development Association (CCDA) Chairman and, the six Chairmen of the six zones. Furthermore, we examine the values of COR as a way to strengthen community participation. We described the work of the COR in the rural settlement. We discussed the various stages through which the work progressed, from the initial contact with the settlement through a period of acting as chairman. We outlined the variety of projects in which the COR was involved. The community called Ladegboye Community won the best community in Lagos state, Nigeria in 2012 with a price of N2,500,000 ($16,400), and in 2018, won the best community in Ikorodu Local Government of Lagos State.

2 - Management Leadership Styles and Retention of Gen Z Employees: An AHP Approach
Adebola Glorious Adekoya, Abdul-Hameed Sulaimon, Omotola Bamigbaiye-Elatuyi

Understanding the generation during this incredibly challenging labour market has become important. The rise of Gen-Z in the workplace is something that has continued to impact the way that businesses are managed. Organisations are currently discussing varying leadership styles and practices to manage and retain these generation of employees. The challenge that organizations encounter nowadays is not only how to manage the Gen Z employees, but also how to keep them on the job as long as possible and how to maintain their vigorous and ambitious nature. Studies have shown that significant differences exist between generational groups in terms of leadership styles and employee retention. Considering the rapid growth of this set of employees in the workplace, there arises a need to understand and prioritize the different leadership styles which influence Gen-Z employees' intention to stay in an organization. This study explores the application of the AHP model to examine the leadership styles that are critical for Gen-Z employees' retention within Lagos metropolis, Nigeria. Adopting the quantitative approach and a descriptive and exploratory survey (AHP based questionnaire), this study aims to (i) analyze the leadership styles that influence Gen-Z employees' retention using AHP; (ii) prioritize the leadership styles that influence Gen-Z employees' retention among organizations; and (iii) rank the leadership styles that influence Gen-Z employees.

3 - Environmental cleaning of effluent of selected textile industries by biosurfactant producing bacteria
Abiodun Waidi Ashiru

The aim of this study is to isolate, screen and molecular characterize biosurfactant producing bacteria from effluent of selected textile industries. Effluent samples were collected from ABY textile industrial company, Agege Motor Road, Mushin Lagos state and from Sunflag Nigeria Limited, Surulere Lagos state. Bacteria isolation from the effluents was done by serial dilution and spread plate method on Nutrient agar medium then passes through incubation process for 24 hours for colonies to be present. Screening method used are hemolytic, drop collapse and oilspread techniques to check for biosurfactant present in the effluent samples, which results as positive, negative, gamma, alpha and beta. Gram staining was done to the isolates and viewed under microscopic view showing mostly of Gram positive bacillus and also Gram negative bacillus. Biochemical test was done. Molecular Characterization was done showing, Bacillus tropicus, Lysinibacillus fluoroglycofenilyticus, Paenibacillus sonchi, and Bacillus tianshenii. The PCR analysis of amplified, full length bacterial 16SrRNA fragments from the isolates obtained. The suspected organisms isolated from the samples includes; Bacillus thuringesis, Bacillus subtilis, with different Bacillus spp. The result of the gram staining done from the isolate collected from the textile industries is mostly Gram Positive Bacilli showing the predominant Bacilli present in the effluents from the industries.

4 - Improving Healthcare Accessibility in Rural Regions: An application of Self-serve Pharmacy Kiosks
Gohram Baloch

In recent years, self-serve Kiosks have been widely adopted in the healthcare industry to improve healthcare access, streamline processes, and reduce wait times. In this presentation, we explore the application of self-serve pharmacy kiosks in enhancing healthcare access in rural regions. We model the problem as a location-inventory problem to make optimal location and inventory decisions that minimize customer travel distances in the presence of both brick-and-mortar pharmacy and self-serve kiosks. Customer choice is modeled through a multinomial logit (MNL) framework, where the utility they derive from a specific kiosk location depends on expected travel distance, which in turn is influenced by the kiosk's fill rate. Operational scenarios where these kiosks improve healthcare accessibility are presented.

■ TA-26

Tuesday, 8:30-10:00 - Room: Maurice Keyworth 1.33

OR Making an Impact: 3 case studies and a discussion

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: *Making An Impact*
Chair: *Ruth Kaufman*
Chair: *Sofiane Oussedik*

1 - Data-Driven TV Scheduling: Optimizing Public Broadcasting at ZDF
Carolin Isabel Bauerhenne, Xenija Neufeld, Andrea Reckenthäler, Andreas Gruen

Public-service media play a crucial role in informing, educating, and entertaining audiences across Europe. As a German TV broadcaster, ZDF leverages advanced analytics to enhance decision-making, including TV scheduling. This talk focuses on the practical implementation of a mathematical programming approach for TV scheduling. Using several years of audience data, we apply constraint programming to maximize audience reach while ensuring smooth transitions between topics and adhering to key constraints - public-service obligations, compliance requirements such as youth protection, license availability, and market-driven aspects like key moments when viewers tend to switch channels during prime time. Beyond methodology, we explore the challenges of adoption, including persuading program schedulers to trust optimization-driven recommendations, refining schedules based on feedback, and integrating data-driven insights into editorial workflows. We share key lessons on balancing analytics with editorial needs and adapting OR models to the complexities of stakeholder-driven media environments.

2 - OR at Ocado: Driving Efficiency in Online Grocery Retail
Anna Moss, Patrick Klein

Ocado Group is a global technology business redefining e-commerce, fulfilment and logistics in online grocery and beyond. We leverage cutting-edge technology solutions in automation, robotics, machine learning and AI for online grocery and non-grocery distribution. These solutions are developed by Ocado Technology, a technological arm of the Ocado Group, and delivered via the Ocado Smart Platform ("OSP"), an end-to-end suite of solutions to enable operational efficiencies and high-standard customer experiences for our global partners.

Fulfilment, the last mile and the supply chain are significant areas of focus for online grocery retailers - impacting profitability and customer experience.

This talk dives into the challenges our solutions need to address in last-mile, replenishment network, and fulfilment optimisation domains. For example, in the last mile, we need to maintain an optimised vehicle routing solution at scale, even as customers continue to place, edit or cancel their orders. In replenishment network optimisation, our solution needs to ensure sufficient stock levels while avoiding purge and satisfying storage, transportation and other operational constraints. In the fulfilment domain, we need to ensure efficient warehouse operations.

We focus on how Ocado Technology's Data Science Team applies OR, ML, and hybrid approaches to develop highly efficient solutions that address these complex challenges while balancing multiple business objectives.

3 - From Chaos to Clarity: Consulting Lessons from Optimizing Alpro's Energy and Production Scheduling
Justine Broihan, Frederik Fiand, Robin Schuchmann

Every optimization model in production tells a deeper story—of translating theory into practice through close collaboration and iterative problem-solving. In this talk, we share the consulting journey behind designing and implementing a GAMS-based decision-support system at Alpro—a leader in plant-based food production. Far beyond just a technical deployment, this project was a masterclass in managing complexity, aligning stakeholders, and building trust.

We'll explore the real-world challenges faced by our consulting team: translating on-site planner needs into mathematical logic, managing the messiness of live operational data, and navigating the cultural shift toward automation and dynamic market participation. Through a structured but adaptive process—iterative prototyping and continuous feedback loops—we helped Alpro optimize energy production and conditional bidding on the day-ahead electricity market.

Whether you're an academic researcher, operations leader, or consultant, this talk gives a candid look at what it takes to bridge the gap between sophisticated models and messy real-world implementation.

4 - Case studies: discussion of what works, what doesn't
Making An Impact

Following the presentation of the three case studies that make up this session, the speakers will discuss with each other, and with the audience, some of the common challenges, success factors, lessons, and questions that have emerged.

■ TA-27

Tuesday, 8:30-10:00 - Room: Maurice Keyworth G.02

Applications of Optimization under Uncertainty

Stream: Stochastic and Robust optimization
Invited session
Chair: *Solène Delannoy-Pavy*

1 - Exploring Strategies for Refining Column-and-Constraint Generation in Solving Two-Stage P2P Energy Trading Models under Uncertainty
Albert Farriol Salas, Fernando García, Josh Eichman

This study presents two strategies for applying the column-and-constraint generation (CCG) algorithm to large-scale optimization problems. These strategies are designed to address potential memory limitations by delaying the expansion of the master model and incorporating initial scenarios to streamline the problem-solving process. The proposed methods are designed to improve the performance of the algorithm in broader large-scale optimization problems although they are tested in a peer-to-peer energy trading model. To evaluate the effectiveness of these strategies, simulations are conducted using the IEEE 33-bus system. The analysis focuses on the impact of the proposed strategies on execution time, the number of iterations, and the handling of unused scenarios in the master model. Initial tests are performed with all strategies and their combinations, followed by an increase in the number of total scenarios to further examine the performance of the best combinations in managing larger-scale optimization problems. The results indicate that selection of the most appropriate strategy is a tradeoff between the size of the problem and the execution time. Strategies were proposed that can reduce execution time by up to 29% compared to the classic CCG formulation, and other strategies were able to reduce the size of the problem by more than 20%, enabling solution of larger problems, at the expense of a moderate increase in execution time.

2 - Estimating maintenance cost of offshore electrical substations
Solène Delannoy-Pavy, Vincent Leclere, Axel Parmentier, Manuel Ruiz

Offshore wind power is rapidly expanding as part of the green transition. The French Transmission System Operator (TSO) owns and maintains offshore electrical substations that connect wind farms to the grid. We present a decision support tool to estimate maintenance costs for various strategic decisions, such as substation design selection and stock management policies. We formulate a discrete, finite-horizon Markov Decision Process where states represent substation degradation levels, and actions correspond to maintenance operations. Costs are derived from penalties incurred by the TSO, proportional to untransmitted production beyond a specified quota of free maintenance days. Our focus is on heavy maintenance, which requires substation shutdowns. Maintenance decisions must consider stochastic access conditions, influenced by factors like wave height and wind speed. To address this uncertainty, we introduce two decision rules that account for random access conditions, simplifying the problem to an open-loop format. We propose a fast approximate solution method using Sample Average Approximation. Additionally, we extend the model to a closed-loop formulation to represent different maintenance types. To manage model ambiguity, we incorporate Bayesian and Distributionally Robust Optimization.

3 - Multistage Distributionally Robust Optimization under Stochastic Disruptions
Haoxiang Yang

A stochastic disruption is a type of infrequent event in which the timing and the magnitude are random. We introduce the concept of stochastic disruptions, and a stochastic optimization framework is proposed for such problems. In this talk, we discuss two possibilities where we do not know the exact probabilistic distribution of the uncertainty under the stochastic disruption setting, one for the uncertainty magnitude and the other for the timing. We formulate a multi-stage distributionally robust optimization model while considering potential stochastic disruptions. To solve such complex models, we propose stochastic programming models for each case and solve them using cutting-plane methods. We present the computational results of our approach applied to an optimal power flow problem with N-1 contingencies.

4 - Learning Optimization: A Machine Learning framework for predicting Vehicle Routing outcomes under demand uncertainty
Lorenzo Saccucci, Giuseppe Stecca, Marco Boresta

In industrial settings, optimization problems like the Vehicle Routing Problem (VRP) frequently recur with similar characteristics, where only a few parameters of previously solved instances vary while most features remain constant. This research proposes a data-driven approach using Machine Learning (ML) to predict optimal solution characteristics for recurring instances by leveraging historical data patterns, particularly when facing demand uncertainty, without requiring complete re-optimization. A comprehensive ML pipeline has been developed to capture patterns in recurring VRP instances with time windows, encompassing the generation of artificial instances, feature extraction, and training of predictive models to forecast key aspects of optimal solutions. The methodology bridges traditional optimization methods with predictive analytics, creating a framework that predicts

solution values efficiently when demand variations occur. Experimental results demonstrate high accuracy in predicting critical solution features, such as the required number of vehicles and optimal route structures. Moreover, initial explorations indicate that these predictions can be embedded within heuristic methods, showing promise in accelerating the resolution of complex instances. This approach enables the avoidance of costly re-optimization for daily demand fluctuations while providing theoretical insights and practical benefits for industries tackling VRP challenges with variable demand.

■ TA-28

Tuesday, 8:30-10:00 - Room: Maurice Keyworth 1.03

AI and Machine Learning for Decision Support

Stream: Decision Support Systems
Invited session
Chair: *Junhong Guo*

1 - PFL-MDoE: A Personalized Federated Learning Framework with Mixture of Disease Experts for Robust Medical Image Classification
Tianrun Cai, Qing Yin, Yu-Wang Chen, Xian Yang

AI-driven decision methods have demonstrated superior performance for medical image classification tasks compared to traditional rule-based or statistical approaches. However, these methods need large-scale centralized data for model training which is impractical in healthcare due to patient data sensitivity and strict privacy regulations. Federated Learning (FL) offers a privacy-preserving solution by enabling local model training on private data for global model aggregation on a central server. However, FL faces significant statistical heterogeneity during model training, such as feature and label heterogeneity across medical institutions. Such heterogeneity often leads to aggregated global models making biased decisions in diverse institutions. Therefore, this paper introduces a novel framework called PFL-MDoE, an acronym for Personalized Federated Learning (PFL) with Mixture of Disease Experts (MDoE). The PFL component incorporates personalized modules that adapt to local data distributions, mitigating feature heterogeneity. In addition, the MDoE architecture incorporates dedicated expert modules designed for diseases with different frequencies. The gating mechanism dynamically assigns weights to the corresponding modules based on the disease category. By integrating specialized knowledge in this manner, MDoE addresses label heterogeneity. Consequently, our framework offers a personalized and secure AI training solution for diverse medical image classification tasks.

2 - An overview on the predictive maintenance planning: the integration of learning algorithms and digital twins
Anıl Akpunar, Şener Akpınar

The advancement of Industry 4.0 has introduced transformative technologies that enhance industrial efficiency, reliability, and decision-making capabilities. Among these, the digital twin stands out as a key innovation that creates a real-time virtual representation of physical systems, enabling comprehensive evaluation, optimization, and predictive analysis while supporting data-driven decision-making processes. Learning algorithms further enhances this digital ecosystem by leveraging real-time data from digital twins, such as condition monitoring and production progress metrics, to enable adaptive and autonomous decision-making. Predictive maintenance plays a crucial role in improving machine availability by preventing unexpected failures and enabling just-in-time maintenance actions. By utilizing advanced analytics on condition monitoring data collected through high-performance sensors, predictive models can assess the current health status of machines and estimate their remaining useful life. This predictive capability facilitates the adoption of proactive maintenance strategies, optimizing resource allocation, reducing downtime, and improving overall operational efficiency. In this study, the integration of digital twins, learning algorithms, and predictive maintenance establishes a framework for intelligent industrial management, while a systematic literature review categorizes relevant studies on learning algorithm applications in maintenance planning and optimization.

3 - Machine Learning Based Hierarchical Algorithms: An Application In Plastic Injection Industry
Alara Baysal, Cevdet Utku Şafak, Ahmet Eralp Avunduk, Eyyüb Batuhan Ünal, Erinc Albey

Many plastic injection moulding facilities rely on labor-intensive quality control methods, presenting an opportunity for machine learning algorithms to enhance real-time detection of defective products. This study introduces a hierarchical algorithm that utilizes machine parameters and cavity sensor data to evaluate plastic injection parts' quality and fault types.

We explore the effects of sensor placements, including pressure and temperature sensors near mould gates and cavity edges, and extract features using linear fitting techniques. These features, combined with machine parameters, facilitate the prediction of multiple fault types. The hierarchical approach provides valuable insights into process deviations by capturing interactions between machine settings and sensor data.

The results show the algorithm achieves approximately 90% accuracy in 1/0 fault detection and between 90% and 95% for various common faults in the industry. These findings could help recommend real-time corrective actions, leading to improved equipment efficiency and reduced downtime.

4 - A Two-Stage Machine Learning and Evidential Reasoning Framework for Trustworthy Decision Support
Junhong Guo, Dong-Ling Xu, Jian-Bo Yang

Balancing predictive performance and interpretability is a critical challenge in decision support systems, particularly in high-stake domains such as medical diagnosis and financial risk assessment, where both accuracy and transparency are essential. Traditional interpretable models struggle to capture latent relationships among complex data, while high-performance machine learning (ML) models lack transparency, limiting their applicability in high- stake decision-making. To address this issue, we propose a Two-stage Machine Learning-Evidential Reasoning (TMLER) framework, which integrates ML and Evidential Reasoning (ER) to strike an optimal balance between accuracy and interpretability. In the first stage, ML methods extract high-level, human-recognizable features, such as medical risk scores or imaging-derived indicators, from multimodal data, replacing manual preliminary assessments. In the second stage, these extracted features are systematically fused within the transparent ER framework to combine evidence and handle uncertainty, generating structured and traceable decision support. Experimental validation on real-world medical datasets demonstrates that TMLER provides structured and explainable decision support without compromising predictive performance, offering a viable solution for trustworthy AI-driven decision-making.

■ TA-29

Tuesday, 8:30-10:00 - Room: Maurice Keyworth 1.04

Pricing and Contract Design in Logistics & Networks

Stream: Pricing and Revenue Management Innovations
Invited session
Chair: *Christopher Kirkbride*

1 - Combining a Smart Pricing Policy with a Simple Replenishment Policy: Managing Uncertainties in the Presence of Stochastic Purchase Returns
Alys Liang

Regarded as the “ticking time bomb” in the industry, returns have cost retailers hundreds of billions of dollars in the US. This has prompted businesses to adapt by charging extra delivery fees, increasing prices (to compensate for the return cost) or allowing “returnless refunds”. Undesirable as returns are, it is generally accepted that they cannot be entirely eliminated and lenient return policies are necessary to maintain customer loyalty. Motivated by this reality, we ask: How can a retailer offering a free return and refund policy improve profitability through joint inventory and pricing control? We model a single store/warehouse setting with lost sales, positive lead time, periodic review, and Binomial (Poisson) demand. Any purchase can be returned at a full refund within a grace period and might be restocked after passing inspection. Jointly optimizing inventory and pricing is challenging since the state variables must track the return status of all past purchases. We develop an easy-to-implement heuristic policy that combines a “smart” adaptive pricing policy with a very simple replenishment policy. Our key insight is that uncertainties in both demands and returns are effectively managed by the price control. We show that the relative loss of this policy converges to zero at a rate much faster than the usual square-root when the annual market size becomes large. In addition, our results can be extended to more general settings including: (1) return fees and pa

2 - Optimizing Discrete Dynamic Pricing in the Online Bus Market: A Choice-Based Network Revenue Management Approach
Akshitha Suryapeta

The "One Nation, One Permit" policy is expected to benefit bus operators and passengers by reducing permit costs and fostering competition, potentially lowering fares. In India’s online bus market, pricing plays a crucial role in operator success. This study examines the discrete dynamic pricing problem, where only a few predetermined prices are offered per origin-destination pair. A comparison is made between leg-based booking limits using expected demand and the Choice-based Deterministic Linear Program (CDLP). A choice-based network revenue management model is considered, addressing challenges such as estimating arrival rates and choice probabilities from past booking data. This requires a discrete choice demand model and optimization of large action spaces, similar to dynamic assortment optimization in e-commerce. Since choice-based revenue management models are intractable, CDLP is used to approximate value functions. By integrating customer choice and selecting prices from a finite set, the problem is formulated as a constrained maximization task. Numerical experiments will evaluate average revenue, seats sold per leg, seats sold per fare class, and computational efficiency.

3 - Contract design for the third-party logistics firm: logistics service vs financial service
Chen Li

In recent years, small and medium-sized enterprises (SMEs) play a major role in economic growth. Due to low credit rating and nonstandard financial documents, SMEs are difficult to meet the financing conditions and standards of banks, resulting in the financing difficulties. The integrated logistics and financial service (IFLs) of third-party logistics (3PL) firms provides a new method to solve the financing problem. In the paper, we study a two-level supply chain with a 3PL firm and a small or medium-sized retailer and explore how the 3PL firm provides joint logistics and financial services to the budget-constrained retailer with different budget levels, and how to design the service contract to obtain a win-win situation. We consider pricing problems in three scenarios: the benchmark contract, the integrated service contract and the bargaining contract and obtain equilibrium solutions. Finally, a numerical analysis is executed to explore the influence of retailers’ own budgets on members’ selection of contracts.

4 - Algorithms for min-buying in networks
Christopher Kirkbride, Trivikram Dokka, Ben Black, Aaditya Bhardwaj

This work is motivated by pricing decisions faced by forecourt fuel retailers across their outlets on a road network. Through our modelling approach we are able adapt the network structure to a bipartite graph with demand nodes representing volumes of fuel from customers using a specific route that connects to the seller’s outlet nodes that intersect that route on the network. Customers may have their demand satisfied at the lowest priced competitor on their route. However, the seller can satisfy some or all of this demand by matching or beating this price via one of their outlets intersecting the route. We give a practical extension to min-pricing by considering a binary logit variant for buyers evaluating the choice between two sellers. We derive two MIP formulations for min-buying in the case of general demand. We also propose several constructive heuristics, based on insertion and selection operations, suitable for problem instances beyond the scope of the exact methods. The performance of models and algorithms are evaluated in a numerical study and develop insights from the results. Importantly, we are able to highlight the value of price-matching decisions under buyer demand sensitivity.

■ TA-30

Tuesday, 8:30-10:00 - Room: Maurice Keyworth 1.05

Production and Transportation

Stream: Advanced Lot Sizing and Inventory Strategies
Invited session
Chair: *Anand Paul*

1 - Centralized and Decentralized Inventory Stocking, Transshipment and Transportaiton
Anand Paul

We make a detailed analytical cost comparison between centralized and decentralized inventory stocking policies in a region with stochastic aggregate demand, divided into a finite number of demand centres. Each demand centre has a demand that is a random fraction of the aggregate demand. In the decentralized model, each demand centre is served by a warehouse whereas in the centralized model there is only one warehouse that serves all the demand centres. We study the difference in the expected cost in the centralized and decentralized models, both with and without transshipment of inventory between demand centres, and study how the cost difference scales with the number of demand centres. Finally we make an analytical study of the tradeoff between inventory and transportation costs, and show that transportation costs tend to increase in proportion to the square root of the number of demand centres.

2 - Integrated Production and Transportation Scheduling with Intermediate Storage
Jasper van Doorn, Joost Berkhout, Rob van der Mei

Production scheduling and vehicle routing are both well-known and widely studied problems within the field of operations research. Numerous solving methods exist to find solutions for both of these problem types based on exact, heuristic as well as metaheuristic approaches. These methods have proven effective for finding feasible or even optimal solutions but are generally computationally intensive. As a result, in practice scheduling and routing are often considered separately.

However, many real-world supply chains involve sequential production and routing stages that are highly interdependent. Scheduling decisions in one stage may restrict feasible choices in another, making unintegrated solutions prone to inefficiency or even infeasibility. These interdependent constraints can introduce additional release times or deadlines to ensure the feasibility of precedence-constrained tasks. When intermediate storage capacity between two stages is limited, this interdependency becomes even stronger.

In this work, we introduce a problem formulation for integrated scheduling with intermediate storage. Using realistic data and key performance indicators from relevant industries, we demonstrate the value of integrated scheduling methods compared to current practices. Additionally, we address the scalability of the integrated methods on industry-sized instances.

3 - AI-Enhanced Full-Objective MCDM: A Data-Driven Approach for Sustainable Decision-Making
Sarfaraz Hashemkhani Zolfani

As decision-making becomes increasingly complex in modern society, the need for objective, data-driven approaches in Multi-Criteria Decision-Making (MCDM) is more critical than ever. Traditional weighting methods often rely on subjective judgment, which can introduce bias and inconsistencies. This study explores the advancement of full-objective MCDM methods, such as ITARA, CRITIC, and MEREC, and their integration with Artificial Intelligence (AI) and Machine Learning (ML) to enhance decision-making processes.

By leveraging AI, full-objective methods can be automated, adaptive, and scalable, allowing real-time analysis of large datasets. Machine learning techniques, such as clustering, deep learning, and reinforcement learning, can refine weight assignment, identify patterns, and optimize decision outcomes. Additionally, AI-powered Intelligent Decision Support Systems (IDSS) can enhance transparency and interpretability, making MCDM more accessible for policymakers and industry leaders.

A key focus of this study is the role of AI-driven MCDM in sustainable development. By improving resource allocation, climate resilience planning, and green infrastructure development, these models can support evidence-based policies for urban sustainability, energy efficiency, and environmental conservation.

■ TA-31

Tuesday, 8:30-10:00 - Room: Maurice Keyworth 1.06

Optimization under uncertainty in healthcare and cloud computing

Stream: Stochastic and Robust optimization
Invited session
Chair: Ozlem Cavus

1 - Optimality and Fairness: application to reimbursement of COVID-19 vaccines
Monika Kal'atová, Milos Kopa, Bismark Singh

There are various points of view with regard to the distribution of COVID-19 vaccines. Every part of a distribution chain may aim to maximize its profit or minimize its costs. For example, a distributor may seek to sell as many vaccines as possible to maximize the profit. Similarly, hospitals (vaccination centers) and health insurance companies act rationally; however, taking into account some different criteria. For example, the health insurance company wants to make a fair allocation of vaccines to the hospitals. In our paper, we understand the fairness criteria in various ways and every criterion determines the model's upper level objective function. In the lower level problem, we work with well-known newsboy problem applied to the hospitals. It models the goal of hospital's to maximize the expected profit from vaccination. Combining upper and lower level problems, we obtain the bi-level optimization problem which allocates the fair number of vaccines to reimburse with respect to the optimal number of vaccines demanded by the hospitals. The numerical results will be presented.

2 - Online Multi-appointment scheduling under Demand for Oncology Patient Treatment
Macarena Fredes Araya, Sebastián Dávila, Franco Quezada

This research aims to optimize the scheduling of Oncology Care Routes (OCR) in high-demand settings with limited resources, to reduce delays in appointments and treatment times. Three algorithms are proposed: one online algorithm that schedules appointments as soon as possible, another online algorithm that prioritizes resource availability, and a third algorithm that simulates current sequential scheduling practices. Additionally, an offline Mixed-Integer Linear Programming (MILP) model optimizes scheduling with complete information. Moreover, a stochastic model with rolling horizon generates assignments under demand uncertainty.

The results obtained with data from the Fundación Arturo López Pérez (FALP) show a reduction in waiting times and delays in the events that make up an OCR. The framework integrates diagnostics, laboratory tests, and treatments, ensuring adequate timing for OCRs. The proposed solutions are practical and balance operational efficiency with clinical outcomes.

Future research will explore additional strategies addressed in the literature, such as multi-objective programming and Markov decision models, with the goal of reducing the total duration of OCRs and improving system efficiency. This framework has the potential to transform oncology scheduling and enhance patient care in high-demand healthcare systems.

3 - Cloud Computing Resource Provisioning Under Uncertainty
Melis Boran, Secil Savasaneril, Demet Batur

Cloud computing is a business model that allows users to flexibly control, customize, and scale computing resources according to their needs without requiring infrastructure investment. Since the 2000s, its adoption has grown, but cloud cost management remains a major challenge. Infrastructure-as-a-service (IaaS) providers make their computing resources available to users, and users should commit to resource provisioning to fulfill the computing needs of their workloads over a given planning horizon. However, cloud computing resource provisioning is challenging due to the inherent uncertainty in workloads; the demand for computing resources can exhibit high variability in both scale and timing. Users must select the appropriate amount of computing resources with the best pricing plan to meet their needs. In this study, we address this problem, modeling it as a Markov decision process (MDP). The solution of the model yields a dynamic optimal provisioning policy. For small-scale problems, we prove that the optimal policy is a state-dependent provisioning policy, which is monotone and nonincreasing in the number of available resources. Large-scale problems are intractable due to the curse of dimensionality. Thus, we propose an easy-to-compute heuristic policy. We compare the heuristic policy with the optimal policy for small-size computational configurations and with benchmark policies for larger-size configurations.

4 - Risk-Averse Treatment Allocation in Clinical Trials: A Multiarmed Bandit Design
Ozlem Cavus, Milad Malekipirbazari

Multiarmed bandit problems (MABs) present a class of optimal control problems well-suited for modeling resource allocation under uncertainty. This study explores the application of MABs in the context of clinical trial design. While traditional risk-neutral MABs aim to maximize the expected total number of effective treatments, this study considers the limitations of this objective, as treatments that perform well on average may exhibit significant variability and adverse effects for certain patients. To address this, a novel risk-averse MAB approach using dynamic risk measures is introduced for treatment allocation, employing a Bayesian Bernoulli model. The performance of this approach is evaluated against other allocation rules, including fixed randomization. The findings shed light on the benefits of incorporating risk-averse strategies in clinical trial designs, offering insights for more effective and patient-centric decision-making.

■ TA-32

Tuesday, 8:30-10:00 - Room: Maurice Keyworth 1.09

Low- and zero-emission solutions for maritime operations-2

Stream: Maritime and Port Logistics
Invited session
Chair: Kjetil Fagerholt
Chair: Peter Schütz

1 - Decarbonizing the Norwegian Coastal Fishing Fleet
Peter Schütz, Sarka Stadlerova

We study how to decarbonize the Norwegian coastal fishing fleet such that the total decarbonization cost are minimized. We use a model for optimal fleet renewal to study which zero- and low-emission technologies should be part of the future energy mix in the Norwegian fishing sector. The model accounts for both investment costs in new vessels, operating costs (incl. fuel costs) of the fishing vessels and carbon taxes. Our analysis shows that financial incentives need to be supplemented by a development of the regulatory boundary conditions to achieve a cost-effective decarbonization.

2 - Bunker Fuel Management Optimization for Dual-Fuel Engine Vessels: A Machine Learning and Mean-Variance Optimization Approach
Qian Zhao, Arijit De, Richard Allmendinger

The maritime shipping industry faces increasing pressure to reduce operational costs while adopting low-emission practices. With new International Maritime Organization regulations accelerating the adoption of Liquefied Natural Gas (LNG) propulsion and operational improvements like slow steaming, efficient bunker fuel management strategies are crucial. Bunker fuel costs, accounting for 50-60% of total operating expenses, are highly volatile, posing significant financial risks. This study develops an optimization framework for bunker fuel management in dual-fuel engine vessels. First, machine learning models predict fuel prices for Very Low Sulphur Fuel Oil and LNG, incorporating variance and covariance measures to quantify and mitigate financial risk. Second, fuel consumption is predicted using noon report data to generate interval forecasts based on relevant factors, such as speed, main engine performance, and environmental conditions. Random Forest and Gradient Boosting Regression models achieve an R' score above 0.8. These predictions enhance fuel efficiency and support emission reduction efforts. Finally, these forecasts are integrated into a Mixed-Integer Non-Linear Programming model, which applies mean-variance optimization to determine optimal bunkering ports, fuel quantities, and fuel types. This comprehensive approach minimizes costs and risks while facilitating the transition to sustainable maritime operations through LNG adoption and improved fuel efficiency.

3 - Empty Container Repositioning. Research agenda.
Celia Jiménez-Piqueras, Dario Pacino

The transportation of containerized goods follows an iterative process that begins with a shipping company providing an exporter with an empty container. The exporter loads the container, which is then transported to the importer, who must return the empty container to the shipping company. The container is subsequently delivered to a new exporter, and the cycle repeats. However, some regions primarily export goods, while others mainly import them, creating an imbalance that necessitates the relocation of empty containers to meet exporters' demands. This operation, known as Empty Container Repositioning (ECR), can significantly reduce costs for shipping companies when supported by effective decision-making. An efficient ECR strategy balances empty container stocks at import and export locations, preventing congestion in import areas and ensuring availability for exporters. Additionally, it can help reduce the container fleet size and the transportation of empty containers, leading to lower storage and maintenance costs and environmental impact. However, developing an efficient ECR strategy is challenging due to the scale of the problem and the uncertainty in empty container demand across locations. This study reviews scientific literature on ECR and identifies unmet needs of shipping companies, highlighting current challenges and proposing several research directions.

■ TA-33

Tuesday, 8:30-10:00 - Room: Maurice Keyworth 1.31

Decision Analysis and Artificial Intelligence (AI)

Stream: Decision Analysis
Invited session
Chair: *Richard Hodgett*

1 - Beyond the Black Box: Unraveling the Role of Explainability in Human-AI Collaboration
Caner Canyakmaz, Tamer Boyaci, Francis de Véricourt

Explainable AI models have been increasingly studied to bring transparency to decision-making processes and alleviate users' inappropriate reliance on AI inputs. Despite the promise, evidence from recent empirical studies has been quite mixed. We develop an analytical model that incorporates the limited but flexible nature of human cognition with imperfect machine recommendations and explanations that reflect the quality of these predictions. We investigate the impact of explainability on decision accuracy, underreliance, overreliance as well as cognitive effort. We find that while low explainability levels have no impact on accuracy and reliance levels, they lessen users' cognitive burden. On the other hand, providing higher explainability levels enhances accuracy by improving overreliance but at the expense of higher underreliance. Furthermore, the incremental impact of explainability is higher when the decision-maker is more cognitively constrained and the decision task is sufficiently complex. Surprisingly, we find that higher explainability levels can escalate the overall cognitive burden, especially when the decision-maker is particularly pressed for time to complete a complex task and initially doubts the machine's quality, scenarios where explanations are most needed. By eliciting the comprehensive effects of explainability, our study contributes to our understanding of designing effective human-AI systems in diverse decision-making environments.

2 - Is AI for big companies only? Investigating the adoption of AI in the SME sector and whether explainable AI can help
Ahmad Alhamidi, Richard Hodgett, Sajid Siraj

Artificial Intelligence (AI) has the potential to revolutionize organizational operations, enhancing productivity, accuracy, and profitability through various applications, such as automation and product development. Despite its benefits, AI adoption among small and medium-sized enterprises (SMEs) remains limited. According to the Annual Report on European SMEs only 6% of SMEs implementing AI technologies due to financial constraints, lack of strategic clarity, and insufficient decision-maker support.

The research aims to identify success factors and barriers influencing AI adoption in SMEs, develop a self-assessment tool tailored for these organizations, and highlight the importance of Explainable AI (XAI) in enhancing AI trustworthiness.

We are currently employing a mixed-methodology approach, starting with qualitative interviews of organizational decision-makers to validate our research constructs. At present, thematic analysis is being used to extract key insights from these interviews. Subsequently, we will utilize advanced quantitative methods to analyze and elucidate the contribution of each identified factor to AI adoption and their importance in developing a self-assessment tool from the cross-sectional survey data. The findings will guide SMEs towards adopting AI as a competitive advantage, ensuring a structured and trust-based approach to AI integration.

3 - Smart Health Check-up 2.0: Developing a Performance Evaluation System for Health Examination Centers Using AI and Big Data Analytics
Sun-Weng Huang, Jian-Hua Xia, James Liou, Tony Y. L. Chiang, Gwo-Hshiung Tzeng

With the rapid advancement of artificial intelligence (AI) and big data analytics, effectively assessing the performance and service quality of health examination centers has become increasingly crucial. Traditional evaluation methods often overlook the potential offered by medical data analysis, resulting in incomplete representations of health check-up performance and quality. Thus, this research aims to establish a comprehensive and objective performance evaluation framework for health examination centers by leveraging AI and data analytics techniques while integrating the perspectives of experts and stakeholders. First, semi-structured interviews are conducted to identify key indicators and requirements from health examination stakeholders. Subsequently, AI and data analytics methods are applied to medical service data, quantifying relationships and identifying critical influencing factors among various performance indicators. Finally, the Fuzzy Delphi Method is employed to reach expert consensus, thereby selecting and confirming core indicators of performance and service quality. The outcomes of this study can provide valuable guidance for future health examination center planning and healthcare policy formulation, effectively enhancing the quality of health check-up services.

4 - Enhancing Data Quality and Insights in Complex Systems
Leif Meier

The efficacy of modern information and application systems is deeply rooted in the quality and comprehensiveness of their underlying data.

This work introduces and evaluates a set of methodologies aimed at providing clarity over complex datasets and examines supportive techniques to assess and enhance data quality for reliable subsequent analysis.

Our approach investigates the spectrum of interdepedent data fields, scrutinizes dependencies and confidence bands, evaluates logical consistencies, and simulates probability scenarios.

Such methodologies are relevant in any field dealing with intricate data structures: Through a blend of statistical analysis, machine learning, and simulation techniques, we propose a comprehensive framework that not only ensures the accuracy of ingoing information but also enhances its analytical value.

By applying these principles, industries facing data complexity can improve operational efficiency and decision-making processes. Our research underscores the importance of a robust data foundation and seeks to offer practical insights into achieving sustainable data quality management practices.

■ TA-34

Tuesday, 8:30-10:00 - Room: Michael Sadler LG10

Advancements of OR-analytics in statistics, machine learning and data science 2

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: *Helper Zhou*
Chair: *Dolores Romero Morales*
Chair: *Gerhard-Wilhelm Weber*

1 - Stratified Treatment Optimization under Partial Observation Scarcity across Patient Subgroups
Haiyan Yu

Stratified medicine presents a promising opportunity to improve clinical outcomes by recommending a possibly distinct treatment to each patient stratum (e.g., contextualized by age group, sex, etc.). However, this encounters the challenge of having inadequate observations from some under-represented patient subgroups (assigned to one treatment) of the stratum as compared to other subgroups in the same stratum. We call this phenomenon partial observation scarcity across patient subgroups, which magnifies the common challenge of limited observations across patient strata, relative to additional patient- level covariates. We propose a weighting-estimation-then-optimization (WETO) approach to optimize the stratified treatment rule (assignment of each stratum to some treatment) under partial observation scarcity. To address the challenge of small sample sizes in underrepresented subgroups, we introduce the concept of subgroup pattern (SP) to leverage the estimates from a few well-represented subgroups specified by the SP. To make fair comparisons between treatments while combating the heterogeneity within each patient subgroup due to additional covariates, we optimize the weights of individual patients in each well-represented subgroup through entropy balancing optimization, to reduce the confounding effects of the covariates. A case study based on real clinical records of hospitalized type-2 diabetic patients confirms that the WETO-based analytics framework with the incorporation

2 - AI-Driven Primal-Dual Optimization for Solving European Option Pricing Model
Snehashish Chakraverty, Bhubaneswari Mishra

The Black-Scholes model is a cornerstone in financial mathematics for pricing European options, offering closed-form solutions under idealized assumptions. However, these assumptions often fail to capture real-world complexities, limiting their practical applicability. This investigation introduces an innovative optimization-based approach using the AI method viz. Least Squares Support Vector Machine (LS-SVM) to solve the Black-Scholes partial differential equation (PDE). By reformulating the PDE into a constrained optimization problem, the method employs the primal-dual framework to derive the solutions. The optimization objective involves minimizing a regularized least-square cost function and incorporating a kernel-based structure to model the non-linear relationships inherent in option pricing effectively. Further, different Kernels have also been used to obtain comparative results showing the performance of these kernels in solving this problem. Compared to traditional numerical techniques, such as the finite difference method (FDM) and finite element method (FEM), the LS-SVM approach significantly enhances computational performance and accuracy. This study demonstrates the utility of optimization techniques for strengthening derivative pricing models, bridging theoretical and practical aspects of financial engineering. These findings underscore the potential of optimization-driven machine learning methodologies to revolutionize financial modeling.

3 - Privacy-Preserving Resource Allocation: Near-Optimal Algorithms and Public Policy Implications
Du Chen, Geoffrey A. Chua, Victor Jose

Resource allocation is an important and pervasive problem in management science. Recent growth in privacy concerns has made this problem more challenging because decision makers attempting to optimally distribute limited resources may inadvertently leak agents' private data through the optimal allocation decisions. To address this potential privacy leakage, we develop a generic algorithm called Noisy Dual Mirror Descent (NDMD) that provides privacy guarantees without sacrificing optimality by much. This algorithm applies a noisy mirror descent approach to the dual problem and privatizes the shadow prices in the resource allocation problem, which can then be used to coordinate allocations in the original problem. We show that this proposed algorithm is jointly differentially private (JDP), a tailored concept for allocation problems under the differential privacy (DP) framework. Furthermore, we show that the algorithm can achieve near-optimal convergence rates of suboptimality in the minimax sense. Finally, we demonstrate the use and benefit of this NDMD approach by applying it to an important policy problem; namely, the allocation of Title I US education grants. When compared to a popular DP algorithm that privatizes the raw input data, our approach significantly reduces nationwide misallocation by as much as 52%. We also show that this allocation can significantly mitigate the disproportionate impact of privacy protection on historically disadvantaged and underrepresented

4 - Deep Reinforcement Learning for Multi-Echelon Inventory Management with Markov-Modulated Demand, Lead Times, and Transshipment Crossing
Fatemeh Fakhredin, Joern Meissner

Effective inventory management in multi-echelon supply chains requires making dynamic ordering decisions under stochastic demand and lead times. This paper formulates the problem as a Markov Decision Process (MDP) and applies deep reinforcement learning (DRL) using Proximal Policy Optimization (PPO) to minimize total inventory costs. Unlike traditional inventory control methods, our approach learns an adaptive ordering policy through interactions with a simulated environment. We model a linear multi-echelon supply chain where Markov-modulated demand and lead times introduce temporal dependencies, capturing seasonality, market fluctuations, and disruptions. Another key challenge is transshipment crossing, where shipments placed at different times may arrive simultaneously due to varying lead times. This disrupts sequential fulfillment assumptions, making traditional optimization methods less effective. To address this, we employ PPO, a policy-based DRL method, which iteratively refines a stochastic ordering policy by observing inventory levels, backorders, shipments, demand history, and the Markov state. This study advances data-driven supply chain optimization, demonstrating how reinforcement learning can adapt to dynamic uncertainties, offering a scalable alternative to rule-based inventory policies.

■ TA-35

Tuesday, 8:30-10:00 - Room: Michael Sadler LG15

Nonlinear Optimization Algorithms and Applications: 4

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: *Ya-xiang Yuan*
Chair: *Zaikun Zhang*
Chair: *Xin Liu*
Chair: *Cong Sun*

1 - A multilevel stochastic regularized first-order method with application to training
Margherita Porcelli, Filippo Marini, Elisa Riccietti

We present a new multilevel stochastic framework for the solution of optimization problems. The proposed approach uses random regularized first-order models that exploit an available hierarchical description of the problem, being either in the classical variable space or in the function space, meaning that different levels of accuracy for the objective function are available. We present the converge analysis of the method and show its numerical behavior on the solution of finite-sum minimization problems arising in binary classification problems.

2 - Complexity of trust-region methods in the presence of unbounded Hessian approximations
Youssef Diouane, Mohamed Laghdaf Habiboullah, Dominique Orban

We extend traditional complexity analyses of trust-region methods for unconstrained, possibly nonconvex, optimization. Whereas most complexity analyses assume uniform boundedness of the model Hessians, we work with potentially unbounded model Hessians. Boundedness is not guaranteed in practical implementations, in particular ones based on quasi-Newton updates such as PSB, BFGS and SR1. Our analysis is conducted for a family of trust-region methods that includes most known methods as special cases. We examine two regimes of Hessian growth: one bounded by a power of the number of successful iterations, and one bounded by a power of the number of iterations. When the model Hessians grow as $mathcalO(kp)$, where k is the iteration counter and $0 le p le 1$, we derived a sharp $mathcalO(epsilon−2/(1−p))$ worst-case evaluation complexity bound to reach an $epsilon$-stationary point. Additionally, for the case where $p = 1$, we established a new $mathcalO(exp(cepsilon−2))$ worst-case evaluation complexity bound, for some constant $c > 0$. We derived similar sharp bounds when the model Hessians grow linearly with the number of successful iterations. Among others, our results confirmed the profound intuition of Powell on complexity for multiple quasi-Newton approximations.

3 - A new SLP algorithm applied to Topology Optimization
Luis Felipe Bueno, Ernesto G. Birgin, Dimary Moreno, Tiara Martini Santos, Thiago Santos, Thadeu Senne

In this work we present a globally convergent version of a Sequential Linear Programming (SLP) algorithm and illustrate its numerical performance in Topology Optimization problems. The theoretical part of the work is based on recent advances in identifying key elements for the globalization of constrained nonlinear programming methods. The computational experiments focus on the application of Topology Optimization in which we are interested in building a structure in order to minimize a certain objective, respecting some necessary physical properties. Using a finite element scheme, the problem can be written as a nonlinear integer programming problem, for which we consider a continuous relaxation using the solid isotropic material with penalization strategy.

4 - Subsampled Trust-Region Methods with Deterministic Worst-Case Complexity Guarantees
Geovani Grapiglia

In this work, we develop and analyze subsampled trust-region methods for solving finite-sum optimization problems. These methods use random subsampling strategies to approximate the gradient and Hessian of the objective function, thereby significantly reducing the overall computational cost. However, the sample size for gradients (or gradients and Hessians) is chosen deterministically, with the notable feature that a full sample size maybe never required. We establish deterministic worst-case iteration complexity bounds for obtaining approximate first and second-order stationary points. Finally, numerical experiments illustrate the promising performance of the proposed algorithms.

■ TA-38

Tuesday, 8:30-10:00 - Room: Michael Sadler LG19

Forecasting, prediction and optimization 1

Stream: Data Science meets Optimization
Invited session
Chair: *Vittorio Maniezzo*

1 - A Hierarchical Approach to Forecasting Censored Demand in Lost-Sales Systems
Diego José Pedregal Tercero, Juan Ramon Trapero Arenas

Accurate demand forecasting is critical for inventory management, especially in lost-sales systems where stockouts lead to unobservable demand. Traditional forecasting models relying solely on sales data systematically underestimate demand, resulting in biased forecasts and suboptimal inventory policies. To address this, we propose an extension of the Tobit Exponential Smoothing (TETS) model that integrates temporal hierarchies to enhance demand estimation across different time frequencies. This approach leverages state-space models to reconcile high-frequency data (e.g., hourly sales) with lower-frequency demand forecasts (e.g., daily replenishments). By capturing censoring constraints at multiple aggregation levels, our method significantly reduces forecasting bias and improves the estimation of demand variance—crucial for defining safety stock. Through simulated case studies and a real-world dataset from the M5 competition, we demonstrate that our model outperforms conventional exponential smoothing and

Tobit-based methods, leading to lower lost sales and excess inventory. Additionally, we analyze the spiral-down effect, where naïve forecasting approaches exacerbate stockouts over time, and show how our method mitigates this issue. The results highlight the practical advantages of temporal hierarchies for demand forecasting, offering a robust, theoretically grounded framework for inventory optimization in supply chain management.

2 - Estimating True Demand Under Stockouts and Interruptions: A Hybrid Tobit Kalman Filter and Conformal Prediction Approach
Harsha Halgamuwe Hewage, Bahman Rostami-Tabar, Aris Syntetos

Accurate demand estimation is critical for family planning supply chain management, particularly in contexts where stockouts and operational disruptions frequently lead to censored demand observations. Standard forecasting models often fail to capture true demand due to lost sales. In this study, we propose a hybrid Tobit Kalman Filter and conformal prediction framework to reconstruct true demand by correcting censored observations. We model demand as a state-space system incorporating baseline level, trend, seasonality, and a dynamic missing demand correction component. The Tobit Kalman Filter estimates true demand by adjusting for stockouts, interruptions and external factors such as high and low consumption indicators. To address uncertainty in censored demand estimation, we integrate conformal prediction with residual sampling, providing distribution-free prediction intervals instead of relying on restrictive normality assumptions. This ensures robust uncertainty quantification, improving true demand estimation even under highly volatile and non-Gaussian demand patterns. Unlike existing models, our approach explicitly differentiates partial censorship (stockouts) from full censorship (interruptions and no stock received), enabling context-sensitive corrections. We evaluate the performance of our proposed model through simulation studies and real-world contraceptive supply chain data, presenting a scalable solution with significant implications for inventory management.

3 - Comparing traditional and machine learning methods on company cash flow forecasts in the logistics industry
Alice Wolfe, Sarah Van der Auweraer, Kristof Coussement

Company cash flow management is a critical operation that impacts daily operations, investments, revenue and risk management. With enhanced cash flow forecasting companies can improve their cash management, becoming more agile in their investment decisions and operations, which can bring significant increases in revenue.

Despite its high importance to any operating company, it remains a limited field of study within academic forecasting research and has largely focused on the utilization of traditional forecasting methods. Cash flow forecasting lags behind general financial forecasting in the exploration of Machine Learning methods and their potential improvement to the forecast. The aim of this research is therefore to inspect the application of Machine Learning methods on company cashflow forecasting compared to traditional forecasting methods.

This research is carried out in close collaboration with an international logistics company in the fashion and lifestyle industry. The company provided a data set of approximately 8 million financial records comprised of client and supplier invoice and payment records from 2016 to 2025. This context-specific data is combined with factors regarding contextual client and company data. Using this data, we test and compare traditional forecasting methods: ARIMA and ETS, with Machine Learning methods: LSTM, SVR and Gradient Boosting, to provide a forecast of the company's cash flow across different time horizons.

4 - Enhancing Routine Immunisation Demand Forecasting: A Hybrid Probabilistic and Domain-Specific Approach
Udeshi Salgado

Accurate demand forecasting is crucial for effective routine immunisation supply chains. In low- and middle-income countries (LMICs), traditional methods often rely on outdated population estimates, static wastage assumptions, and simplistic stock adjustment heuristics. These methodological limitations contribute to stock imbalances, missed vaccination opportunities, and unreliable supply projections, ultimately reducing immunisation coverage and increasing the prevalence of vaccine-preventable diseases. We propose a hybrid intelligence framework integrating domain-specific knowledge with probabilistic forecasting and machine learning to improve vaccine demand prediction. Our approach replaces static population estimates with dynamic survival birth rate modeling and incorporates consumption-based forecasting to capture missed vaccination opportunities. This ensures a more adaptive and data-driven supply chain by quantifying uncertainty, enabling proactive inventory adjustments, and reducing missed vaccination opportunities. We evaluate our model through simulations and real-world routine immunisation supply chain data. This framework holds promise for enhancing forecasting accuracy, enabling more confident supply planning, and ultimately improving routine immunisation coverage.

■ TA-39

Tuesday, 8:30-10:00 - Room: Newlyn LG.01

Sustainability in Logistics

Stream: Sustainable & Resilient Systems and Infrastructures
Invited session
Chair: *Ronald Mac-Ginty*

1 - Global Cargo Vessel Traffic Emissions Prediction under a Changing Climate
Elise Miller-Hooks, Alireza Azadnia, Wenjie Li

Maritime shipping accounts for approximately 3% of global GHG emissions, a disproportionately large amount of which is from container vessels. As the Arctic warms and sea ice thaws, commercial vessel traffic is expected to grow in this region, affecting global traffic patterns. This presentation describes a risk and flows based methodological framework for estimating emissions from GHGs and other pollutants due to changes in global container vessel traffic flow patterns, and consequential changes in vessel traffic through the Arctic, over coming decades. The method takes as input projections of environmental conditions, including ice thickness, ice concentration, maximum wave height, bathymetry, wind speed and temperature, through 2069 that affect demand for Arctic transit and projects these emissions under these forecasted changing conditions. Emissions reduction policies have been applied or are under consideration that aim to curb emissions from the commercial shipping sector. These policies include implementing emission control areas, carbon tax regulations, virtual arrival strategies and vessel speed reduction incentive programs. How these policies will transform global shipping traffic flow patterns into the future is difficult to assess, yet assessing their effectiveness is crucial to their adoption. The proposed method is applied to investigate the potential effectiveness of two of these control policy implementations on local and global emissions.

2 - Methodological proposal for designing a dynamic sustainability model for a mining region: large-scale copper mining, antofagasta region, chile (2001-2020).
Ronald Mac-Ginty, Astrid Oddershede, Luis Quezada, Pedro Palominos

This research proposes a methodology for designing a dynamic sustainability model in a copper mining area in Chile. The global push for sustainable development and climate change action has led to regulatory changes impacting the mining industry. The hypothesis of this research posits that variables associated with regional sustainability increasingly limit the growth of the copper mining industry. Using mixed research methodology, qualitative and quantitative, data from 2001 to 2020, are analyzed. The results indicate that stable mining production over two decades has relied on increased mineral processing to

compensate for declining ore grades. But, this increase in processing also raises sustainability variables, as solid waste generation, water consumption, and energy demand. Strict environmental regulations obstruct the approval of impact studies, confirming the hypothesis and highlighting challenges for large-scale copper mining in Chile. The main contribution of this study is the introduction of dynamic modeling in mining industry, allowing for the quantitative evaluation of environmental impacts and the evolution of industry over time. The modeling also revealed natural limits to the growth of mining production and allowed for an estimation of the resource's lifespan under current conditions. Finally, it is recommended to conduct future studies on circular economy in the copper industry and to apply this methodology in other mining regions.

3 - Sustainable supplier selection; from operational to ESG risk mitigation
Leili Soltanisehat, Soheil Sibdari

Aligned with the Sustainable Development Goals (SDGs), companies are increasingly integrating Environmental, Social, and Governance (ESG) considerations into their supplier selection processes. Supplier selection plays a crucial role in supply chain risk management, a key target of the SDGs, as it extends beyond traditional cost and efficiency metrics to include sustainability and ethical practices. By adopting sustainable supplier selection criteria, organizations can enhance their environmental impact, promote social responsibility, and achieve long-term financial and operational resilience. However, traditional supplier selection methods often fail to capture the complex, multifaceted risks associated with modern supply chains. Conventional approaches typically focus on limited factors, such as supplier reliability or price competitiveness, while overlooking broader ESG-related risks that can affect supply chain performance. Additionally, many existing tools do not support collaboration or information sharing across supply chain tiers, hindering the ability to identify, assess, and mitigate risks that propagate through the network. To address these gaps, this research proposes a comprehensive supplier selection framework based on a mathematical modeling approach. The framework integrates supply chain dynamics, material flows, and risk propagation within the supplier network. It considers a wide range of risks, including ESG, operational, and material risks, providing a hol

4 - A multidimensional framework for evaluating circular orange peel waste management
Patrizia Lombardi, Silvia Barbero, Silvia Fiore, Ilaria Orlandella, Fabiana Rovera, Elena Todella, Tonia Tommasi

Adopting a circular economy approach helps significantly reduce waste and aligns with the EU's strategic objectives of prevention, reuse, and recycling (EC, 2019). Italy is the EU's second-largest agricultural producer and confronts relevant issues, such as food waste (ISTAT, 2023). In alignment with the EU Green Deal, the National Research Centre for Agricultural Technologies (AGRITECH) tackles the challenges of circular agriculture in Italy using an integrated approach. This study focuses on orange peel waste (OPW) considering that, during the orange juice production process, approximately 55 million tons of OPW is generated annually, representing up to 60% of the fresh citrus weight. There are various possible uses of OPW, including anaerobic digestion, solid state fermentation, animal feed and incineration. Seeking new ways to make waste management circular, this research proposes a multi-dimensional evaluation of the technology currently developed by an Italian company, which is currently producing an orange-based biocomposite with a biopolymer matrix. An innovative three-step sustainability assessment framework is proposed which includes: (i) a Holistic Diagnosis; (ii) a Life Cycle Assessment of OPW streams; and (iii) a Multi-Criteria Decision Analysis and Circular Economy Assessment of the technology. The research is ongoing, but preliminary results are interesting for supporting possible improvements in the current technology used.

■ TA-41

Tuesday, 8:30-10:00 - Room: Newlyn GR.01

Problem Structuring Methods in Government

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Rachel Bennett*

1 - Participatory Systems Mapping for cancer strategy monitoring and evaluation
Rebecca Brouwers

Participatory Systems Mapping and Rich Pictures were used to support monitoring and evaluation of the Scottish Government Cancer Strategy. The project purpose was threefold. Firstly, to assist with the evaluation of the Cancer Strategy by providing focal points for evaluation. Secondly, to assist with strategic planning by identifying leverage points and linking to the theory of change. Lastly, to identify any relevant new indicators. We ran a series of virtual workshops with health care professionals. The output was a systems map capturing their views of how the Cancer Strategy will impact and be impacted by the health and care system. Eleven participants were involved in this exploratory project, representing a range of perspectives from different professions, specialties and geographies. The PRSM software supported qualitative and quantitative analysis. The system map was converted to an interactive tool using the DESNZ Net Zero Systems Tool. There are some key caveats which limit how the map is interpreted. This includes the small sample size due to the exploratory nature of the project, and lack of time to weight the links resulting in some factors having disproportionate influence. Timescale of change is an important aspect of the system that is not well captured in the map. Despite the limitations, the interactive tool allowed us to share the output with policy stakeholders in a format where they could explore new policy decisions for monitoring and evaluation.

2 - Embedding complex problem structuring in a Government agency for national infrastructure planning
Gayathri Eknath

The Planning Inspectorate (PINS) in UK Government is responsible for providing the application service for Nationally Significant Infrastructure Projects (NSIP) across six primary sectors: Energy, Transport, Business & Commercial, Waste, Water, Waste Water.

Since each project application spans a few years, understanding the resourcing needs of PINS for infrastructure projects poses many challenges. As the applicants' proposals evolve, and PINS helps bring applications to a submission-ready standard, the pertinent question of how much time and inspector involvement each application requires is asked. If there are delays in an applicant's submission, understanding how PINS can deploy inspectors effectively to make the most of its resource and avoid any 'dead' queueing time is critical.

In this work, we identify different factors which influence the resourcing demand for NSIP using a multi-method problem structuring approach. We bring together semi-structured interviews and systems mapping to understand how different people in PINS view the resourcing demand problem. We then use the systems approach to inform a discrete event simulation.

Our results reflect how we overcame the challenges of demonstrating the efficacy of OR techniques to stakeholders who have not been inducted in OR in a Government operational delivery setting, and embedded a systems approach with positive stakeholder engagement for the first time within PINS.

3 - Systems Mapping in Developing a 10 Year Drug Strategy
Tanya Powell

In December 2021, the government published a 10 year strategy to tackle illicit drugs (https://www.gov.uk/government/publications/from-harm-to-hope-a-10-year-drugs-plan-to-cut-crime-and-save-lives).

This put forward a whole system approach to tackling a complex problem with far reaching effects. This presentation will cover the systems mapping work (using Kumu) that was used to build understanding of the scale, influence and reach of the problem, and support engagement with wider stakeholders. How this was used on a strategic scale looking at supply, demand and prevention, through to the considering how the system needs to sit around an individual. How the work influenced the design and the approach of the strategy and then how it is being reviewed and developed to continue with the ongoing work.

4 - Experiences of applying problem structuring methods in UK government
Rachel Bennett

The UK government employs over 1400 operational researchers across more than 25 government departments, bringing their expertise of mathematical modelling to a variety of complex problems areas. All apply Soft OR and Problem Structuring Methods (PSMs) in some form, but only some overtly, and even fewer consider problem structuring their primary role. Additionally, numerous civil service professionals from policymakers to programme managers, digital developers to engineers, use uncodified problem structuring in their work.

This presentation offers some examples of where PSMs have been applied overtly by operational researchers, including Net Zero policy and Welfare system modelling, and discusses the challenges and opportunities that this presents. We contrast this to examples of problem structuring applied 'under the radar', including bus emissions research and climate adaptation. Finally, we reflect on the implications of these experiences for both operational researchers and the wider PSM community.

■ TA-42

Tuesday, 8:30-10:00 - Room: Newlyn GR.02

Sustainable supply chains II

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: *Athanasios Rentizelas*

1 - Cash Flow Dynamics in Supply Chains: Addressing Cash-Out Risks through Trade Credit and Reserve Cash Strategies
Sanket Mishra, Jayendran Venkateswaran

In supply chains (SCs), coordinating inventory, information, and financial flows is vital for SC sustainability. While inventory flows have been notably investigated in the context of the bullwhip effect (BWE), the dynamics of financial flows have not been extensively studied. Analogous to the BWE, a phenomenon is observed in cash flows (CF) called the cash flow bullwhip (CFB). CFB causes high variability in CF, which results in payment default risks, bankruptcy, and, ultimately, the shutdown of firms. Firms are assumed to utilise the cash generated from selling inventory to fund inventory ordering. However, downstream entities (buyers) may face situations where cash on hand (COH) is insufficient to order the desired inventory. We refer to such situations as cash-out. In such cases, the buyer may utilise two primary options: (i) bank financing for inventory orders and (ii) trade credit (TC), where the supplier allows delayed payment from the buyer. Under TC, suppliers face challenges in determining suitable interest rates (r), upper limits (u), and permissible payment delays (d). To address this, we model a bilateral SC consisting of a supplier and a buyer using a system dynamics approach, incorporating inventory and CFs to analyse inventory orders under COH and TC feedback. Scenario analysis is conducted using different values of r, u, d, and COH to avoid stock-out and cash-out cases. Finally, the study presents a novel solution of utilising reserve cash to address cash-out.

2 - Interdependencies and Trade-offs Between Climate Change and Waste Management Policies: Operational Impact and Policy Effectiveness
Jamal Sakaya, Andrea Masini

The urgency to mitigate climate change and reduce waste is prompting governments worldwide to adopt stricter regulations to abate greenhouse gas emissions and foster the implementation of circular economy models. As tighter environmental standards may impact firms' operations and, ultimately, their competitiveness, optimizing the design of regulatory instruments to maximize their effectiveness while mitigating potential negative impacts is of paramount importance. However, policies targeting climate change and waste reduction have often been studied in isolation, overlooking their potential interdependencies. We argue that failing to consider their interaction may undermine the effectiveness of regulatory mechanisms and lead to counter-intuitive outcomes. This study builds upon and extends existing operations management models to analyze the interplay between two regulatory mechanisms: carbon allowance-based policies targeting suppliers in emissions-intensive industries and product take-back policies mandating minimum recycling by manufacturers. Our findings reveal contrasting effects: stricter carbon policies lower profits, consumer surplus, and emissions abatement but reduce untreated waste, while stringent take-back policies yield the opposite when recycling is inexpensive. These results highlight the potential for conflicts between environmental objectives and underscore the importance of coordinated policy design.

3 - Assessing the reliability of sustainable transition to electric bus transit network using discrete event simulation
Athanasios Rentizelas, Anastasios Latsoudis

The study focuses on assessing the behaviour of electric buses when replacing conventional fuel (diesel) buses in urban transit networks, through key performance indicators, considering stochastic weather and traffic conditions. A case study of one bus line in the city of Athens, Greece was analyzed using discrete event simulation, aiming to understand the service level that can be achieved by specific sizes of electric buses fleets and under stochastic scenarios of weather and traffic conditions. The aim was to achieve at least the current service level obtained using conventional buses. The simulation model developed models all energy-consuming subsystems of an electric bus and considers the exact route characteristics of a specific bus line. The results indicate that same size fleets of electric buses can achieve the same service level as conventional (diesel) buses under typical conditions; however, under more extreme conditions (e.g. very hot weather, increased traffic) the service level drops significantly and a much higher number of buses is required to bring it to the desired level. Additionally, a strategy where all electric buses were starting their shift at the same time would lead to extreme peaks in charger station traffic, which leads to management challenges.

■ TA-43

Tuesday, 8:30-10:00 - Room: Newlyn GR.07

Global and Nonlinear Solvers

Stream: Software for Optimization
Invited session
Chair: *Hugo Chareyre*

1 - What's new for the global solver in FICO Xpress
Tristan Gally

This talk discusses the latest updates and improvements to the global optimization capability within FICO Xpress Solver, which allows to solve general mixed-integer nonlinear problems to global optimality. We will discuss the internal workings of the solver, its features, and recent performance improvements.

2 - Solving MINLP polynomial problems to global optimality: Recent advances in RAPOSa
Julio González-Díaz, Brais González Rodríguez, Pietro Belotti, Iria Rodríguez-Acevedo, Ignacio Gómez-Casares

This talk aims to showcase the latest developments in RAPOSa, a global solver for polynomial optimization problems, with a primary focus on its two most recent functionalities: i) the extension to solve mixed-integer MINLP problems and ii) the extension to solve problems on unbounded domains. With the inclusion of these two extensions, RAPOSa can now tackle any MINLP polynomial optimization problem and, eventually, solve it to certified global optimality.

The talk will delve into various facets of the key challenges encountered in these extensions, including some unexpected findings related to the impact of seemingly innocuous modeling choices.

3 - Latest developments for mixed-integer nonlinear programming in Artelys Knitro
Hugo Chareyre, Marvin Stanczak

Artelys Knitro is a solver for nonlinear and mixed-integer nonlinear programming problems. It handles various input structures, including linear, quadratic, and black-box functions, ideally with their first and second-order derivatives. Knitro uses derivative-based algorithms to find optimal solutions, guaranteeing global optimality for convex problems and converging to a stationary point for non-convex problems. For continuous nonlinear problems, Knitro offers interior-point algorithms and sequential quadratic programming (SQP) algorithms. For mixed-integer nonlinear problems, it includes branch-and-bound and mixed sequential quadratic programming (SQP) algorithms.

In this talk, we will present the latest developments in Artelys Knitro 15.0, focusing on some of the recent advances in solving mixed-integer nonlinear problems (both convex and non-convex), and multi-start heuristics for global optimization. We will also present Knitro results on large-scale models demonstrating speedups achieved with the latest Knitro releases.

4 - Hexaly, a new kind of global optimization solver
Frédéric Gardi

Hexaly is a new kind of global optimization solver. Hexaly APIs unify modeling concepts from mixed-linear programming, nonlinear programming, and constraint programming. Its modeling interface is nonlinear and set-oriented. It also supports user-coded functions, thus enabling black-box optimization and, more particularly, simulation optimization. Under the hood, Hexaly combines various exact and heuristic optimization methods: spatial branch-and-bound, simplex methods, interior-point methods, automatic Dantzig-Wolfe reformulation, column and row generation, propagation methods, local search, population-based methods, and surrogate modeling techniques for black-box optimization. We illustrate these new modeling concepts on the seminal Traveling Salesman Problem (TSP), thus offering natural and compact modeling of the problem and performance on par with Concorde, the renowned TSP solver.

■ TA-44

Tuesday, 8:30-10:00 - Room: Newlyn 1.01

Modelling coordination challenges in the energy transition

Stream: Energy Economics & Management
Invited session
Chair: *Christoph Weber*
Chair: *Hendrik Kramer*

1 - The benefit of time-of-use network charges in distribution grids for prosumers and network operators - A model-based evaluation of Germany's new regulation.
Hendrik Kramer

Demand flexibility is seen as necessity to achieve decarbonization in energy systems. Dynamic tariffs can align power supply and residential demand in the energy system. Such tariffs have already been researched and are implemented. Yet, varying network charges in distribution grids are less common. Accounting for local information, tailored network charges can better mitigate congestion in distribution networks and may defer reinforcement investments. In Germany, residential prosumers can choose a time-of-use network charge scheme set by the network operator. The new regulation is especially foreseen as incentive for flexible devices e.g., heat pumps, photovoltaic buffer storage, etc. This research first compares the temporal and monetary attributes of the time-of-use network charges of various network operators. Then, this work assesses the benefits for end consumers under different tariff and network charge schemes. An optimization model, focusing on flexible residential demand is developed and applied. Also, differences in foresight horizons are implemented and discussed. Preliminary results indicate that a three-segment quarterly time-of-use network charge scheme per distribution network operator is promising to shift demand peaks in distribution grids. This configuration partially counteracts the efficient allocation based on wholesale market price signals.

2 - Coordinating the energy transition in the presence of agent failure risks
Christoph Weber

The decarbonization of the energy system is entering a critical phase: not only the international politics have other priorities than climate change. But at the same time deep decarbonization calls for the build-up of entirely new supply chains and grid infrastructures: for low-carbon fuels like green hydrogen, for carbon atoms from sustainable sources (e.g. biogas) or for the disposal of CO2. New technologies, new partnerships, new markets and infrastructures imply substantial risks for the players involved - notably the risks of technology failures or counterpart defaults. The presentation explores the implications of such risks both in a stylized example and in a for-mal framework rooted in stochastic optimization, whereby especially the dual formulation is explored to derive equilibrium market prices. The applications indicate that the presence of such risks may considerably affect the prices observed on the markets - and hence the framework may explain the gap between the current price indications on hydrogen markets and the out-come of energy system models.

3 - Modeling Demand Response in Generation Expansion Planning Problems with High Levels of Intermittent Renewable Electricity : A Case Study on the Turkish Power Sector
Bora Kat, Oliver Schenker

Within the scope of the Paris Agreement and the decarbonization targets set by the countries all over the world, studies that focus on possible transition pathways for both the entire economy and specific energy-intensive sectors have gained prominence. In this context, studies on the clean energy transition in the power sector (the key sector in decarbonization of most economies), have also been accelerated in recent years. These studies point out that several flexibility mechanisms are crucial in overcoming challenging issues such as the intermittency of renewable technologies, over-increasing demand due to the widespread electrification plans in almost all sectors, and major changes in consumption patterns. This study investigates one of the main flexibility mechanisms, i.e., the Demand Response (DR). In this regard, the generation expansion planning (GEP) model developed for Türkiye (TR-Power) is enhanced by comprehensively integrating the DR characteristics beyond the current modeling efforts in the literature especially in terms of representing the cost of implementing DR schemes. The revised model is run under the updated base year and an extensive set of scenarios defined in line with the recently published energy plan and based on DR parameters specific to the Turkish economy. Moreover, theoretical upper bounds on the DR potential are determined under hypothetical load curves.

4 - Structural Program of Electricity Demand Response in Brazil: State-of-the-Art, Challenges, Opportunities, and Market Equilibrium
Bruno Fanzeres, Gabriel Miguez Longhi

In this talk, we evaluate the Brazilian Demand Response (DR) initiative called Structural Program (SP) from the perspective of both consumers and market-design agents. We begin by providing an overview of the current state of DR programs in Brazil, examining regulatory environments, market designs, and recent efforts to increase consumer involvement in DR initiatives. We particularly explore the rationale and conceptual design of the SP. From a methodological viewpoint, we model the pipeline for decision-making in this DR initiative, beginning by describing its auction structure and characterizing its operational and financial dynamics. Then, we propose a methodology for devising bidding strategies for consumers in the program as a two-stage problem modeled in a bilevel optimization structure. More specifically, the first stage aims to maximize the consumer benefits by optimizing bid parameters to achieve high revenue levels compensated by opportunity costs, and the second stage evaluates market and system dynamics to assess the bids clearance in the day-ahead dispatch program. Finally, we devise a procedure to identify Nash Equilibrium points in the SP based on fixed-point techniques. A numerical experiment using real data from the Brazilian power system is presented to discuss insights into the SP under a Nash Equilibrium point. We illustrate that this DR initiative can enhance participant outcomes, improve market efficiency, and strengthen system flexibility.

■ TA-46

Tuesday, 8:30-10:00 - Room: Newlyn 1.07

Optimization and learning in energy and transport

Stream: Energy Economics & Management
Invited session
Chair: *Trine Krogh Boomsma*

1 - Exploring Renewable Fuel Infrastructures to Support Decarbonisation of the Nordic Maritime Sector
Frederik Fristed, Rasmus Bramstoft, Marie Münster

Decarbonising Europe's maritime transport sector may require the expansion of synthetic fuel production and supply chains for renewable electricity, hydrogen, and carbon sources. This transition requires extensive infrastructure for production, transport, and storage, while the specific needs depend on local availability of renewable energy, including biomass and CO2, in competition with other sectors, and on demand characteristics of individual regions. This study examines infrastructure investments for maritime fuel production in the Nordic region at NUTS3 spatial resolution, incorporating port-level fuel demand and facility-level CO2 sources and sequestration sites. We use a hard link between the sector-coupled energy system model, Balmorel, and the dedicated network flow model, OptiFlow, that captures PtX and CO2 infrastructure investments and tracks energy and feedstocks across conversion processes. We analyse maritime and energy system decarbonisation from 2030 to 2050 under three scenarios in which the aggregated Nordic system may (1) net-export, (2) be net-neutral, or (3) net-import electricity, hydrogen, CO2, and synthetic fuels. Fuel imports from outside Europe are included, with prices derived from a global trade model. Combining a large-scale energy system model with a network flow approach that integrates detailed spatial characteristics, we highlight the interplay between power, hydrogen, and CO2 infrastructures and the potential for regional self-sufficiency.

2 - Betting vs. Trading: Learning a Linear Decision Policy for Selling Wind Power and Hydrogen
Farzaneh Pourahmadi

In this work, we develop a bidding strategy for a hybrid power plant combining co-located wind turbines and an electrolyzer, constructing a price-quantity bidding curve for the day-ahead electricity market while optimally scheduling hydrogen production. Without risk management, single imbalance pricing leads to an all-or-nothing trading strategy, which we term "betting". To address this, we propose a data-driven, pragmatic approach that leverages contextual information to train linear decision policies for both power bidding and hydrogen scheduling. By introducing explicit risk constraints to limit imbalances, we move from the all-or-nothing approach to a "trading" strategy, where the plant diversifies its power trading decisions. We evaluate the model under three scenarios: when the plant is either conditionally allowed, always allowed, or not allowed to buy power from the grid, which impacts the green certification of the hydrogen produced. Comparing our data-driven strategy with an oracle model that has perfect foresight, we show that the risk-constrained, data-driven approach delivers satisfactory performance.

3 - Learning Prosumer Behavior in Energy Communities: Integrating Bilevel Programming and Online Learning
Lesia Mitridati, Bennevis Crowley, Jalal Kazempour, Mahnoosh Alizadeh

Dynamic pricing through bilevel programming is widely used for demand response but often assumes perfect knowledge of prosumer behavior, which is unrealistic in practical applications. This paper presents a novel framework that integrates bilevel programming with online learning, specifically Thompson sampling, to overcome this limitation. The approach dynamically sets optimal prices while simultaneously learning prosumer behaviors through observed responses, eliminating the need for extensive pre-existing datasets. Applied to an energy community providing capacity limitation services to a distribution system operator, the framework allows the community manager to infer individual prosumer characteristics, including usage patterns for photovoltaic systems, electric vehicles, home batteries, and heat pumps. Numerical simulations with 25 prosumers, each represented by 10 potential signatures, demonstrate rapid learning with low regret, with most prosumer characteristics learned within five days and full convergence achieved in 100 days.

4 - Optimal management of electrical vehicle fleets
Eleni Michaelidou, Miguel Anjos

We consider an electric vehicle (EV) charging service provider that operates a set of charging stations and uses time-based pricing to minimize the impact of a large EV fleet — as operated by transportation and delivery companies, among others — on the power grid by encouraging the fleet operator to shift its flexible load to off-peak hours and benefit from lower electricity rates. We propose an optimistic bilevel optimization problem that captures the hierarchical interaction between the provider (leader) and the EV fleet owner (follower). The latter can participate in vehicle-to-grid (V2G) schemes, where EV batteries can be used as energy storage devices to supply energy back to the grid during peak hours. At the upper level, the provider defines the charging and discharging prices to minimize peak demand. In response, at the lower level, the EV fleet owner decides when to charge and whether and when to discharge while considering several operational constraints of the fleet, mainly related to the delivery schedule of the fleet, to minimize its total charging cost. The bilevel optimization problem is reformulated into a single-level formulation using a Karush-Kuhn-Tucker (KKT)-based heuristic approach along with the Special Ordered Sets 1 (SOS1) technique, which can be solved using off-the-shelf solvers. We report preliminary computational results for the proposed model.

■ TA-47

Tuesday, 8:30-10:00 - Room: Parkinson B08

Retail Inventory Management

Stream: Retail Operations
Invited session
Chair: *Walid Klibi*
Chair: *Sérgio Castro*

1 - Optimization of Order Allocation Decisions in Online Marketplaces Considering Vendor Satisfaction
Sérgio Castro, Willem van Jaarsveld, Gonçalo Figueira, Bernardo Almada-Lobo

Online marketplaces connect suppliers with customers by providing a platform for vendors to sell their products worldwide. Order allocation directly impacts fulfillment costs and customer satisfaction, while also determining the volume of business received by suppliers, a critical determinant of supplier retention to the platform. We introduce and study the Multi-Item Order Fulfillment Problem in Online Marketplaces, which explicitly considers the perspective of suppliers via sales targets to be achieved over the selling season. As solution methods, we adapt various myopic rule-based policies popular in industry, along with two randomized policies with attractive properties proposed by Ma (2022). We moreover propose to apply deep reinforcement learning (DRL) to the problem, leveraging a tailored MDP formulation that enables the application of the Deep Controlled Learning algorithm. We test these policies on a comprehensive set of problem instances developed based on extensive interactions with an online marketplace. In the absence of supplier sales targets, the policies by Ma perform particularly well when demand over the selling season is relatively high, while DRL is competitive across a wide range of instances, especially when season demand is relatively low. Moreover, when supplier sales targets are considered, the proposed DRL approach achieves balanced outcomes that ensure supplier satisfaction while keeping fulfillment costs low and customer satisfaction high.

2 - A hybrid optimization approach for bulk order allocation in fulfillment centers in Trendyol
Fikret Batu Sagay, Mehmet Orhan Yildirim, Betül Ahat, Ahmet Çınar, Meltem Sanisoğlu

In e-commerce fulfillment, B2C orders are traditionally allocated in real-time, one by one, as they are placed. While this ensures immediate processing, it disregards potential efficiency gains from bulk order allocation—where multiple orders are assigned simultaneously within a predefined time window or after reaching a threshold. By clustering orders, fulfillment centers can reduce travel distances, enhance picking efficiency, and optimize resource utilization.

This study presents a metaheuristic approach using Simulated Annealing for bulk order allocation, designed to optimize the picking process in a limited amount of time. We also introduce a mixed-integer programming model to monitor the efficiency of the proposed metaheuristic. The model accounts for key constraints, including order proximity, picking efficiency, and warehouse capacity, ensuring an optimized allocation process. While bulk allocation introduces computational complexity, the proposed approach leverages advanced optimization techniques to balance solution speed and effectiveness.

The findings demonstrate that strategic bulk allocation can significantly enhance fulfillment efficiency up to 10%, reducing operational costs and improving order processing workflows in high-volume e-commerce environments.

3 - Learning Inventory Control in the Face of Censored Demand and Shrinkage
Recep Bekci

Inventory shrinkage, driven by theft and operational inefficiencies, poses a significant financial burden on retailers, with annual losses exceeding $100 billion. A critical challenge lies in mitigating shrinkage in real time when inventory levels are unobservable and demand is uncertain. Traditional inventory control policies rely on precise stock data, which is often unavailable due to high auditing costs and latent shrinkage processes. This paper addresses this gap by formulating a dynamic inventory control problem under partial observability, where retailers can only infer stock levels through sales data and stock-out events. We propose COSIL (Cycle-based Online Shrinkage Inventory Learning), a novel algorithm that dynamically adjusts order-up-to levels by learning both demand patterns and shrinkage rates over cycles defined by stock-out occurrences. COSIL leverages gradient-based updates and a shrinkage estimation subroutine to refine inventory decisions without direct observation of stock levels. Theoretical analysis demonstrates the algorithm's efficiency, while computational experiments validate its robustness across diverse demand and shrinkage scenarios. Our results offer retailers a practical, data-driven framework to reduce losses while adapting to evolving operational uncertainties, with implications for automated replenishment systems and loss prevention strategies.

4 - Collaborative Efforts for Improving Process Inefficiency in Retailer's Backroom: A Game-Theoretic Analysis
Ashutosh Sarkar, Varun Gupta

Retail backrooms operations can cause discrepancies in inventory records due to product misplacement, damage during handling and transportation, theft, and transaction errors. Such errors cause stock outs, lost sales, and dissatisfied customers. While reactive measures like, periodic audits have been extensively evaluated, proactive strategies such as process optimization, adoption of RFID technology for real-time tracking, and closer collaboration between suppliers and retailers are also equally effective. In this context, understanding the individual motivations and incentives for collaborative efforts for process improvement is necessary, especially in a decentralized supply chains. Therefore, we develop a game-theoretic model to capture the dynamics of inventory movement from the backroom to the shelf. The model incorporates uncertainty in the retailer's operational efficiency and randomness in inventory errors and analyses the impact of different cost structures, the relationship between effort and improvement, and the structure of the supply chain on collaborative efforts and overall profitability. Moreover, we explore the effectiveness of a cost-sharing contract, where the supplier partially subsidizes the retailer's investment, as a mechanism to incentivize collaboration. Our findings provide valuable insights into the conditions under which collaboration becomes beneficial and offer managerial implications for optimizing backroom operations.

■ TA-49

Tuesday, 8:30-10:00 - Room: Parkinson B10

Fair and Interpretable Machine Learning

Stream: Analytics
Invited session
Chair: *Belen Martin Barragan*
Chair: *Yujia Chen*

1 - Algorithmic Fairness on Imbalanced Datasets
Yujia Chen, Raffaella Calabrese

Class imbalance is a well-known challenge in credit scoring. While extensive research has focused on the impact of imbalance on model accuracy and explanation performance, its effect on algorithmic fairness remains largely unexplored. In this study, we analyse fairness metrics as the default rate varies from 1% to 50% across three open credit scoring datasets and three machine learning models. We focus on four threshold-based metrics and propose to compute the mean fairness metrics over a range of decision thresholds. Additionally, we compare these metrics with distribution-based metrics that evaluate fairness by considering entire score distributions. Our findings reveal that threshold-based metrics tend to show smaller fairness gaps in extremely imbalanced settings due to the scarcity of positive cases, while more balanced datasets expose larger disparities. In contrast,

distribution-based metrics yield opposite trends: LEO indicates improved fairness with increasing balance, whereas ABROCA remains relatively stable across default rates. Furthermore, we propose a weighting scheme based on the inverse default rate for the threshold-based metrics, which reverses the observed patterns by emphasising disparities when positive events are rare. These findings provide important insights for selecting and interpreting fairness metrics in credit scoring applications, particularly under varying degrees of class imbalance.

2 - Fairness stability and its connections with explainability
Pablo Casas, Huan Yu, Christophe Mues

Ensuring fairness in credit scoring models, in the context of regulatory frameworks such as the AI Act, has attracted considerable attention in the literature. However, to date, there is a lack of understanding of the temporal stability of fairness, and the factors that affect it. This is especially relevant in nonlinear models where data shifts can cause counter-intuitive results. To bridge this gap, we investigate the temporal evolution of fairness for XGBoost with fairness and stability enhancements, focusing on the interplay between fairness stability metrics under conditions of data drift and the stability of the explanations. In doing so, we establish a connection between fairness declines and the stability in proxy variables. To measure this, we employ the Population Stability Index (PSI) to quantify changes in Shapley value distributions, providing insights into the evolving feature interpretations and their impact on fairness. Furthermore, we address the limitations of traditional fairness metrics, introducing generalized measures that accommodate diverse data types and nonlinear fairness concerns, building upon the principles of separation and independence. By quantifying the effects of data shifts on both fairness and model interpretability, this research thus aims to provide practical methodologies for monitoring and maintaining equitable credit scoring systems.

3 - Measuring the Driving Forces of Predictive Performance: Application to Credit Scoring
Sébastien Saurin, Sullivan Hué, Christophe Hurlin, Christophe Pérignon

As they play an increasingly important role in determining access to credit, credit scoring models are under growing scrutiny from banking supervisors and internal model validators. These authorities need to monitor the model performance and identify its key drivers. To facilitate this, we introduce the XPER methodology to decompose a performance metric (e.g., AUC, R2) into specific contributions associated with the various features of a forecasting model. XPER is theoretically grounded on Shapley values and is both model-agnostic and performance metric-agnostic. Furthermore, it can be implemented either at the model level or at the individual level. Using a novel dataset of car loans, we decompose the AUC of a machine-learning model trained to forecast the default probability of loan applicants. We show that a small number of features can explain a surprisingly large part of the model performance. Notably, the features that contribute the most to the predictive performance of the model may not be the ones that contribute the most to individual forecasts (SHAP). Finally, we show how XPER can be used to deal with heterogeneity issues and improve performance.

4 - Challenging the Performance-Interpretability Trade-off: An Evaluation of Interpretable Machine Learning Models
Nico Hambauer, Sven Kruschel, Sven Weinzierl, Sandra Zilker, Mathias Kraus, Patrick Zschech

Machine learning is permeating every conceivable domain to promote data-driven decision support. The focus is often on advanced black-box models due to their assumed performance advantages, whereas interpretable models are often associated with inferior predictive qualities. More recently, however, a new generation of generalized additive models (GAMs) has been proposed that offer promising properties for capturing complex, non-linear patterns while remaining fully interpretable. To uncover the merits and limitations of these models, this study examines the predictive performance of seven different GAMs in comparison to seven commonly used machine learning models based on a collection of twenty tabular benchmark datasets. To ensure a fair and robust model comparison, an extensive hyperparameter search combined with cross-validation was performed, resulting in 68,500 model runs. In addition, this study qualitatively examines the visual output of the models to assess their level of interpretability. Based on these results, the paper dispels the misconception that only black-box models can achieve high accuracy by demonstrating that there is no strict trade-off between predictive performance and model interpretability for tabular data. Furthermore, the paper discusses the importance of GAMs as powerful interpretable models for the field of information systems and derives implications for future work from a socio-technical perspective.

■ TA-53

Tuesday, 8:30-10:00 - Room: Liberty Moot Court

New Trends in Game Theory IV

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Ulrike Leopold-Wildburger*
Chair: *Gernot Tragler*

1 - EV Charging Service: Fast Charging or Battery Swapping? Strategic Investment Dilemma
Yitong Chen

In recent years, the growing popularity of electric vehicles (EVs) has led to an increasing demand for public charging infrastructure, especially fast-charging (FC) and battery-swapping (BS) services. The battery-swapping (BS) service, with its three-minute automated quick-recharge capability, has been favored by customers who are highly sensitive to time and seeking premium recharge options. However, due to the limited scale and number of existing BS stations, during high-demand periods, customers have to wait for extended periods, inevitably reducing the overall recharge experience. By analyzing the combined effects of internal technical and operational factors (i.e., the construction costs of FC and BS station) and external market factors (i.e., peak-valley price differences and market expansion), this paper explores strategic options for EV charging service. We establish a service system in which customers experience congestion disutility linearly related to the demand rates, and profit-maximizing EV charging service providers serve customers through FC and/or BS channels. The findings show that while the introduction of BS consistently increases overall sales (i.e., the demand-expansion effect), it also attracts FC customers to the lower-margin BS channel (i.e., the cannibalization effect). Consequently, service providers should strategically introduce BS when the cannibalization effect is relatively small (i.e., when the demand for BS is moderate).

2 - Screening or Pooling? Dual-channel Competition in Healthcare under Information Asymmetry
Fangyuan Cao, Jie Wang, Yong-Hong Kuo, Feng Tian

Healthcare platforms, such as HealthTap and Dingxiang Doctor, have gained popularity in recent years due to their convenience and flexibility, competing with in-person hospitals within the market for medical consultations. Although platforms can verify the qualifications of physicians, physicians' actual performance remains unknown to the public. In this research, we consider that, to strive for excellence, the online healthcare provider offers physicians two types of contracts for the service provided: a screening contract and a pooling contract. We develop a sequential game theory model to (i) analyze the optimal contract type to physicians on an online revenue-focused healthcare provider where physician efficiency is private information and (ii) study its effects on healthcare providers and patients in dual-channel competition. We find that, interestingly, the pooling contract may be more beneficial for an online healthcare provider when the failure cost

is low, the offline hassle cost is sufficiently high, or it is more likely for a patient to encounter a low-type physician. Our contributions lie in the modeling framework and insights derived for the situation faced by online healthcare providers in managing information asymmetry about physicians, while also considering competition from traditional offline healthcare providers.

3 - Playing by the Rules? Uncovering Validator Strategies to Game the Incentives Set by Proof-of-Stake Slashing Mechanisms
Sascha Hägele

Despite being the first and largest cryptocurrency by market capitalization, many modern successful cryptocurrencies differ significantly from Bitcoin, particularly in their consensus mechanisms. Meanwhile, Proof-of-Stake (PoS) has been introduced as an alternative to Bitcoin's Proof-of-Work (PoW), with the goal of drastically reducing the energy consumption and environmental impact associated with cryptocurrency networks. This shift has led to major cryptocurrencies implementing PoS, most notably Ethereum. However, unlike PoW, which imposes significant computational costs on voting and especially block proposals due to the energy consumption required for mining, PoS does not inherently impose such costs. To address this issue, so-called slashing mechanisms have been introduced to incentivize truthful proposals and voting while penalizing dishonest behavior and spam. Despite the widespread adoption of PoS in various blockchain ecosystems, including Ethereum, Cardano, and Avalanche, slashing mechanisms vary widely in their design and terminology. This study aims to establish a common framework for analyzing the incentive structures of these mechanisms. Using game-theoretic and agent-based modeling approaches, the study examines how validators can strategically navigate the incentives set by these slashing mechanisms. Empirical results support the theoretical analysis and highlight potential vulnerabilities and deviations from the intended economic incentives.

4 - Optimal control of cartel violence: Multiple equilibria, narrow corridors, and weak Skiba curves
Gernot Tragler, Jonathan Caulkins, Dieter Grass, Gian Maria Campedelli, Gustav Feichtinger, Rafael Prieto-Curiel, Stefan Wrzaczek

We present an optimal control model for evaluating how Mexico might best use two instruments (security measures and social programs) to control a pair of criminal cartels that are in lethal conflict with each other. For our model and parameters being made as realistic as possible, our analysis is meant to provide guidance to the Mexican government. In this presentation we will mostly focus on variations on our model and parameters that reveal interesting structural features, because we believe that the basic architecture of our model is intrinsically interesting to the optimal control community - both with respect to the structure of the solutions and their economic interpretation. Our results are derived with the help of bifurcation analyses and include solutions with as many as ten equilibria, some separated by double and even triple Skiba points.

■ TA-57

Tuesday, 8:30-10:00 - Room: Liberty 1.12

Railways applications

Stream: Transportation
Invited session
Chair: Anne Schönhofen

1 - Keeping Track of Energy Efficiency in Rail Networks: A Trajectory-Based Approach
Lars Geese, Cedric Steinbach, Andreas Oetting

The efficiency of rail operations can be improved by energy-efficient train control through Driver Advisory Systems (DAS). Practice shows that energy consumption varies significantly over time and within subsets of a network, vehicle types, and scheduled trains. For railway operators, identifying affected parts of their fleet or network and addressing the causes of increased energy consumption are crucial for improving efficiency. A cost-effective way to collect operational data is retrofitting trains to track basic trajectory data, such as time-distance and speed-distance diagrams. This research aims to develop and implement a method for analyzing trajectory data and identifying inefficiency causes, adaptable to different rail networks and their characteristics. The approach aims to identify patterns in deviations between calculated optimal trajectories and actual driving behavior. Beyond trajectory data, additional factors such as disruptions, equipment failures, occupancy rates, and weather conditions must be incorporated into the analysis to understand causal relationships. Therefore, statistical methods, exact trajectory and energy consumption calculations, and expert or user knowledge acquisition techniques are combined. Preliminary findings on the key requirements of individual methods and the overall framework for their integrating are presented. Additionally, initial insights from a dataset of a German rail network, used as a case study, are included.

2 - A partial duty formulation for the crew scheduling problem
Bart van Rossum, Twan Dollevoet, Remy Spliet

The goal of crew scheduling is to cover tasks with a minimum-cost set of duties. The state-of-the art solution approach for this problem is to formulate it as a set partition problem, each column corresponding to a duty, and solve it using column generation. However, we show that the pricing problem for this standard formulation is weakly NP-hard. To avoid this complexity, we propose a partial duty formulation, where columns represent either the first or second half of a duty and are later combined in the master problem. We prove that the pricing problem for this formulation can be solved in polynomial time. Furthermore, we introduce matching-based cuts that restore the bound of the regular duty formulation and can be separated in polynomial time. Incorporating these cuts renders the partial duty pricing problem weakly NP-hard again. Experimental results on large synthetic instances demonstrate the effectiveness of our approach.

3 - A Digital Twin-based approach to improve the performance of single-track rail lines
Luca De Matteis, Marilisa Botte, Immacolata Cilento, Rosario Stefanelli, Mario D Avino, Sebastiano D Avanzo, Luca D'Acierno

Rail transport is crucial for sustainable mobility, but in low-density regions, it often relies on single-track and diesel-powered lines. This infrastructural constraint limits operational efficiency, as trains travelling in opposite directions must use designated meeting points, usually at stations, reducing service attractiveness. Hence, single-track railways face significant challenges in performance and investment feasibility. Indeed, high costs and low passenger demand make infrastructure upgrades, such as track doubling, difficult to justify. Moreover, diesel traction contradicts sustainability objectives, necessitating greener alternatives such as electrification, hydrogen or hybrid trains. This paper presents a Digital Twin-based methodology to analyse and optimise single-track railway lines. The proposed model identifies bottlenecks and inefficiencies, allowing for the assessment of technological and operational improvements. By integrating real-world data and advanced simulation capabilities, the Digital Twin framework serves as a decision-support tool for railway planners, aiding in infrastructure investments, scheduling optimization, and the transition to sustainable propulsion systems. A case study on a regional railway in southern Italy demonstrates the potential of this approach, showing how the Digital Twin model can enhance service reliability and attractiveness.

4 - A Machine Learning-based Selection Strategy for Railway Crew Scheduling with Trip Shifting
Anne Schönhofen, Ulrich Thonemann

Traditionally, timetabling and crew scheduling are subsequent tasks in the workforce planning process in airline, railway, and public bus

transportation. Trip shifting offers an opportunity to enhance flexibility in crew schedule planning by allowing the scheduled time of trips to be adjusted within predefined discrete time windows. This approach is widely acknowledged in the literature for generating highly cost-efficient schedules. In graph-based solution approaches, time shifts are typically modeled by duplicating arcs corresponding to scheduled trips. From a computational perspective, this leads to a significant increase in graph size and problem complexity. In practice, planners seek to maximize cost savings while shifting only a small number of trains. Motivated by this practical insight, we address the computational complexity by training a machine learning model to predict the most promising time shift options before optimization. By including only promising shifts, we keep the graph's size manageable and ensure the resulting crew schedule remains applicable in practice. We integrate our approach into a column generation heuristic and test it on real-world datasets provided by a major European railway freight carrier. The results demonstrate that our approach realizes a large share of the optimization potential and achieves greater cost reductions than a known method from the literature while having a comparable network size.

■ TA-58

Tuesday, 8:30-10:00 - Room: Liberty 1.13

Warehouse Operations

Stream: Vehicle Routing and Logistics
Invited session
Chair: Antoine Sauré

1 - Joint optimisation of order batching and collaborative picker routing in human-assisted robot-to-part order picking
Sina Khodaee, Melih Celik, Vaggelis Giannikas

With the rise of warehouse automation due to the efficiency benefits it offers, many facilities use a collaborative system involving Autonomous Mobile Robots (AMRs) and human pickers in order-picking. This study examines a picker-to-part system where AMRs, equipped with bins, navigate the warehouse while a fewer number of human pickers load them. Human pickers, unburdened by carrying items, follow a free-floating policy, moving freely between AMRs without returning to the depot. The key challenge is jointly batching orders for AMRs and routing all the pickers to minimise the makespan, defined as the return time of the last AMR. To tackle this, we propose an interactive two-stage decomposition-based heuristic approach wherein we first solve the AMR order batching and routing problem using a Variable Neighbourhood Search (VNS) algorithm. In the second stage, we determine the routes for human pickers by treating AMR arrival times at item locations as soft due times. By iteratively refining the interaction between these two stages, we enhance solution quality. We validate our approach through sensitivity analysis and demonstrate its advantages over traditional fixed-assignment and manual picking systems.

2 - Balancing Storage Location Assignment Strategies in Warehouses: A Data-Driven Approach
Mostafa Bahadornia, Katrien Ramaekers, Kris Braekers, Trijntje Cornelissens, Ruben D'Haen

The rapid growth of online retailing necessitates flexible warehouse management strategies to adapt to this evolving landscape. One of the critical challenges in this area is to reduce the order-picking travel distance. This travel distance is highly affected by the Storage Location Assignment (SLA) decision, which determines how products are allocated to locations in the warehouse. Prevalent SLA strategies are turnover-based assignment, correlated storage assignment, and scattered storage assignment. This study proposes a mixed SLA approach that adopts each prevalent SLA strategy to some degree, tailored to the customer order pattern. To this end, three analytical measures are defined to assess the degree of realization of each SLA strategy. To address the dynamic nature of business needs, a data-driven approach is introduced to calculate the weight of each measure using customer order data. Next, a novel multi-dimensional mathematical model for SLA optimization is proposed. This model incorporates the weighted measures and operational constraints. As the primary goal of SLA optimization is to reduce the order-picking travel distance, the proposed model is tested in a collaborative human-robot order-picking configuration in a mixed-shelves layout. Finally, results indicate that the proposed model provides better storage assignments than when focusing on classical strategies individually.

3 - Mathematical Models and Algorithms for Warehouse Execution System (WES)
Takufumi Yoshida

Japan's logistics industry faces serious challenges, including an increase in cargo volume and a severe labor shortage. In warehouses, the adoption of automation and AI technologies to enhance operational efficiency while reducing manpower dependency has become an urgent issue. To address these challenges, we have developed a Warehouse Execution System (WES) that serves as an intermediary between the central Warehouse Management System (WMS) and multiple distributed Warehouse Control Systems (WCSs). The WES leverages data collected from the WMS to provide WCSs with valuable instructions and recommendations, thereby enhancing overall warehouse operations. To enable seamless collaboration between WMS and WCSs, the WES offers a suite of visualization, simulation, and optimization functions to support warehouse operations effectively. At the conference, we will present mathematical models and algorithms designed for the WES optimization suite, including: • Person-Robot Dispatching: Determines whether goods from storage should be assigned to a human worker or a robot to maximize throughput. • Truck-Berth Allocation: Schedules truck loading and unloading at warehouse berths to minimize driver waiting time. • Real-Time Personnel Reassignment: Predicts work progress in different warehouse areas and suggests personnel redistribution to balance workload across sections. These optimizations enhance warehouse efficiency and adaptability in dynamic environments.

4 - A Cost-Efficient Storage Location and Order Picking Policy for Improved Warehouse Management
Antoine Sauré, Amirhossein Moosavi, Behrad Erfani

This study investigates storage location and order picking challenges faced by third-party logistics (3PL) providers managing temperature-sensitive, perishable products. In our setting, complexity arises from varying product expiration dates, specific customer requirements for remaining shelf life, and stochastic demand and arrivals. Despite the interdependence of storage and picking decisions, these are traditionally handled separately and manually. To improve efficiency, we propose a data-driven solution approach based on an infinite-horizon Markov Decision Process. To address the curse of dimensionality, we employ an affine approximation architecture and solve an equivalent linear programming model via column generation to derive approximate optimal policies. These policies inform the development of an intelligent yet easy-to-implement heuristic. Numerical results demonstrate that our heuristic outperforms alternative decision rules, including the one currently used by our 3PL partner, leading to more efficient warehouse operations.

■ TA-59

Tuesday, 8:30-10:00 - Room: Liberty 1.14

Road network optimization, monitoring and control

Stream: Transportation
Invited session
Chair: Michael Dreyfuss

1 - Adaptable robust traffic control for urban networks with uncertain capacity
Suh-Wen Chiou

In order to effectively mitigate congestion and propagate uncertainty in urban traffic networks, a robust signal control with adaption to traffic dynamics can be presented. A stochastic traffic model is introduced to appropriately address spatial evolution of traffic congestion inside road links. An Identification of Robust Family (IRF) for Stochastic Performance Index (SPI) is proposed. A stochastic program can be proposed and efficiently solved by a variant of Benders' decomposition. While time-varying SPI value functions can be improved progressively by proposed adaption algorithm, the feasibility of constraints against high-consequence realization of capacity uncertainty is recursively enforced for unknown probability distribution of occurrence. Numerical experiments are performed at a real-data city network. As compared to recently proposed the state-of-the-art traffic signal control, obtained results showed that the proposed robust signal control can exhibit sufficient gain of achieving network effectiveness while attenuating time-varying congestion in the presence of uncertain capacity at links downstream.

2 - Optimal Resource Allocation for Enhancing Road Safety
Michael Dreyfuss

This study analyzes the current Israeli public-private partnership (PPP) project of automatic enforcement cameras. There are fewer cameras than poles in Israeli law enforcement; therefore, the cameras are moved between the poles. First, the authors present a linear programming approach (mobility model) to determine the optimal allocation of cameras on the poles based on road crash data and geographical constraints. Second, the authors determine the optimal number of cameras to buy and number of movements required (cameramovement tradeoff model). Third, the authors use a Monte-Carlo simulation of the camera failures to define an optimal inventory policy (inventory model). The authors demonstrate that applying the outcomes of the mobility model results in a 25% enhancement (from 55% to 80%) of road crash coverage. The results of the camera-movement tradeoff model indicate that when the movements are relatively inexpensive (a movement costs less than 10% of the price of a camera), it is not worthwhile to buy new cameras. Finally, the results of the inventory model show that a repair period of 1 or 2 months does not seriously decrease the road crash coverage, and thus, for any future PPP project, it is unnecessary to insist that the repairs be completed within 2 months.

3 - Multi-criteria Traffic Signal Control Optimization using Multi-policy Reinforcement Learning
Zakir Farahmand, Oskar Eikenbroek, Konstantinos Gkiotsalitis, Eric van Berkum

With increasing mobility demand, a key challenge in urban areas is to efficiently allocate limited road capacity among different user-groups, including passenger cars, freight, public transport, bicycles and pedestrians. Particularly at intersections with demand-supply imbalance, poor traffic signal controls (TSC) leads to excessive delays, increased fuel consumption, higher emissions, noise pollution and air quality deterioration. Conventional TSCs like vehicle-actuated typically focus on minimizing waiting time, often conflicting with reducing emissions arising from frequent braking and acceleration manoeuvres, especially for heavy-duty vehicles. The primary question is how to balance between conflicting objectives while responding to highly volatile traffic demand in real-time? In this study, we propose a novel modular multi-policy deep reinforcement learning (MMDRL) in which the agent aims to find a set of optimal policies. The method combines the theory of Pareto optimality and Deep Q-Networks to derive a Pareto front of non-dominated policies without relying on a priori preferences or scalarization function. This enables the agent to simultaneously minimize (i) person-based delays and (ii) emissions (CO_2, CO, NO[U+2093]) near intersections. Simulation results show that MMDRL significantly outperforms conventional (e.g., vehicle-actuated) TSCs in waiting times, emissions, and number of stops while dynamically adjusting signal plans to changing traffic conditions.

4 - How to optimize an entire road network
Yves Lucet, Paavai Manimaran V., Warren Hare, John Thompson

We extend current road design optimization from a single road between two points to an entire network of roads such as those required to deploy a wind farm. The first step is to determine corridor locations using extended shortest path, minimum spanning tree, and Steiner tree techniques. Next, we identify each road between 2 connection points: turbine location, or access road, and we compute the horizontal alignment using a bilevel optimization approach (upper uses branch-and-bound while the lower level is a mixed-integer linear program). Finally, with the horizontal alignments fixed, we fine tune the results by recomputing all the vertical alignment for the entire network as a convex quadratically-constrained quadratic optimization problem.

■ TA-60

Tuesday, 8:30-10:00 - Room: Western LT

DEA methodological developments II

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: John Lamb

1 - Cross Efficiency and DEA
Sara Hosseini

We propose a novel approach to cross-efficiency evaluation in Data Envelopment Analysis (DEA) that is applicable to various DEA models and accommodates any returns to scale. A key advantage of our method is that it ensures the diseconomy of scale of one Decision-Making Unit (DMU) is never used to assess another, addressing a critical limitation in existing methods. We demonstrate that our approach offers stronger theoretical justification while maintaining consistency with the standard cross-efficiency method under constant returns to scale (CRS). To support our methodology, we introduce a unique measure for the diseconomy of scale of a DMU and define the concept of preferred scope. While preferred scope is not uniquely determined, we establish centroid preferred scope as a well-defined, average measure to facilitate analysis. Using variable returns to scale (VRS) DEA, we compare our method with existing approaches and illustrate how hierarchical cluster analysis based on centroid preferred scope can reveal meaningful differences in performance. A major challenge in cross-efficiency analysis has been its limited application beyond CRS models, with only a few exceptions (Lim & Zhu, 2015; Su & Lu, 2019). Previous methods primarily focus on ensuring nonnegative cross-efficiencies by translating inputs and outputs or imposing additional constraints, both of which lack strong justification and have not gained widespread adoption. Our approach addresses this gap by offering a gener

2 - A centroid method for neutral cross efficiency
John Lamb

Cross efficiency extends data envelopment analysis. In it we compute a cross efficiency for every decision-making unit (DMU) and for every peer. Then we compute the cross-efficiency score as an average efficiency over all peers. Cross efficiency increases our ability to discriminate among DMUs. But it presents a challenge. The cross efficiencies are not uniquely defined. Doyle and Green (1993, 1994) suggest aggressive and benevolent methods to resolve this. But the solutions can be unusual. Wang and Chin (2010) and Shi et al (2021) suggest neutral cross-efficiency methods based on secondary goals. We show there is another method, which we call the centroid method, that does not require secondary goals and gives a unique, average, cross efficiency. We also show how existing neutral methods can be extended to ensure unique solutions and provide some comparisons among methods.

3 - Efficiency Measurement and Returns-to-Scale Analysis in Selective Slacks-Based Models
Maria Trnovska, Margareta Halicka

In this contribution, we present a unified framework for selective slack-based models, where a specific subset of inputs and outputs is selected, and the corresponding slacks are incorporated into the efficiency measure to evaluate a unit. This framework encompasses standard graph slacks-based models, including the additive, range-adjusted, Russell measure, and SBM models, as well as their oriented versions. It is particularly useful when only certain inputs or outputs are subject to improvement, while others remain fixed due to external constraints such as regulatory limits or technological restrictions. We derive a general, economically interpretable multiplier form applicable to the entire class of models and leverage duality theory to establish connections between the optimal solutions of the dual problem and the supporting hyper-planes of the underlying technology set. Several returns-to-scale (RTS) techniques are closely tied to these supporting hyper-planes. We propose and compare RTS methods within the unified framework for the entire class of models. Additionally, we discuss the main advantages and disadvantages of the proposed methods, illustrating them with numerical examples.

4 - Exploring the Interplay Between Productivity, Efficiency, and Effectiveness Using Multi-Regression Analysis: Case Study in the Food Industry
Sahand Daneshvar, Fatemeh Abbasi

Productivity is a most important objective for companies striving to improve overall performance and foster economic growth. Historically, productivity has often been misinterpreted as synonymous with efficiency or effectiveness, despite their distinct definitions. Contemporary research highlights that efficiency and effectiveness are interdependent dimensions of productivity, both essential for a comprehensive understanding. This study introduces a novel framework to explore the relationship between productivity, efficiency, and effectiveness. The proposed methodology integrates Data Envelopment Analysis (DEA) with multi-regression analysis to model productivity as a function of two key regressors: efficiency and effectiveness. These variables are calculated separately as random variables under specified evaluation scenarios by selecting appropriate inputs and outputs within DEA models. The framework is applied to a case study of a bakery in Nigeria, analyzing productivity over three consecutive years (2016-2018). The estimated productivity for 2018, derived using a linear regression model, demonstrates strong alignment with the double-frontier Malmquist Productivity Index, achieving an accuracy of less than 0.01. This case study underscores the practical utility of the proposed approach in the food industry, offering a robust and systematic tool for productivity analysis.

■ TA-61

Tuesday, 8:30-10:00 - Room: Maurice Keyworth G.31

Addressing behavioral issues of real-world problems 1

Stream: Behavioural OR
Invited session
Chair: Alice H. Aubert

1 - Serious gaming to foster urban climate adaptation?
Lisa Scholten, Aashna Mittal, Geertje Bekebrede, Carissa Champlin

Decision support and simulation tools often overlook human complexities critical for shifting behavior to address societal challenges, such as motivating households to adopt climate adaptation measures. Serious games offer a promising alternative for simulating real-world dynamics and consequences, while fostering learning, motivation, and decision-making. However, systematic design and evaluation regarding the intended cognitive and behavioral changes of the target population is often missing, limiting intervention effectiveness. To bridge this gap, we developed and evaluated Sudsbury 2.0, a board game aimed at supporting household climate adaptation through game-based learning. Our design hypothesized that gameplay would positively influence learning and behavioral factors that drive goal-setting and implementation intentions, key stages in a self-regulated behavior change process. We used a quasi-experimental design to evaluate gameplay effects, conducting 25 sessions with 4-6 players (135 participants total) across the Netherlands. We measured gameplay experience, knowledge acquisition, behavioral factors, intentions, and participant characteristics using pre- and post-game questionnaires, followed by statistical analysis. We present design considerations, evaluation results, and recommendations for scaling game-based interventions to address behavioral issues in real-world problems.

2 - How to communicate uncertainty?
Anna Cajochen, Michael Siegrist, Judit Lienert

Environmental challenges such as water pollution must be addressed through effective strategies based on reliable information. However, information can be uncertain. Uncertainties stem from measurement inaccuracies, unknown causality, disagreement among experts, and unpredictable events. Uncertainty is unavoidable but should be considered for effective strategic decision-making. To date, little is known about how to best communicate uncertainty to stakeholders and the public. Reasons include the complexity of uncertainty itself and the interplay between communication formats, individual responses, and individual factors. This study examines the impact of different uncertainty communication formats on, for example, the understanding, and perception of uncertainty information. In an online survey, we randomly assign participants to experimental groups, which receive uncertain information about the effectiveness of wastewater infrastructure in preventing combined sewer overflows. We examine different uncertainty communication formats recommended in existing guidelines. This research aims to provide empirical evidence to support and refine the guidelines. It also seeks to identify straightforward ways for effectively communicating uncertainty to lay people. Developing effective and straightforward approaches can help ensure that uncertainty communication reaches a broad audience, enabling more inclusive decision-making on shared challenges like environmental issues.

3 - Incorporating stakeholder preferences in policy evaluation
Milena Wiget, Judit Lienert

Agricultural pesticide use is a pressing sustainability issue. National policy solutions must be evaluated against trade-offs, considering various interests and uncertainty. But these evaluations rarely consider stakeholder preferences, particularly risk attitudes. We did so in a case from Switzerland, where national policies to reduce pesticide risks are strongly debated. For policy evaluation, we used participatory multi-criteria decision analysis (multi-attribute value/utility theory), incorporating predictions of policy consequences, uncertainty, and preferences for the uncertain consequences. We interviewed experts for the predictions and considered the preferences of stakeholders representing the entire value spectrum in economy, administration, and civil society. The evaluation results were sensitive to extreme risk attitudes, especially when combined with the weights assigned to the objectives based on principles. Although principles do not consider context-specific attribute ranges and are prone to bias, they are often used in politics. Still, we found one policy mix that performed well despite diverse preferences and high uncertainty. It included risk-based taxes on pesticide use and an adapted approval process. This result contradicted the limited support for the policy instruments among some stakeholders when asked directly. Based on our evaluation, we propose to focus on stakeholder preferences, particularly risk attitudes, when discussing policy solutions.

4 - Rethinking livestock future: Behavioural insights from value-focused thinking and MCDA
Alice H. Aubert, Isabel Jaisli

Transforming agri-food systems, e.g. livestock production, is a pressing challenge due to different visions, unavoidable trade-offs between sustainability dimensions, conflicting opinions and multiple uncertainties. To advance the debate on the future of Swiss livestock production, we conducted a multi-criteria decision analysis using value-focused thinking. We developed four visions (business-as-usual, efficient, consistent and sufficient) and a hierarchy of 14 objectives based on literature and expert feedback. Twenty actors from the Swiss livestock value chain, covering the three policy clusters that make up the Swiss agricultural landscape, participated in a survey. We elicited (1)[U+202F]their a priori preferred vision for livestock production in 2050 and (2)[U+202F]their weighting of the sustainability dimensions. Our findings revealed key behavioral issues. First, for one cluster, the a priori preferred vision diverged from the MCDA-recommended vision. Second, the weightings of the objectives reflected each cluster's beliefs, with major disagreements between clusters around self-sufficiency and animal welfare. Third, despite these differences, the consistent and sufficient visions performed best across clusters. These results suggest that one cluster may misunderstand or lack proper information about the system's predictions. We propose measures to address these gaps, fostering informed decision-making and paving the way toward more sustainable livestock production.

Tuesday, 10:30-12:00

■ TB-01

Tuesday, 10:30-12:00 - Room: Great Hall

Kaisa Miettinen

Stream: Keynotes
Keynote session
Chair: *Juuso Liesiö*

1 - Decision Support with Interactive Multiobjective Optimization Methods and Software
Kaisa Miettinen

We encounter multiobjective optimization problems in various domains when we must make a decision while considering several conflicting objective functions simultaneously. Because of the conflict, we can identify so-called Pareto optimal solutions representing different trade-offs and we need some additional information to order these solutions. Typically, we assume to get preference information from a domain expert called a decision maker. Multiobjective optimization methods support the decision maker in finding the best balance among the trade-offs, that is, the most preferred solution.

In this talk, I concentrate on interactive methods, where the decision maker augments the problem formulation with domain expertise and directs an iterative solution process with preferences. In an iterative fashion, the decision maker gains insight into the interdependencies and trade-offs among the conflicting objective functions and learns about the feasibility of the preferences. Based on the learning, the decision maker can update the preferences and eventually get convinced of the quality of the most preferred solution. I demonstrate the advantages of some interactive methods with real examples. In addition, I also give a brief overview of the modular, open-source software framework DESDEO that hosts different interactive methods and enables e.g. switching the method during the solution process to support the decision maker better.

■ TB-03

Tuesday, 10:30-12:00 - Room: Esther Simpson 1.01

Young Women 4OR - 2

Stream: WISDOM - Women in OR
Invited session
Chair: *Heletje van Staden*

1 - A passion for Transportation Optimisation
Yue Su

My passion for transportation optimization began early and led me from China to France through multiple engineering degrees. During my master's, I worked on transport network design and discovered the power of operations research (OR) in improving public transportation systems. This experience inspired my PhD at Centrale Supelec, where I focused on the Electric Autonomous Dial-a-Ride Problem (E-ADARP)—a timely challenge of rendering ride-sharing services more eco-friendly. The E-ADARP involves scheduling electric autonomous vehicles (EAVs) to offer ride-sharing services under energy and routing constraints. I developed both heuristic and exact algorithms to solve single- and bi-objective variants, including a novel fragment-based approach and a branch-and-price algorithm. These methods led to a lot of new best-known solutions and revealed key insights into the trade-offs between operational efficiency and user satisfaction. I also had the opportunity to visit Johannes Kepler University Linz and publish my works in journals such as Transportation Research Part B. After completing my PhD, I pursued a postdoc on integrating machine learning

(ML) with OR for applications in revenue management. Since 2024, I've been an associate professor at the University of Lille, where I continue to explore the interaction between OR, ML, and on-demand mobilities. My goal is to develop efficient and real-time decision-support tools to further improve the efficiency of transportation systems.

2 - Assessing Sustainability in a Two-Echelon Location-Routing Problem: A Comprehensive Framework for Client and Company Emissions
Valentina Bonomi

The rapid rise of e-commerce has amplified the need for logistics operators to offer fast, reliable, and eco-friendly last-mile delivery (LMD) services. Today, LMD activities account for more than 30% of total CO_2 emissions in the logistics sector, contributing to increased urban congestion, noise pollution, and energy consumption. To confront these challenges, we propose a novel, sustainability-oriented LMD model that incorporates both operational and tactical decision-making to minimize emissions from both client and company sources. Specifically, we optimize a two-echelon system by adopting multiple transportations modes. A distinguishing feature of this approach is the explicit inclusion of diverse customer behaviors, accounting for varying levels of environmental awareness. We develop a MILP model whose objective function targets overall emissions as well as the cost of integrating satellites. Validated on realistic datasets covering both densely populated urban zones and sparsely inhabited areas, our method sheds light on the trade-offs between cost, service quality, and environmental impact. These insights offer clear, actionable guidelines for logistics providers aiming to implement more sustainable and efficient LMD practices, accounting for emissions from both company operations and client choices.

3 - Semi-flexible demand-responsive public bus systems for imbalanced demand scenarios
Dilay Aktas Dejaegere, Pieter Vansteenwegen, Kenneth Sörensen

Traditional public bus systems typically operate with fixed routes and timetables. Demand patterns are considered when designing these routes and schedules; however, these decisions are based on historical data and cater to long-term trends rather than individual passenger needs. As a result, while these systems function efficiently in situations with consistently high demand, they struggle in low-demand or highly variable-demand settings, such as rural areas or during off-peak hours. In such cases, this rigid structure often leads to inefficiencies—buses either run nearly empty, wasting resources, or become overcrowded, reducing service quality. The rise of digital technologies and smartphones has paved the way for demand-responsive bus systems, which can adapt routes and schedules based on actual passenger needs. Over the past decades, various demand-responsive approaches have been studied, offering different levels of flexibility. However, much of the existing literature focuses on fully flexible systems that optimize routes and timetables from scratch—an approach that is still impractical in high-demand urban areas due to the operational costs of maintaining a large fleet of small vehicles. While the emergence of autonomous vehicles may make such systems feasible in the future, large-scale real-world applications remain limited. An alternative approach, semi-flexible demand-responsive systems, introduces elements of flexibility while preserving key features of traditional public transport. By retaining characteristics such as designated bus stops, a partially fixed route, and/or a fixed timetable, these systems leverage the strengths of traditional public transport while adapting to demand variations. This makes them particularly well-suited for high-demand areas while utilizing existing public transport fleets efficiently.

4 - Leveraging Support Vector Machines to construct Margin Optimal Decision Trees
Marta Monaci

In recent years, there has been growing interest in interpretable machine learning models that provide explanatory insights into their decision-making process. In this context, thanks to their inherent interpretability, decision tree methods have been extensively studied for classification and regression tasks. While traditional approaches to building decision trees rely on greedy heuristics, the remarkable advances in mixed-integer programming (MIP) over the last decades have led to the formulation of various MIP models for training optimal decision trees. Along this research line, we introduce Margin Optimal Trees, a class of optimal trees that embed margin-based multivariate hyperplanes nested in a binary tree structure. We first present a quadratic mixed-integer formulation that leverages the generalization capabilities of Support Vector Machines for binary classification and then discuss variants of the proposed model. The formulation relies on big-M constraints, which lead to a weak continuous relaxation that limits the method's scalability on large instances. To improve the computational performance of the proposed method, we investigate a tailored algorithmic approach that exploits the decomposable structure of the problem. Finally, we evaluate the method on benchmark datasets to assess its computational efficiency and generalization capabilities.

■ TB-04

Tuesday, 10:30-12:00 - Room: Rupert Beckett LT

EURO Journal on Computational Optimization (EJCO)

Stream: OR Journals
Invited session
Chair: Immanuel Bomze
Chair: *Miguel Anjos*
Chair: *Sarah Fores*

1 - Fast Facts about EJCO
Immanuel Bomze

This short presentation will emphasise the current status of the EURO Journal on Computational Optimization, including its successful bibliometrics for a young outlet. It features Special Issues with their Guest Editors, the Marguerite Frank Award for the Best Paper, and the drivers: the Associate Editors.

2 - EJCO EUROpt Special Issue and Progress in Locating EV Charging Stations
Miguel Anjos

The first EJCO Special Issue was dedicated to the 20th anniversary of the foundation in 2000 of the EUROpt Working Group. It contained 2 historical notes and 9 survey papers, and represents an archival record of the achievements of the working group and its continuing success. We will briefly recall the context and motivation for this Special Issue, and its impact since publication. In addition, we will present recent progress in solving large-scale real-world instances of optimal location of EV charging stations.

3 - Unboxing tree ensembles for interpretability: A hierarchical visualization tool and a multivariate optimal rebuilt tree
Laura Palagi, Giulia Di Teodoro, Marta Monaci

The interpretability of models has become a crucial issue in Machine Learning because of algorithmic decisions' growing impact on real-world applications. Tree ensemble methods, such as Random Forests or XGBoost, are powerful learning tools for classification tasks. However, while combining multiple trees may provide higher prediction quality than a single one, it sacrifices the interpretability property resulting in "black-box" models. In light of this, we aim to develop an interpretable representation of a tree-ensemble model that can provide valuable insights into its behavior. First, given a target tree-ensemble model, we develop a hierarchical visualization tool based on a heatmap representation of the forest's feature use, considering the frequency of a feature and the level at which it is selected as an indicator of importance. Next, we propose a mixed-integer linear programming (MILP) formulation for constructing a single optimal multivariate tree that accurately mimics the target model predictions. The goal is to provide an interpretable surrogate model based on oblique hyperplane splits, which uses only the most relevant features according to the defined

forest's importance indicators. The MILP model includes a penalty on feature selection based on their frequency in the forest to further induce sparsity of the splits. The natural formulation has been strengthened to improve the computational performance of mixed-integer software. Computational experience is carried out on benchmark datasets from the UCI repository using a state-of-the-art off-the-shelf solver. Results show that the proposed model is effective in yielding a shallow interpretable tree approximating the tree-ensemble decision function.

4 - Optimization problems in last-mile delivery
Claudia Archetti

Last-mile delivery poses numerous challenges to logistic and transportation companies, mostly due to fast delivery times and lack of consolidation opportunities. Both the industrial and research communities have come up with strategies and technologies to tackle the challenges and help companies in reducing costs and remaining competitive. As a consequence, interesting and inspiring optimization problems have emerged which are attracting the attention of many research groups. This short talk will focus on few of them and present recent ideas.

5 - Mixed Integer Non Linear Optimization: methods and applications
Claudia D'Ambrosio

In this short talk I will provide an overview of my research. Mixed-integer nonlinear optimization (MINLO) involves continuous and integer decision variables, where constraint and objective functions are nonlinear function of such decision variables. MINLO problems are challenging both from a theoretical and practical viewpoint. From a methodological viewpoint, it is custom to identify mathematical properties of subclasses of MINLO, which can be exploited to identify tailored algorithms. From a practical viewpoint, plenty of real-world problems can be modelled as MINLO. My most recent applied works concerns applications in energy systems, transportation, and machine learning.

6 - Advances in Optimization Under Uncertainty: From Tractable Multi-Stage Decision Making and Fair Robust Classification to Sustainable Logistics
Francesca Maggioni

This short talk highlights three research directions within the broader field of optimization under uncertainty, spanning sequential decision-making, machine learning and sustainable logistics. The first research line addresses the tractability of multi-stage and multi-horizon optimization under uncertainty. We develop bounding and approximation techniques based on scenario grouping, scenario reduction, decomposition methods and constraint sampling. These approaches enable efficient decision-making in complex settings offering theoretical guarantees. The second focuses on robust and fair support vector machines. We develop models that account for uncertainty in training data through robust and distributionally robust optimization, enhancing classification reliability and fairness to reduce bias with respect to sensitive attributes. The third direction is dedicated to sustainable logistics, with a focus on fleet sizing, routing, and electric vehicle operations under uncertainty. We propose stochastic programming models to jointly minimize operational costs and environmental impact, accounting for uncertain demand and stochastic energy consumption. Solutions combine decomposition algorithms and tailored heuristics, applied to problems such as Last Mile delivery and electric vehicle routing with threshold-based recharging.

7 - From Academia to Industry: The Case for Pragmatic Operations Research
Rubén Ruiz

We present our efforts in addressing the gap between academic Operations Research theory and industrial practice, highlighting how the pursuit of perfect mathematical solutions often conflicts with real-world needs. We advocate for practical, flexible approaches over theoretical optimality, arguing that simpler, adaptable solutions often perform better in complex industrial settings.

8 - On some recent advances in bilevel and robust optimization
Martin Schmidt

In this elevator pitch, we will present the research topics of the nonlinear optimization group at Trier University (Germany) and will sketch some of the group's recent results regarding theory, algorithms, and applications of (multilevel) robust optimization as well bilevel optimization.

9 - The Capacitated Vehicle Routing Problem: chapter on a coming book
Juan José Salazar González

This talk summarizes a forthcoming book in "Handbook on Transport Modeling", edited by Sophie N. Parragh and Tom Van Woensel, and particularly on a chapter by Juan-José Salazar-González and Daniele Vigo on the well-known Capacitated Vehicle Routing Problem. This chapter presents several mathematical formulations in a unified integer linear programming framework. Some models are based on a polynomial number of variables and constraints, while other models rely on exponential numbers of variables or columns. All the models are implemented in a companion Julia code to help a reader better understand the advantages and disadvantages of using each formulation.

■ TB-07

Tuesday, 10:30-12:00 - Room: Clarendon GR.01

Scheduling in humanitarian operations

Stream: Scheduling and Project Management
Invited session
Chair: Istenc Tarhan
Chair: *Ceyda Oguz*

1 - Strategic Resource Deployment for Sustainable Humanitarian Supply Chains: Modelling Challenges
M. Ali Ülkü

Climate change increasingly disrupts global humanitarian operations, introducing new challenges to rescue and relief efforts. Extreme weather events such as floods, hurricanes, droughts, and wildfires are becoming more frequent and intense, making it harder to predict and respond to humanitarian crises. Additionally, rampant geopolitical conflicts and economic downturns propel the number of displaced people. Humanitarian supply chains face unique obstacles, including unpredictable demand, constrained resources, and geographic and infrastructural limitations. To that end, the efficient and sustainable deployment of resources is critical for ensuring timely and effective disaster response. Strategic resource deployment (SRD) plays a pivotal role in building resilient humanitarian supply chains, yet significant challenges remain in optimizing the use of resources across complex and dynamic environments. This study explores the modeling challenges associated with SRD in humanitarian contexts, focusing on achieving sustainability in both short-term relief and long-term recovery processes. Sustainable SRD requires robust models for operational efficiency and environmental, social, economic, and cultural (i.e., the quadruple bottom line) sustainability. These models must navigate complexities such as fluctuating resource availability, uncertain transportation routes, and balancing immediate relief with long-term sustainability goals. This talk will propose approaches for overcoming

2 - Fair location-allocation in disaster response: A metaheuristic approach
Özge Şatir Akpunar, Şener Akpınar

Drones have become an essential tool in disaster response, enabling efficient operations in areas with limited access. Given the urgency of the response and resource constraints, optimising the use of drones is critical to improve operational efficiency and effectiveness. This work investigates the problem of multiple visit coverage tours for drones to maximise temporal coverage in a disaster area while ensuring a fair distribution of service time. The system is designed to optimise the use of drones by maximising the number of regions served while maintaining an equitable distribution of operating time across all areas, within the constraints imposed by battery life. This ensures that each region receives a fair and comparable amount of service, effectively balancing coverage and resource constraints. A Mixed Integer Linear Program (MILP) is formulated by incorporating decisions on region selection, service time optimisation and visit scheduling. A metaheuristic based on greedy and local search algorithms is proposed to solve larger instances within a reasonable computational time.

3 - Optimizing post-disaster debris removal: bridging strategic planning and operational routing
Félix Combaud, Andréa Cynthia Santos, Christophe Duhamel

One of the major challenges in the aftermath of a disaster in an urban area is the removal of debris generated by the demolition of damaged buildings or the clearing of road networks. This problem, known as the Scheduling and Routing Problem to Clean Debris (SRP-CD), requires managing two distinct resources: (i) work-troops, which extract debris from sites, and (ii) trucks, which transport materials to landfills. In a post-disaster context, the vast debris volume and the size of the affected area require a long-term cleaning schedule spanning months or years. While such strategic planning provides valuable estimates, the scale of the problem makes vehicle routing decisions complex, leading to the use of simplifications and heuristic methods.

This work aims to bridge the gap between strategic and operational planning. We propose a multi-day vehicle routing model that explicitly considers (i) multiple debris types per site (e.g., concrete and metal), (ii) split multi-trips, where trucks can collect debris from multiple sites before reaching a landfill, (iii) resource constraints, where a truck carries only one debris type per trip, and (iv) debris stock management, ensuring that uncollected debris at the end of a time period is carried over to the next, influencing subsequent routing decisions. The resulting problem and its dedicated solving strategies will be presented, with a focus on efficiently coordinating work-troops and trucks over an extended planning horizon.

4 - Modeling and Solving the Disaster Relief Supplies Allocation and Distribution Problem with Efficiency and Fairness Considerations
Istenc Tarhan, Konstantinos G. Zografos

This study focuses on the allocation and distribution of relief supplies that need to be transported from central warehouses to disaster-affected areas. We consider a multi-layer transportation network, where the first layer consists of central warehouses, the last layer includes impacted areas and the intermediate layers serve as transshipment locations. Relief supplies move in one direction, from the central warehouses to the impacted areas, with the intermediate layers used for cross-docking and temporary storage. Each warehouse and transshipment location operates its own fleet, and various transportation modes may be employed between layers, depending on the fleet type.

We first propose a time-expanded network model to generate vehicle schedules that optimize distribution efficiency, ensure equitable distribution of supplies in terms of both quantity and arrival time, and minimize overall costs. To achieve these objectives, we utilize a hybrid approach combining the epsilon constraint method with goal programming, allowing us to solve sequential single-objective versions of the original problem. For large-scale instances, we develop a matheuristic algorithm to efficiently solve the single-objective subproblems.

Computational experiments show the successful performance of the proposed approach and offer valuable managerial and methodological insights.

■ TB-08

Tuesday, 10:30-12:00 - Room: Clarendon SR 2.08

MCDA and Composite Indicators: Issues, advances and applications

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: *Panagiotis Ravanos*
Chair: *Menelaos Tasiou*

1 - On Benefit-of-the-Doubt and weighted arithmetic average composite indicators: Benchmarking and direction-specific improvement paths
Panagiotis Ravanos, Giulio Caperna, Giannis Karagiannis

In this paper, we examine the relation between two alternative approaches that are used for aggregating a set of normalized indicators into a composite indicator, namely the weighted arithmetic average and the Benefit-of-the-Doubt (BoD) model. We show that the two approaches differ in terms of two modelling choices: the evaluation benchmark and the aggregation weights, which together determine the best-practice boundary against which entities are evaluated. We verify that the weighted arithmetic average composite indicator can be obtained by means of a directional distance function BoD model regardless of the chosen direction. We demonstrate the usefulness of this result for policy purposes, namely that it enables the identification of optimal improvement paths and targets for individual indicators required for an entity to achieve a particular score for the weighted average composite indicator based on an improvement direction of its choice. We also show how, for radial improvement choices, the overall difference between the BoD and the weighted arithmetic average composite indicator decomposes multiplicatively into a benchmark change and a weighting change component. We illustrate our findings using data from the European Commission's Cultural and Creative Cities Monitor.

2 - Overcoming the Limitations of Human Development Index - A Choquet Integral Approach to Account for Inter-dependencies
Faran Ahmed, Sajid Siraj, Mujtaba Agha

Multiple Criteria Decision Making (MCDM) methods provide robust frameworks for evaluating complex problems involving several dimensions. Assigning weights and the subsequent aggregation of these dimensions into a single representative composite score significantly impacts the outcome of the overall assessment. Traditional aggregation methods often assume that dimensions are independent, overlooking potential interactions among them. In several applications, this simplification can lead to inaccurate representative composite scores, as it fails to account for synergies or trade-offs between dimensions while synthesizing information across dimensions. This study proposes a novel framework to calculate composite scores incorporating multi-linear regression to estimate weights of the individual dimensions and the Choquet Integral to account for interactions among the dimensions included in the evaluation. The proposed framework is applied in the context of human development, where such methods offer a structured approach to aggregating diverse indicators into a single composite index. The geometric mean method currently used to calculate the Human Development Index (HDI) fails to account for the inter-dependencies between its core dimensions of health, education, and income. The proposed methodology addresses this limitation and demonstrates a superior ability to reflect more reliable human development by incorporating the inter-dependencies among its core dimensions.

3 - Ranking Members of Parliament with Automatic Democratic Weighting
Chris Tofallis

Choosing criteria weights when constructing a multi-dimensional score is difficult for a number of reasons. Firstly, there is the problem of lack of understanding regarding what those weights represent - this will vary according to the scoring method used. Secondly, there may be wide disagreement on weight values amongst those who are being assessed. The Automatic Democratic Method avoids both these issues. It has two steps: (1) Find the weights which will maximize the score for each individual or unit being assessed, subject to the condition that they do not lead to anyone exceeding a score of 100%. For N individuals there will be N optimizations and sets of weights. There is widely available free software which will carry out these optimizations. (2) In the second step we generate a single common set of weights by carrying out a regression of the scores from step (1) on the criteria data. Some results will be presented applying this method to the activities of UK Members of Parliament.

4 - An instrument for assessing digital maturity of schools
Bojan Žugec

The aim of this talk is to describe the development of an instrument for assessing the digital maturity of schools. It was determined that the most suitable instrument for this purpose was a rubric combined with a TOPSIS-like method for calculating the level of digital maturity. A rubric is commonly used in performance evaluation and includes descriptions of quality performance levels based on selected criteria. This instrument was employed to assess the digital maturity of Croatian schools as part of the project "e-Schools: Development of the System of Digitally Mature Schools," funded by the European Commission. In this project, a Framework for Digitally Mature Schools (FDMS) was developed, defining five levels of digital maturity along with accompanying elements that served as criteria in the rubric. Consequently, five descriptors were defined for each criterion to describe the expected performance at each level. More than 1,300 schools were evaluated using this instrument both at the beginning and end of the project. In addition to assessing the current level of digital maturity, the instrument provides guidelines for improving a school's position on the digital maturity scale. One of its key advantages is its versatility — its underlying concept is quite general and could be applied to other areas of evaluation beyond digital maturity.

■ TB-09

Tuesday, 10:30-12:00 - Room: Clarendon SR 2.01

Complexity in finance

Stream: OR in Finance and Insurance
Invited session
Chair: *Roy Cerqueti*

1 - A Comprehensive Methodology for Predicting Volatility: Leveraging Intrinsic Entropy Estimates through the Integration of GARCH Models and LSTM Networks
Claudiu Vinte, Marcel Ausloos, Bogdan Iftimie, Titus-Felix Furtună

To assess the overall volatility of the market, we utilize the Cross-Sectional Intrinsic Entropy (CSIE) model as the foundational methodology for monitoring the aggregate volatility of all symbols listed and traded on a specific stock market. In contrast, a market index intrinsic entropy (IE) volatility estimates are derived from n-day rolling windows. Consequently, CSIE market volatility estimates are incorporated into the research methodology as comparable n-day moving averages. We introduce a synergistic methodology that integrates GARCH models with Long Short-Term Memory (LSTM) networks, further augmented by intrinsic entropy estimates. This research employs over 5,500 historical end-of-day (EOD) data points, which encompass opening, high, low, and closing prices, along with traded volume (OHLCV) for all companies listed on the New York Stock Exchange (NYSE) and NASDAQ. Furthermore, it integrates the relevant market indices, specifically the S&P 500 and the NASDAQ Composite. To effectively model the relationship between consecutive values in a series of volatility estimates, we introduce specific step functions. The output produced by the proposed step functions is utilized by the LSTM networks. We conduct training for GARCH and LSTM models independently and subsequently integrate their predictions. By decoupling the models, this methodology facilitates the capture of distinct aspects of volatility and improves prediction accuracy for the step functions output.

2 - Rank-Size Analysis of Optimal Portfolio Weights Across Portfolio Optimization Models
Valerio Ficcadenti, Alessio Di Paolo, Francesco Cesarone, Roy Cerqueti

Portfolio optimisation has been widely studied, yet a unified framework for comparing optimal portfolio weight distributions across rank-size models remains unexplored. We introduce a rank-size analysis approach to systematically characterise these distributions in portfolio optimisation models. Four portfolio selection strategies—Mean-Variance, Conditional Value-at-Risk, Most Diversified, and Risk Parity—are analysed across the constituents of major financial indices (e.g., FTSE 100) over the period 2009-2023. The resulting empirical distributions of optimal weights are modelled using various rank-size functions, including the Exponential Law, Discrete Generalised Beta Distribution, and the Universal Law. By fitting these functions to weight distributions, we extract insights into the concentration patterns of portfolios, enabling the comparison of different strategies based on allocation ranks. To determine the most representative rank-size function, we introduce a selection methodology based on stochastic dominance, applied to the RMSE distribution of best-fit series. This approach ensures that the chosen function minimises average error while remaining robust across various quantiles of the weight distribution. The findings suggest that certain rank-size laws consistently outperform others in capturing the underlying structure of optimal portfolio weights, offering a novel lens through which to evaluate and compare portfolio construction strategies.

3 - Resilience of multilayer networks through community detection with a portfolio stability application
Saverio Storani, Roy Cerqueti, Raffaele Mattera

Network resilience is a key concept in complex network theory, extensively studied from both theoretical and applied perspectives. While resilience has been widely explored in monolayer networks, its implications in multilayer structures remain underdeveloped. In this paper, we contribute to this debate by introducing a novel resilience measure for multilayer networks, based on community detection applied within individual layers. Specifically, we model a multilayer network where nodes are connected through multidimensional attributes, with intralayer links determined by attribute similarity and interlayer links established via hierarchical clustering.

To assess resilience, we define external shocks that alter the network's structure. Shock type 1 isolates a node by modifying its community assignment, while shock type 2 removes interlayer connections, inducing structural changes. We measure resilience by quantifying variations in the community configuration following these perturbations.

As an application, we examine the resilience of financial multilayer networks, where layers represent key asset characteristics: expected returns, conditional variances, and unconditional correlations. Using distance measures tailored to each financial attribute, we construct a multilayer structure and analyze its stability under shocks. Our findings provide insights into the robustness of financial systems and the role of individual assets in network destabilization.

4 - Analytical adjustment of the IRB for Supervisory Formula for the estimation error
Mariacristina Uberti, Simone Casellina, Simone Landini, Patrick Zoi

The Internal-Ratings Based (IRB) approach is aimed at providing a measure of the maximum loss that a credit portfolio could generate over a year and with a given confidence level. As most of the standard risk measures, such as the Value-at-Risk (VaR), or the Expected Shortfall (ES), also the IRB measure depends on some parameters that must be estimated. The usual plug-in approach, consisting in substituting the

theoretical formulas the parameters with their estimates, does not consider the effect of the additional uncertainty generated by the estimation error. In this paper, we develop an analytical correction to the IRB formula that enables us to correct for the parameters uncertainty, using the theoretical setting developed by Gourieroux and Zakoïan (2013) and, to our knowledge, this is the first application of that approach to credit risk. This approach provides an approximated correction that depends on the variance-covariance matrix of the estimated parameters and does not require specific assumptions on their prior distribution, avoiding also computationally intensive Monte Carlo simulations. We show the validity of our correction on simulated data and show that our results are consistent with Tarashev (2010) who adopts Bayesian methods. We argue that our approach is more flexible and suited to be extended to the estimation of other parameters of the IRB formula. The opinions are of the authors and do not necessarily coincide with those of their Institutions.

■ TB-11

Tuesday, 10:30-12:00 - Room: Clarendon SR 1.03

Hospitals

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Melanie Reuter-Oppermann*

1 - Blended Payment Scheme of NHS England: Issues and Remedies
Sara Mohammadi, *Kenan Arifoglu*, *Bilal Gokpinar*

The National Health Service (NHS) England has implemented the blended payment scheme, integrating elements from two previously established payment systems: block contracts and Payment by Results (PbR). Block contracts entail a prospective lump-sum payment given to hospitals for accessing a defined range of services for a particular period. On the other hand, PbR is an activity-based payment under which a hospital receives a certain payment for each patient admission. Under the blended approach, hospitals receive an annual fixed payment similar to block contracts to secure an adequate supply of healthcare services. Then, the fixed payment is supplemented by a variable component to reflect differences between planned and actual levels of activity. Blended payment is developed to help hospitals make the most efficient use of available resources and remain in financial balance. Consequently, it can influence hospitals' decisions about their costs and planned activity levels which reflect their preparedness to deliver the anticipated level of services. Utilizing a principal-agent model, we compare hospitals' decisions regarding their planned activity levels and costs under the three defined payment schemes with socially optimal actions. Our findings reveal that due to information asymmetry between hospitals and the NHS, none of the existing payment schemes can achieve socially optimal outcomes. Consequently, we propose a new payment model to address this issue effectively.

2 - Generalised or Specialised Hospitals: an optimisation model considering the nosocomial effect.
Mohammad Aminjarahi, *Navid Izady*, *Dimitris Paraskevopoulos*

In multi-hospital networks (MHNs), a critical challenge is the allocation of clinical services across hospitals with limited capacity. This decision typically lies between two extremes: a fully generalized configuration, where all services are offered at every hospital, and a fully specialized configuration, where each hospital provides only one service. However, research and practical evidence suggest that neither extreme is optimal. In this paper, we develop a mathematical model to determine the optimal service configuration in an MHN with two capacitated hospitals and two services. Our model accounts for the nosocomial effect—the potential transmission of diseases—which significantly impacts patient service and waiting times. To address uncertainty, we incorporate queueing theory and economies of scale, both crucial in service configuration decisions. We propose a simulation-based optimization model alongside a numerical optimization approach, evaluating an extensive range of scenarios.

3 - A Patient-Centered Hospital Procurement of Physician Preferred Implants
Renato de Matta

This paper studies the hospital's procurement of physician preferred implants where both hospital surplus (profit) and patient surplus (value) are maximized. For better flexibility with minimal revision risk to patients, we introduce the substitution of another device that belongs in the category of the physician-preferred implant. This allows for improving the hospital surplus through larger revenues and volume discounts, although it implies that there is an additional cost to train the physician who may need to use the substituted implant and associated surgical procedure for safety and quality assurance. We model the procurement problem as a single period multi-product stochastic programming problem with substitution. The problem is NP-hard. We propose two heuristic procedures for finding good feasible solutions and for estimating the bound on the optimal value. The results of our experiments using patient-reported costs and total hip replacement outcomes from the medical literature show that a modest increase in flexibility could improve the hospital's financial performance, produce better patient outcomes, and reduce the negative effects of demand uncertainty.

4 - Towards a hospital-wide simulation framework
Melanie Reuter-Oppermann, *Michael O'Sullivan*

Healthcare systems worldwide are complex service networks with many dependencies and interrelations. Within these networks, hospitals play a central role and serve as one of the key providers of healthcare services. In a hospital, all departments are connected, and every logistical decision can impact others. Due to the complexity, it is not possible to build mathematical optimisation models that address all aspects simultaneously. In addition, some decisions must be made onsite and in real-time. Simulation models can help with online decision making as well as analysing the potential consequences when transferring solutions from mathematical models into practice. With the support of the Julius von Haast Fellowship by the Royal Society of New Zealand, we aim to design a hospital-wide simulation framework to model a complete hospital allowing to investigate all interdependencies and improvement potentials and to analyse the benefit of integrated planning. In this talk, we want to discuss valuable use cases for such a hospital-wide simulation framework, based on input we received from New Zealand hospitals, and present a conceptual model that we built for those hospitals.

■ TB-12

Tuesday, 10:30-12:00 - Room: Clarendon SR 1.02

Emerging trends, challenges and innovations in scheduling and project management

Stream: Scheduling and Project Management
Invited session
Chair: *Maria Elena Bruni*
Chair: *Oncu Hazir*

1 - A Multi-Stage Optimization Framework for Resource-Constrained Project Scheduling: Integration of Constraint Programming, Critical Path Drag, and Metaheuristics
Andy Forrester

Efficiently managing large-scale, resource-constrained projects requires balancing duration, resource utilization, and task dependencies. This study introduces a novel three-stage optimization framework combining Constraint Programming (CP), Critical Path Drag (CP Drag) analysis, and Metaheuristics to address these challenges.

In the first stage, CP generates a feasible baseline schedule by minimizing makespan while satisfying resource and precedence constraints. The second stage applies CP Drag analysis to identify tasks with high resource impact, guiding targeted refinements. The final stage uses metaheuristic algorithms to explore alternative schedules, reducing overallocations and improving resource efficiency.

This hybrid approach aims to provide a scalable solution for real-world project management challenges, demonstrating its potential to enhance scheduling efficiency, eliminate resource overallocation, and improve task prioritization. The framework bridges theoretical advancements with practical applications, paving the way for further exploration in multi-project and dynamic environments.

2 - Investigating the Monte-Carlo Tree Search Approach for the Job Shop Scheduling Problem
Laurie Boveroux, Damien Ernst, Quentin Louveaux

The Job Shop Scheduling Problem (JSSP) is a well-known optimization prob- lem in manufacturing, where the goal is to determine the optimal sequence of jobs across different machines to minimize a given objective. In this work, we focus on minimising the weighted sum of job completion times. We explore the potential of Monte Carlo Tree Search (MCTS), a heuristic-based reinforcement learning technique, to solve large-scale JSSPs, especially those with recirculation. We propose several Markov Decision Process (MDP) formulations to model the JSSP for the MCTS algorithm. In addition, we introduce a new synthetic benchmark derived from real manufacturing data, which captures the complexity of large, non-rectangular instances often encountered in practice. Our experimental results show that MCTS effectively produces good-quality solutions for large-scale JSSP instances, outperforming our constraint programming approach.

3 - On the integration of discrete choice models in load scheduling for energy communities
Maria Elena Bruni, Dario Vezzali, Sara Khodaparasti, Haoqi Xie

Load scheduling for energy communities represents an innovative application at the boundary between operations research and energy management. An energy community consists of traditional consumers, prosumers, and distributed storage units, and is conceived with the objective of minimising the load collected from the public grid by shifting so-called controllable loads. This may come at the cost of reducing the service level and satisfaction of users who are not willing to change their habits to optimize energy consumption within the energy community. Discrete choice models (DCM) are able to capture the impact of these decisions on users' behaviour, considering the heterogeneity of their preferences, and have been successfully integrated into optimization models. In this work, we introduce a novel mixed integer linear programming (MILP) model with an embedded DCM, which captures user preferences in terms of utility functions, to solve the load scheduling problem for energy communities.

4 - Constraint Programming Approach for Customer Order Scheduling Problem with Sequence-Dependent Setup Times
Funda Guner, John H. Drake

The customer order scheduling (COS) problem is a fundamental scheduling problem where customer orders consist of one or more jobs that must be processed and delivered together. Efficient scheduling of customer orders is crucial for minimizing delays and optimizing resource utilization. In this study, we consider sequence-dependent setup times, where a setup is required before processing each job unless it is the first job in an order and is the same as the last job of the previous order.

We focus on minimizing the total completion time by exploring mixed-integer linear programming (MILP) and constraint programming (CP). MILP is a well-established mathematical modeling approach, while CP is known for efficiently handling complex constraints and combinatorial structures.

We compare the performance of MILP and CP to evaluate their effectiveness in solving the COS problem with sequence-dependent setup times. CP is particularly effective in solving highly constrained instances, while MILP can provide optimal solutions but struggles with scalability for larger instances.

This study contributes to the literature by offering a direct comparison of MILP and CP for COS with sequence-dependent setup times. CP models are easier to modify, making them suitable for dynamic environments. Incorporating setup times adds complexity, requiring efficient scheduling methods. Future research could explore hybrid methods that combine MILP and CP to enhance performance.

■ TB-13

Tuesday, 10:30-12:00 - Room: Clarendon SR 1.01

AI and Machine learning in healthcare

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Marcos Santos

1 - Addressing Endogeneity in Healthcare Operations through Copula-based and Machine Learning Methods
Meera Simon, Shovan Chowdhury

Measuring cost at the patient level is important for the measurement and improvement of value. Healthcare providers must therefore be able to provide coordinated care with minimal expenditure which requires accurate estimation of cost. Understanding the importance of individual-level factors that determine expenditure, researchers have developed models that consider several customer-centric factors like socioeconomic and psychological factors and used regression models to analyse the effect of customer profiles and other factors on expenditure. It is, however, established that endogeneity is an important problem that arises while using regression, and many impactful academic journals require that the issue of endogeneity be addressed. Though till 2015, the issue of endogeneity was not of immense importance in operations management, the note from the editors of the Journal of Operations Management published in 2018 emphasised the importance of addressing the endogeneity, encouraging models that could incorporate endogeneity. In our study, we identify two endogenous variables that commonly occur in healthcare (namely, Length of Stay (LOS) and total expenditure) and develop a model that can address endogeneity through bivariate copula which is an instrument-free approach that can effectively be used to model variables with suspected endogeneity. To accommodate other variables that are linked directly to the variables under study, we also use machine learning techniques.

2 - Assessing ICU Efficiency using Machine Learning: Analysis of 16,985 Patients with Severe Community-Acquired Pneumonia (sCAP) across 220 Brazilian ICUs
Igor Tona Peres, Amanda Quintairos e Silva, Guilherme Ferrari, Joana da Matta Furtado Ferreira, Leonardo S. L. Bastos, Vicente Dantas, Jorge Salluh

Severe community-acquired pneumonia (sCAP) strains intensive care unit (ICU) resources, demanding efficient allocation and robust performance metrics for value-based care. Traditional ICU assessments often lack granularity and risk adjustment, particularly for complex cases such as sCAP. This study evaluated the application of the Standardized Length of Stay Ratio (SLOSR), a machine learning-based metric of ICU efficiency, in sCAP patients. We analyzed 16,985 adult sCAP admissions across 220 ICUs in 57 Brazilian hospitals (January-December 2023), the largest sCAP efficiency cohort to date. SLOSR is calculated as the sum of observed length of stay (LOS) divided by the sum of predicted LOS. The machine learning model predicting ICU LOS uses a stacking model (combining Random Forests and Linear Regression) and was updated and validated using the 2022 and 2023 data. We used

cross-validation and calibration plots to evaluate the predicted LOS at ICU level. Model performance showed a root mean square error of 4.57 and R' = 0.89. Funnel plot analysis revealed a median SLOSR of 1.13 (Q1=0.9; Q3=1.34), demonstrating no bias in its use for benchmarking. To facilitate broader adoption, an R package named SLOS was developed, enabling researchers and clinicians to calculate and analyze SLOSR efficiently. SLOSR is a valuable tool for assessing ICU efficiency in sCAP patients, aligning with value-based care principles and supporting data-driven decision-making in critical care settings.

3 - A machine learning model to predict the risk factors causing feelings of burnout and emotional exhaustion amongst nursing staff in South Africa

Derya Demirtas, Maria Van Zyl, Jacoba Bührmann, Alwiena Blignaut, Siedine Coetzee

Nurses in South Africa face high demands and limited resources, leading to burnout and emotional exhaustion. Identifying key predictive factors is crucial for support and policy decisions. This study explores whether demographic data alone can predict burnout and uses machine learning to analyze contributing factors. Using PyCaret 3.3, supervised machine learning models were developed on 1165 survey responses from nurses in medical-surgical units. Models were evaluated by accuracy, AUC score, and confusion matrix. Predictions based on demographic data alone were compared to full survey data, and key predictive factors were extracted for analysis. The gradient booster classifier (GBC) achieved the highest accuracy: 75.8% for burnout and 76.8% for emotional exhaustion using full survey data, while demographic data alone yielded 60.4% and 68.5%, respectively. Fatigue was the strongest predictor of both outcomes. Confidence in management was the second highest predictor of burnout, while management's willingness to listen was the second highest for emotional exhaustion. We conclude that machine learning effectively predicts burnout and emotional exhaustion from full survey data but not from demographics alone. Addressing fatigue, confidence in management, and management's responsiveness may help mitigate these issues among South African nurses.

4 - Analysis from the TOPSIS Method: Assessment of the Impact of Aircraft Noise on Hearing Loss Passengers

Marcos Santos, Silmara Scontre, Fabio Henrique Martins Queiroz, Antonio Sergio da Silva, Daniel Pereira

Hearing loss affects more than 1.5 billion people worldwide, many of whom use air transport. This study investigates noise levels in Airbus and ATR aircraft during flight, evaluating the impact of these noises on the communication and safety of people with hearing loss. The review was carried out in databases such as PubMed, MEDLINE and Cochrane Library, covering studies published between 2019 and 2024. The article highlights the application of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) in analyzing suitable places for accommodation of people with hearing loss in aircrafts. The alternatives of the problem are: front, middle and rear of the aircraft. The criteria listed are: proximity of communication, speech recognition index, acoustic comfort, ambient noise level, interference and distance from noise sources. Cabin noise levels, both internal and external, are relatively high on turboprop aircraft such as ATR models, where levels can reach up to 80 dB at the front during flight. Passengers with hearing loss are particularly vulnerable to these elevated noise levels, which can complicate speech understanding. This is why we must place the passenger with hearing loss in the appropriate seat to ensure their safety during the flight. The analysis indicates that the middle position of the aircraft provides the least noise interference, facilitating speech understanding.

■ TB-15

Tuesday, 10:30-12:00 - Room: Esther Simpson 1.08

Heuristic Search 2

Stream: Combinatorial Optimization
Invited session

Chair: Rafael Marti
Chair: *Anna Martínez-Gavara*

1 - Parallel Designs for Scatter Search

Sergio Pérez-Peló, Alejandra Casado, Jesus Sanchez-Oro, Abraham Duarte, Manuel Laguna

Scatter Search (SS) is a well-established metaheuristic for tackling complex combinatorial optimization problems, known for its versatility and ease of adaptation. While several SS parallelization schemes have been proposed for specific problems, a general parallel framework remains unexplored. In this work, we introduce three parallel designs for SS, each addressing a distinct goal: reducing computational time, enhancing search exploration, and balancing intensification and diversification. Our experimental evaluation, based on benchmark problems where the state-of-the-art relies on sequential SS, provides insights into the impact of parallelization on solution speed and quality. Additionally, our publicly available code is designed for easy adaptation to new optimization problems. The results highlight promising directions for establishing a robust general framework for SS parallelization.

2 - Metaheuristics for the Induced p-Median problem with Upgrades

Sergio Salazar, J. Manuel Colmenar

Facility location problems (FLPs) are a family of optimisation problems with significant social impact. This class of problems has been the subject of study since the 1960s, with classical approaches including the Weber Problem and the p-median Problem. At the present time, more complex variations of these problems are being investigated. Notably, the Induced p-Median Problem with Upgrading (IpMU) represents a variation of the classical p-Median problem, where the concepts of transport cost and distance are separated as distinct metrics in the input graph of the problem. Furthermore, a set of decision variables is incorporated to relax the costs of the graph, allowing the edges between nodes to be reduced, thus enhancing the associated routes between the designated medians and the customers. In this study, a metaheuristic algorithm is proposed based on the Greedy Random Adaptive Search Procedure (GRASP), wherein a two-phase resolution scheme is established, studying the median problem and the improvement problem independently. In this approach, a large set of state-of-the-art instances has been analysed to ensure a fair comparison with previous proposals. The results obtained are promising when compared to the state of the art, which is based entirely on mathematical models. Execution time has been improved with the same or better quality results in all the studied instances.

3 - A metaheuristic approach for the Three-Stage Remanufacturing System Scheduling Problem

Teodor A. Diaconescu, Alberto Herrán, J. Manuel Colmenar

The Three-Stage Remanufacturing System Scheduling Problem (3T-RSSP) represents a challenge in circular economy implementations and directly supports the United Nations Sustainable Development Goals (SDGs). This NP-hard problem involves scheduling products through the three sequential stages of the system with the objective of minimizing makespan. The remanufacturing system in this problem is equipped with a configuration of unrelated parallel disassembly and reassembly workstations and parallel dedicated flow-shop-type reprocessing lines. In this work, we present an enhanced GRASP metaheuristic that significantly improves solution quality while reducing computational requirements. Our algorithm incorporates an optimized cost function calculation mechanism that substantially decreases execution times. We have determined the values of the parameters using irace. Experimental validation has been conducted on an expanded benchmark of 53 instances. Comparative analysis demonstrates that

our approach consistently outperforms state-of-the-art methods, obtaining a higher percentage of best solutions with execution times reduced by up to two orders of magnitude.

4 - Improving the optimization of the Online Order Batching by combining the Maximum Throughput Time and Picking Time
Sergio Gil-Borras, Eduardo G. Pardo

The Online Order Batching Problem has gained prominence in recent years due to the rapid expansion of e-commerce platforms, which seek to streamline every step of their supply chain. In the context of warehouse management, optimizing the picking process using a batching policy is a critical area for cost reduction. In this study, we focus on enhancing order batching by considering two distinct objective functions simultaneously: minimizing the picking time and minimizing the maximum throughput time. To achieve this, we propose a weighted composite objective function that balances these two goals that will be used as a guiding function. We conduct three experiments to evaluate different configurations. The first one shows that using a combined objective function yields to better results in minimizing the maximum throughput time than using just the original function as guidance. The second configuration targets improvements in the picking time, and the third one seeks to enhance both objectives simultaneously. Our methodology relies on GRASP+VND, an approach previously validated with strong outcomes for OOBP, to generate batches of orders. We then apply the S-Shape heuristic to determine efficient picking routes due to its simplicity and rapid computation. To further refine the results, we test two time-window policies, which influence when new orders enter the batching process. Our findings demonstrate that these strategies can significantly improve warehouse operations.

■ TB-16

Tuesday, 10:30-12:00 - Room: Esther Simpson 2.07

Optimization of complex systems in Agriculture

Stream: Sustainable Food & Agroforestry
Invited session
Chair: *Pol Llagostera Blasco*

1 - A Comparative Study of Evaluating the Efficiency of Feeding Robots for Pig Fattening
Pol Llagostera Blasco, Ijaz Ul-Haq, Pau Font Farre, Daniel Babot Gaspa, Lluís Miquel Pla Aragonès

Digital transformation in the pig industry enhances efficiency, sustainability, and animal welfare, driven by the increasing adoption of sensors and automated feeding robots. These technologies enable continuous monitoring and data collection but raise concerns about consistency in measuring feed intake and live weight due to machine and pig behavior variations. This study compares different feeding robots and manual methods in tracking feed consumption and weight. Conducted at the Centre d'Estudis Porcins in Spain, the experiment monitored 120 pigs using five commercial feeding systems. Data on feeding behavior, weight progression, and feed intake were analyzed with ANOVA, paired t-tests, and principal component analysis (PCA). Results show no significant differences in weight measurements, confirming feeding robots' reliability. However, feed intake records varied due to machine operation and animal behavior inconsistencies, partly linked to software limitations. These findings highlight the need for improved control algorithms while supporting automated feeding systems' role in precision livestock farming. This study contributes to the broader adoption of precision livestock farming technologies by providing insightful information to farmers, technology developers, and policymakers.

2 - AI-Enhanced Decision Framework for Innovative Conceptual Design in Sustainable Food Engineering
Mohamed Saâd El Harrab, Michel Nakhla

Conceptual design in sustainable food engineering demands structured approaches to explore and optimize innovative, viable solutions systematically. Traditional heuristic methods often lack the necessary rigor and structure, limiting their effectiveness in generating feasible outcomes. While large language models (LLMs) effectively enhance knowledge retrieval, they typically do not incorporate structured optimization processes essential for systematic decision-making.

This study introduces a structured decision-making framework integrating Markov Decision Processes (MDPs), Reinforcement Learning (RL), and knowledge integration via LLMs, explicitly targeting conceptual design in sustainable food engineering. Our approach systematically models design decision processes, effectively balancing exploratory creativity with the targeted optimization of sustainability metrics, including nutritional quality, environmental footprint, economic viability, and innovative product differentiation. A practical case study in sustainable food product innovation demonstrates the framework's ability to improve the feasibility, diversity, and sustainability performance of proposed solutions, highlighting its potential as a robust, structured approach to conceptual design.

3 - Sustainable Meat Supply Chains: Supplier Selection, Production, and Distribution
Hossein Zolfagharinia, Mehdi Najafi

Addressing sustainability in supply chain management remains a challenge, particularly in the food industry, where resource consumption and public health are critical concerns. This study presents a multi-objective optimization model for a meat supply chain, integrating supplier selection, production planning, and product distribution while considering economic, environmental, and social sustainability. A novel decision-making framework is developed, employing the Stochastic Analytic Hierarchy Process (SAHP) and TOPSIS methods to evaluate suppliers' environmental impact. The optimization model utilizes the Normalized Normal Constraint (NNC) method to generate Pareto-optimal solutions, balancing cost, product freshness, and environmental impact. A case study in Ontario, Canada, demonstrates that sustainability improvements can be achieved with minimal additional costs. The findings suggest that an integrated approach enhances supply chain efficiency while promoting environmental responsibility and social well-being.

4 - Impact of pig growth curves on the slaughterhouses selection
LluisM Pla, Yun Bao, Pol Llagostera Blasco

Modern pig farming requires effective interdisciplinary decision-making tools to ensure profitability. A decision tool for pig growers based on a mixed integer linear programming (MILP) model to optimize the transportation strategy selecting the most profitable slaughterhouse is introduced. A sensitivity analysis is performed considering different pig growth and the payment grids serving to select the most suitable slaughterhouse.The base case scenario outperformed the official statistics on profits reported to the sector by 12.49 ct EUR /kg liveweight. Our findings also confirm the utility of selecting the most suitable slaughterhouse with potential enhancement of the economic outcome. Results confirm the current trend in slaughter heavier pigs of about 120 kg leading to a larger fattening period. Practical outcomes indicates that low growth pigs generated losses (-0.42 ct EUR /kg) while medium growth pigs (4.24 ct EUR /kg) outperformed higher growth pigs (1.29 ct EUR /kg), suggesting that medium growth pigs are more efficient. The resulting model can be run quickly providing useful insights to decision makers managinf pig fattening farms.

■ TB-17

Tuesday, 10:30-12:00 - Room: Esther Simpson 2.08

Novel applications in warehousing, maritime transport, and healthcare

Stream: Combinatorial Optimization
Invited session

Chair: Alena Otto
Chair: *Erwin Pesch*
Chair: *Sven Mallach*
Chair: *Alessandro Agnetis*

1 - A cluster-based approach to elective surgical planning
Ilaria Salvadori, Alessandro Agnetis, Marco Pranzo

Effective scheduling of operating rooms is crucial for optimizing surgical workflows, enhancing patient outcomes, and maximizing healthcare resources utilization. However, despite the huge literature on surgical planning, only a small fraction of all models has been implemented in practice. This study proposes a new approach to surgical planning that balances surgeon autonomy with efficient resource use. While surgeons value decision-making freedom, managers aim to optimize operating rooms and wards utilization. Consequently, the final plan often results from a negotiation between the parties. Our approach aims at supporting such negotiation, pursuing a compromise between professionals' preferences and hospital efficiency. The key idea of our modeling approach is to partition all surgeries into a limited number of surgical groups (clusters), each being relatively homogeneous in terms of resource consumption. Within the framework of a long-term agreed-upon Master Surgical Schedule, our model computes the number of procedures from each cluster to be performed in the next planning period. This ensures efficiency while still allowing surgeons flexibility in patient selection. We illustrate the model and its validation through a long-term simulation of our decision support tool. Different clustering strategies and objective functions have been implemented, and various performance indicators are observed, allowing a comparison between our approach and the current policy.

2 - Scheduled Service Network Design for Intermodal Sea-Road Freight Transportation
Fran Setiawan, Tolga Bektas, Cagatay Iris

Indonesia, the world's largest archipelagic nation, consists of over 17,500 islands, resulting in a unique geographical structure that inherently necessitates intermodal freight transportation. Maritime transport plays a crucial role in inter-island logistics; however, economic activities remain heavily concentrated on Java, while trade in the eastern regions remains limited and costly. To address this challenge, the Indonesian government launched the Sea-Toll project in 2015 to facilitate the nationwide distribution of essential and staple goods. The initiative includes the development of 24 strategic ports and the provision of scheduled vessel services to strengthen freight connectivity across the archipelago as part of its public service obligation. This research focuses on designing an optimized scheduled service network for intermodal sea-road freight transportation in Indonesia. We propose a formulation that integrates heterogeneous ship types, vessel scheduling and management, and synchronized hinterland distribution to improve efficiency, where the novel aspect is in the consideration of back-and-forth ship movement. The objective is to minimize total transportation costs and delays. Although the proposed model is driven by Sea-Toll project, it can also be applied to other similar settings.

3 - Optimizing Seafood Supply Chains: Minimize Food Loss and Waste by Integrating Vessel Routing, Scheduling, and Energy Usage
Chiara Maragò, Ali Ghavamifar, Dario Pacino, Allan Larsen, Francesca Guerriero, Rosita Guido

The fishing industry operates under complex and dynamic conditions, facing multiple challenges such as uncertainty in fish availability, fluctuating fuel prices, catch quotas, seasonal variations, quality preservation constraints, and sustainability standards. This study develops an optimization model aimed at maximizing the income of an Icelandic fishing company by holistically integrating vessel routing, scheduling, and production decisions. To enhance decision-making, we incorporate fish quality considerations into the model, recognizing their impact on both profitability and energy consumption during processing. We propose a mixed-integer programming (MIP) model that accounts for these interconnected tactical-level decisions while incorporating industry-specific constraints. To address the uncertainty in fish availability, we generate multiple scenarios to represent potential catch locations and supply variability. Given the computational complexity of the problem, we apply a heuristic solution approach to support the company's decision-making process. This data-driven framework integrates critical operational factors to enhance efficiency, reduce costs, and promote sustainability in fisheries management. By optimizing fisheries supply chains, our results provide valuable insights for improving profitability and sustainable practices while ensuring compliance with regulatory constraints.

4 - A dynamic programming algorithm for order picking in robotic mobile fulfillment systems
Erwin Pesch, Jan-Erik Justkowiak, Mikhail Y. Kovalyov

The order scheduling and rack sequencing problem deals with the order picking process in robotic mobile fulfillment systems: automated guided vehicles lift and transport movable storage racks to picking stations to supply items requested by customer orders which are put together in cardboard boxes on a workbench of limited capacity. To efficiently operate the station, the sequence in which racks visit the station one after another and the intervals at which customer orders are scheduled must be coordinated. We present a dynamic programming algorithm for the order scheduling and rack sequencing problem at a single picking station minimizing the number of rack visits. Despite monolithic mixed integer linear programming formulations, our approach appears to be the first combinatorial solution method for the problem. A computational study demonstrates the effectiveness of the approach.

■ TB-20

Tuesday, 10:30-12:00 - Room: Esther Simpson 2.11

Applications of combinatorial optimisation in industry and services 2

Stream: Combinatorial Optimization
Invited session

Chair: *Adriana Cherri*
Chair: José Fernando Oliveira
Chair: *Begoña Vitoriano*

1 - Energy-Efficient Motion Planning for Industrial Robots using Digital Twins
Dimitrios Tsakoumis, Gregory Koronakos, Stathis Plitsos, Johannes Feik, Pavlos Eirinakis

The growing demand for energy-efficient robotic systems in manufacturing necessitates advanced optimization techniques that balance performance and computational feasibility. A promising approach involves leveraging Digital Twin (DT)-based methodologies to model and optimize robotic arm movements. This work presents an Integer Programming model that incorporates a set of operational scenarios, each characterized by varying movement attributes such as velocity, acceleration, and trajectory type, all of which influence energy consumption and task completion time. Given the large solution space, a preprocessing method based on Pareto dominance is introduced to filter out strictly suboptimal scenarios. By retaining only Pareto-optimal scenarios, which represent the best trade-offs between energy efficiency and time, the solution space is reduced without compromising the quality of the solution with respect to optimal energy consumption. Computational experiments demonstrate the scalability and efficiency of the proposed approach. Results show that the use of Pareto

filtering significantly reduces computational time, making it feasible to solve large-scale optimization problems that would otherwise be intractable. The integration of DT-based scenario generation with optimization tools presents a significant advancement in improving robotic energy efficiency and decision-making in automated production systems.

2 - Spatial aspects of optimising social care
Samo Drobne, Carmen Rajer, Marija Bogataj, David Bogataj

The new Long-Term Care Act (ZDOsk and ZDOsk-1) in Slovenia provides for home care for categorised individuals in need of assistance. The legislation includes also new services for home reactivation, such as physiotherapy, occupational therapy, and medical care. However, it does not account for the spatial dispersion of housing for older citizens, nor does it provide for community care in specially adapted accommodations like Silver Villages. These villages would offer concentrated housing for older adults dependent on help, thereby reducing travel costs for carers in rural areas. Our research aims to optimise social care by examining the spatial aspects of home care for older citizens, using the Centre for Social Work Posavje - Unit Krško as a case study. We will investigate the preferences of the elderly for care time slots, their willingness to relocate to a Silver Village, the availability of land for such communities, and the investment costs. This study seeks to improve the accessibility and quality of services for older adults, with potential implications for social care policies and practices.

3 - Adding Relations with Short Communication Lengths between a Delegate and Every Other Member of the Same Level in a Complete K-ary Linking Pin Organization Structure
Kiyoshi Sawada

A linking pin organization is a structure in which relations between members of the same section are added to a pyramid organization where there exist only relations between each superior and his direct subordinates. This study proposes a model of adding relations with short communication lengths between a delegate and every other member of the same level in a complete K-ary linking pin organization structure where every pair of nodes which have the same parent in a complete K-ary tree is adjacent. When edges between one node and every other node of depth N in a complete K-ary linking pin organization structure of height H are added where lengths of adding edges are shorter than lengths of edges of the complete K-ary linking pin organization structure, the total shortening distance which is the sum of shortening lengths of shortest paths between every pair of all nodes by adding edges is formulated. An optimal depth N such that the communication of information between every member in the organization becomes the most efficient is obtained by maximizing the total shortening distance.

4 - Solving the Team Orienteering Problem with Variable Time Windows applied to Wildfire suppression
Begoña Vitoriano, Bibiana Granda

The Orienteering Problem (OP) is a well-known routing problem within Operational Research, from which various variants have emerged over time. The Team Orienteering Problem with Variable Time Windows (TOPVTW) is a new variant based on the Team Orienteering Problem with Time Windows, with time windows evolving dynamically according to the solution and a diffusion process. An application to wildfire suppression will be presented, where the fire spread determines the time windows for brigades to work in a parcel of the landscape or cross through it. Simultaneously, the brigades' work controlling parcels modifies the spread of fire, preventing it from spreading through the controlled area. The aim is to determine the places to be controlled and the brigades' routes through the landscape to minimize the value of the burned area while maintaining safety measures for the teams. This problem must be solved very quickly to be useful. Several methods are explored, and the results will be implemented in a tool for practitioners in the context of the HORIZON Europe project HURRICANE.

■ TB-23

Tuesday, 10:30-12:00 - Room: Esther Simpson 3.01

OR for Socio-Humanitarian Development

Stream: OR for Societal Development
Invited session
Chair: *Nina Kajiji*
Chair: *Elise del Rosario*

1 - Education, Student Performance, and Migration: A Computable General Equilibrium Model Approach
Veronika Mitkova

Migration and its impacts are attracting growing attention as the number of international migrants has increased over the past five decades three times according to the International Organization for Migration. The current global estimate is that there were around 281 million international migrants in the world in 2020, which equates to 3.6 percent of the global population. Most studies on migration have overlooked the education spendings in source and receiving countries. The aim of this work is to contribute to our knowledge of the impact of education spending on student performance and migration. The approach is mainly based on the computable general equilibrium models methodology using data from 80 countries around the data from the world and the Global Trade Analysis Project. Overall, the results indicate that the intelligence quotient and the human development index influence education outcomes more than the share of education spending in GDP. The impact of education on wages of migrants depends on whether they are skilled or unskilled: the wage of unskilled workers decreases due to the migration of skilled workers and increases due to the migration of unskilled workers. On the other hand, the wages of skilled workers increase because of the immigration of skilled workers and decrease as a result of the immigration of unskilled workers. We have obtained encouraging results demonstrating the (in)dependence of the education spendings and wages of immigrant workers.

2 - AI-Enhanced Educational Optimization in Resource-Constrained Environments: The Manko'o Digital Dreams Case Study
Aristide Toundzi Dzouankeu, Bruno Kamdem

This paper introduces the ongoing Manko'o Digital Dreams Program (January-December 2025) in Cameroon, designed to leverage artificial intelligence (AI) to enhance academic performance and foster sustainable development in rural African communities. The program utilizes a robust mathematical framework incorporating reinforcement learning and K-Nearest Neighbors (KNN) algorithms to establish a scalable Learner Digital Twin System. Our methodology features a modified Q-learning algorithm, integrating reward functions that evaluate both academic achievements and community developmental impacts. Concurrently, the KNN model facilitates detailed student profiling, addressing diverse socioeconomic and educational backgrounds. Preliminary outcomes from the project's initial phase indicate significant improvements in STEM competencies and digital literacy among students. Furthermore, we anticipate notable increases in academic performance, with decreased reliance on expensive infrastructure thanks to intelligent resource scheduling. Our comprehensive mathematical framework strategically connects AI-driven educational interventions with measurable sustainable development goals. This initiative establishes a sustainability-oriented parametric approach, optimizing educational outcomes and developmental benefits. We actively invite collaboration from researchers interested in contributing to this impactful endeavor.

3 - Improving Essential Services Accessibility Under Natural Disaster Risks using Multi-Objective Optimization: A Case Study for Cao Bang
Britt van Veggel, Maria Paola Scaparra, Ngoc Dao

Vietnam faces significant risks from natural disasters, with 46% of its population exposed to severe flooding. Landslides and floods frequently damage infrastructure, disrupting access to healthcare, education, and food. These challenges are particularly severe in northern mountainous regions like Cao Bang. This research focuses on optimizing disaster-resilient infrastructure investments to ensure equitable access to essential services under varying disaster conditions. We develop a multi-objective optimization model to improve accessibility by determining optimal infrastructure investments under different disaster scenarios. The model balances two objectives: maximizing service coverage and ensuring fairness by prioritizing high-resilience improvements for infrastructure used by lower-income populations. We also explore a multi-period planning framework to strategically schedule investments within budget constraints. To solve this large-scale problem, we implement a Non-Dominated Sorting Genetic Algorithm II. Our approach integrates data existing data and by combining information from government sources. We collaborate with local institutions for hazard maps and cost estimates. Preliminary findings highlight accessibility gaps and and identify critical infrastructure vulnerabilities.

4 - Instant Deliveries in Mexico City: A Socio-Economic Analysis and Profit Maximization Framework for Couriers.
Ana Bricia Galindo Muro, Jaime Mora Vargas

This study introduces an engineering approach to understanding instant delivery operations within the platform economy via a Case Study in Mexico City. Through two comprehensive surveys, we identified significant risks and challenges faced by couriers, highlighting their precarious working conditions and financial pressures. Our findings emphasize the stark disparity between the platform economy's promise of flexibility and independence and the harsh reality experienced by most couriers. Based on these results, we formulated an assignment model to support technological advancement in the sector. By incorporating a fee algorithm and operational cost calculations, our quantitative model demonstrates that a 20% increase in couriers' income compared to traditional assignment approaches is achievable while remaining advantageous for all stakeholders. The model assigns orders to couriers with the constraint that operational costs (gas consumption, insurance, equipment, etc.) should not exceed the delivery fee, ensuring that couriers receive fair remuneration after each trip. The delivery fee is calculated via an algorithm primarily based on distance parameters, designed to approximate commercial platforms' pricing while respecting their proprietary algorithms. Additionally, a distance restriction ensures no order is accepted if the total travel distance exceeds an established minimum, maintaining service quality.

■ TB-24

Tuesday, 10:30-12:00 - Room: Esther Simpson 3.02

Tutorial:Explaining Machine Learning Models: A Multi-Objective Optimization Perspective

Stream: Tutorials (and Workshops)
Invited session
Chair: *Sanne Wøhlk*
Chair: *Sajid Siraj*

1 - Explaining Machine Learning Models: A Multi-Objective Optimization Perspective
Dolores Romero Morales

State-of-the-art Artificial Intelligence (AI) and Machine Learning (ML) algorithms are ubiquitous. While they can achieve high accuracies, they are also criticized for not being transparent about how they arrive at their decisions, preventing their adoption in Data-Driven Decision-Making. Even when in place, they can be unfair to the citizen, and there are well-documented examples of discriminatory outcomes in high-stakes algorithmic decision-making.

In this tutorial, we aim to train ML models that are more transparent and less unfair, by striking a balance between accuracy, explainability, and unfairness. We will first navigate through Multi-Objective Optimization (MOO) models that train ML models with enhanced explainability and fairness. Then, we will move to models MOO models that derive local and global explanations to the predictions of an opaque model.

■ TB-25

Tuesday, 10:30-12:00 - Room: Maurice Keyworth 1.32

Beyond the sums: how do we engage with our customers and their problems

Stream: Making an Impact: The Practitioners' Stream 2
Making an impact session
Chair: *Eleanor Reynolds*
Chair: *Sofiane Oussedik*

1 - Beyond the sums: how do we engage with our customers and their problems
Eleanor Reynolds, Frances O'Brien

OR people don't just build models: we need to engage with our customers and their problems before we can even start thinking about quantitative solutions.

Very often, nobody teaches us how to do this. We develop our own styles and tactics. When we come across challenges and obstacles, we find our own work-arounds. And we have our own ways of managing the read-across from qualitative to quantitative and back again.

In this interactive workshop, we will explore these activities: individually thinking about our own practice, and discussing, both in small groups and collectively in plenary. The facilitators will use a variety of different methods to help us reflect, and to encourage conversations enabling us to share with, and learn from, each other.

■ TB-26

Tuesday, 10:30-12:00 - Room: Maurice Keyworth 1.33

Explainability for decision support tools : The what, why and how

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: *Anne Liret*

1 - iSee: the challenge of designing Explanation Strategies That Users Trust and Understand
Anne Liret

Explainability is the ability of an AI system to explain why it took a certain decision. By introducing AI within OR systems, we expect improving the robustness but we as well add non deterministic behaviour for instance caused by the learning from experience aspect of AI.

The aim of this session is to provide the attendees some insights on the challenges of building a convincing explanation in Operational Research based decision-making systems, some examples and tools that can help, and lessons learnt from practitioners and for practitioners. Time for panel discussion, questions and answers will be reserved so that attendees can share their thoughts and take away useful knowledge.

First a workshop will detail the challenge of explaining the outcome of decision-making systems including an overview of the iSee project, the explanation experience sharing platform built with this project (isee4xai.com) and case studies.

We will hear about how to respond to the need for explaining the result of AI and OR -based systems, the difficult task of building fit-for-user explanations for decision-making models in business, when an explanation does actually make the best impact, and whether bridging AI and OR could help explaining decision support tools and results.

Hands-on examples will demonstrate how to define explanation needs for a given model, activate recommended strategies for generating explanations based on past explanation experience, and how to evaluate their quality from a user experience perception point of view.

2 - Clues on building convincing explanation for your OR results or systems : Knowledge sharing and panel discussion
Anne Liret, Inès Saad, Ilker Birbil

Explainability is the ability of an AI system to explain why it took a certain decision. By introducing AI within OR systems, we expect improving the robustness but we as well add non deterministic behaviour for instance caused by the learning from experience aspect of AI.

The aim of this session is to provide the attendees some insights on the challenges of building a convincing explanation in Operational Research based decision-making systems, some examples and tools that can help, and lessons learnt from practitioners and for practitioners. Time for panel discussion, questions and answers will be reserved so that attendees can share their thoughts and take away useful knowledge.

In the second part of the session, time will be dedicated to a panel discussion. Attendees and subject matter experts will be able to discuss questions such as : What can make algorithms work with human users? Do we need Human-in-the-loop OR for this ? What is the technical ability to even provide explanations ? How do we know that we can trust a decision-making system?

We will hear thoughts and advices from the following panellists :

-Prof. Ines SAAD, professor of Information Systems and researcher at MIS laboratory, at University of Picardie Jules Verne in France. The focus of her research is on the knowledge management, information system and multiple criteria decision making. She has several publications in international conferences and journals. Inès SAAD is also a reviewer in many international journals and conferences such as EJOR, IEEE Transactions on Systems, Man, and Cybernetics, Decision Support System. Ines will share her thoughts about the need to capturing the explanation goals from decision makers and how to use such knowledge to adapt the explanation content and format to the user prefence, and also to generate trust in multi-criteria recommendation tools.

-Prof. Ilker BIRBIL, professor of AI and Optimisation Techniques for Business and Society, at Amsterdam University, Netherlands. Since February 2022, he has been the head of the Business Analytics section of the university of Amsterdam. His research interests center around optimization methods in data science and decision making, interpretable machine learning and data privacy in operations research. Ilker will share about the need for coherent explanation approach aligned with the behaviour of exact and approximative solving methods.

-Dr. Anne LIRET, research manager and principal research lead in sustainable resource optimisation at British Telecom in Paris, France. Anne will speak about the iSee European project on explainable AI and more specifically first how to elevate decision-support tools with the ability of generate explanations that meet users intent, are meaningful in the form and content, second the needs for repository helping practitioners to reuse explanation methods for their needs, to evaluate their quality from user perspective, and to build an adaptable explanation strategy.

■ TB-27

Tuesday, 10:30-12:00 - Room: Maurice Keyworth G.02

Optimization under Uncertainty in Finance

Stream: Stochastic and Robust optimization
Invited session
Chair: *Giorgio Consigli*

1 - Portfolio optimization with asymptotic second-order stochastic dominance
Chen-En Zhao, Wen-Yi Lee

Stochastic programming has been widely employed to address uncertainty in decision-making processes. Robust optimization deals with stochastic programming by encompassing all potential probability distributions; however, it often results in overly conservative solutions. Although distributionally robust optimization (DRO) was introduced to mitigate the over-conservative, recent studies indicate that DRO can still produce conservative outcomes. Furthermore, many DRO approaches rely on symmetric distributional assumptions (e.g., Gaussian) and invoke the central limit theorem, which do not adequately capture risk-averse investors' risk preferences. To address these challenges, this study integrates asymptotic second-order stochastic dominance (ASSD) into a DRO framework. Using the portfolio optimization problem as an example, we demonstrate how ASSD provides a more comprehensive ranking criterion under lognormal returns that better reflects investor preferences and the heavy-tailed nature of financial markets. The proposed method integrates ASSD into a portfolio model under the scenarios within the Wasserstein ball. We employ the Wasserstein distance as the regularization effect for the portfolio. To maintain computational efficiency, a cutting-plane algorithm is utilized to achieve logarithmic-time complexity, thereby ensuring practical feasibility.

2 - Stochastic portfolio optimization with endogenous randomness
Erik Kočandrle, Milos Kopa

Portfolio optimization problems include a random element corresponding to the losses of various assets. The usual assumption is that the randomness is exogenous, meaning that the distribution of losses can not be influenced by the investor's decisions. However, there may be cases where this assumption is not completely sound, for example when we deal with a combination of a large investor and a companies with a small market capitalization, like start-ups for example. We present a portfolio optimization problem with endogenous randomness, minimizing the CVaR risk measure, while assuming that a large enough investment in an asset can alter its loss scenarios and improve performance. After discretizing the possible effects, different partitions of the feasibility set can be constructed based on the investor's budget and market capitalization of stocks. We study the possible changes in portfolio composition under different budgets and strengths of the investor's influence on asset performance.

3 - Multistage Stochastic Optimisation with Fractional Brownian Motion
Gioele Barbano, Vittorio Moriggia, Sebastiano Vitali

Stochastic optimisation problems are greatly influenced by the adopted scenario generation technique and the assumed stochastic process for random variables that represent uncertain parameters. In particular, when it comes to portfolio optimisation, a classical approach to populate the scenario tree of asset returns is to assume that they evolve according to a geometric Brownian motion. However, this hypothesis turns out to be quite unrealistic in financial markets in which asset returns show some persistency in their trends. In this work, we explore the geometric fractional Brownian motion that enables capturing the trend persistency of the asset return. We propose an innovation with respect to a previous algorithm to generate multistage scenarios under the fractional Brownian motion assumption. Moreover, we solve a

realistic multistage portfolio optimisation problem to highlight the differences between fractional and geometric Brownian motion. Graphical and numerical evidence proves that the fractional Brownian motion assumption has a great impact on the optimal solution.

4 - Multiperiod interval-based stochastic dominance with application to dynamic portfolios
Giorgio Consigli

We consider a multi-stage generalization of interval-based stochastic dominance (ISD) principles. The ISD criterion was motivated specifically in a financial context to allow for contiguous integer SD orders on different portions of a portfolio return distribution against a benchmark distribution. A continuous spanning of SD conditions between first-, second-, and third-order stochastic dominance was introduced in that context, relying on a reference point. Here, by extending the partial order to random data processes, we apply ISD conditions to a multiperiod portfolio selection problem and verify the modeling and computational implications of such an extension. Several theoretical and methodological issues arise in this case that motivate this contribution. The problem is formulated in scenario form as a multistage stochastic recourse program, and we study two possible generalizations of ISD principles in which we either enforce ISD constraints on each stage, independently from the scenario tree process evolution, or we do so conditionally along the scenario tree. We present a comprehensive set of computational results to show that, depending on the benchmark investment policy and the adopted ISD formulation, stochastic dominance conditions of first- or second-order can be enforced dynamically over a range of possible values of the reference point, and their solution carries a specific rationale.

■ TB-28

Tuesday, 10:30-12:00 - Room: Maurice Keyworth 1.03

Multi-Agent Systems and Reinforcement Learning for Decision Support

Stream: Decision Support Systems
Invited session
Chair: *Pavlos Delias*
Chair: *Karim Derrick*

1 - Designing an AI-Powered Agent for Personalized Information Security Assistance Using RAG and Fine-Tuned LLMs
Jui-Hsuan Lee, Kuo-Chun Hsu

The growing complexity of information security presents challenges for non-expert users who must manage security tasks without specialized knowledge. This thesis proposes an AI-powered agent that integrates Retrieval-Augmented Generation (RAG) and fine-tuned Large Language Models (LLMs) to provide personalized, organization-specific security assistance.

A key innovation is the unit-specific RAG pipeline, which structures proprietary security policies and compliance documents for precise retrieval. By combining retrieved knowledge with fine-tuned LLM reasoning, the agent delivers context-aware recommendations aligned with organizational policies. Fine-tuning enhances the model's understanding of domain-specific terminology and compliance requirements, ensuring accurate responses.

Additionally, a built-in risk evaluation tool allows users to assess cybersecurity threats through AI-assisted analysis, evaluating factors such as likelihood, impact, and mitigation effectiveness without requiring prior expertise.

Experimental results demonstrate the system's effectiveness in retrieving relevant security knowledge, improving response accuracy, and guiding users through risk assessments. By leveraging AI-driven recommendations, this research enables non-expert users to manage security tasks efficiently while ensuring compliance.

2 - DMACoop: A Multi-Agent Hierarchical Coopetition Framework for Enhanced Investment Decision-Making
Qing Yin, Richard Allmendinger, Sam Veevers, Xian Yang

In recent years, the integration of generative artificial intelligence (GenAI) into financial analysis and investment decision-making has attracted considerable interest. While existing methods have demonstrated promise through cross-functional agent collaboration aimed at achieving collective goals, they predominantly rely on a simplistic agent organizational structure (manager-analyst collaboration), often neglecting the complex dynamics of competition among multiple agents. This paper introduces the Director-Manager-Analyst Coopetition (DMACoop) framework, a novel hierarchical model that more accurately replicates the complex structures of real-world investment firms. The DMACoop framework facilitates optimal investment decisions by promoting cooperation and healthy competition among managers, guided by directors. Each manager leads their analyst teams to focus on specialized functions. Additionally, this framework strategically allocates specific risk-related responsibilities across various levels, enhancing risk-sharing across the hierarchy. We concentrate on the investment decision-making task within private equity firms by evaluating the investment potential of target companies. Our findings demonstrate that our multi-agent coopetition system significantly outperforms traditional collaborative models, delivering superior accuracy, efficiency, and adaptability in complex financial environments.

3 - Fair Compromises in Participatory Budgeting: a Multi-Agent Deep Reinforcement Learning Approach
Hugh Adams

Participatory budgeting is a method of collectively understanding and addressing spending priorities where citizens vote on how a budget is spent, it is regularly run to improve the fairness of the distribution of public money. Participatory budgeting requires voters to make decisions on projects, this can lead to "choice overload". A multi-agent reinforcement learning approach to decision support can make decision making easier for voters by pointing towards voting strategies that increase the amount of their vote that wins. This approach can also support policymakers by highlighting aspects of election design that enable fair compromise. This paper presents a novel, ethically aligned approach to decision support using multi-agent deep reinforcement learning modelling. This paper introduces a novel use of a branching neural network architecture to overcome scalability challenges of multi-agent reinforcement learning in a decentralised way. Fair compromise is found through optimising voter actions towards greater representation of voter preferences in the winning set. Experimental evaluation with real-world participatory budgeting data reveals a pattern in fair compromise: that it is achievable through projects with smaller cost.

4 - Optimizing Professional Judgement in Insurance Risk Assessment: A Hybrid AI Approach Using Evidential Reasoning and Belief Rule Base
Karim Derrick, Xi Liu, Joe Cunningham, Jian-Bo Yang, Dong-Ling Xu

Professional judgement in insurance, legal, and financial risk assessment is inconsistent and subject to cognitive biases, yet remains central to decision-making. Large Language Models (LLMs) offer new opportunities but are probabilistic, prone to hallucination, and lack explainability. This paper introduces SmartRisk, a hybrid AI framework combining LLMs for attribute extraction with a Belief Rule Base (BRB) model and an evidential reasoning engine to improve accuracy, consistency, and explainability in risk assessment.

Grounded in Operations Research (OR), Multi-Attribute Decision Making (MADM), and Evidential Reasoning (ER), we develop a neuro-symbolic decision model integrating expert knowledge with machine learning. Our approach captures the nonlinear nature of risk assessment, supporting uncertainty representation, dynamic evidence updating, and expert-guided optimization.

Empirical trials demonstrate that SmartRisk:

-Eliminates inter-rater inconsistency (expert assessments $\alpha < 0.4$). -Enhances speed—reducing policy and claims analysis from hours to

minutes. -Mitigates AI biases—constraining LLMs to structured extraction and explainable inference.

This research extends OR methodologies into decision automation, showing that hybrid AI frameworks leveraging BRB and LLMs will define the future of intelligent risk assessment—balancing automation, accountability, and optimal decision support.

■ TB-30

Tuesday, 10:30-12:00 - Room: Maurice Keyworth 1.05

Mathematical programming approaches

Stream: Advanced Lot Sizing and Inventory Strategies
Invited session
Chair: Celia Glass

1 - Solving Economic Lot Scheduling Problems by Mathematical Programming
Waldemar Kaczmarczyk

This paper presents a monolithic mathematical programming model for the extended basic period approach to the ELSP under the power-of-two policy. The lot-sizing and scheduling subproblems, usually solved separately, are optimised here simultaneously. A general-purpose solver can solve the proposed model thanks to a reformulation of the total cost function into a quadratically-constrained programming model, tight and explicit modelling of all decisions, symmetry-breaking constraints, and valid inequalities. Computational experiments with several problem instances confirmed that the solver can determine optimal solutions in a few seconds, and simultaneous optimisation of all decisions ensures additional cost savings.

2 - A new sustainable production-inventory model for products with lost sales and time-dependent demand
Joaquin Sicilia-Rodriguez, Luis A. San-José-Nieto, Manuel Gonzalez-De-la-Rosa, Jaime Febles-Acosta

In this work, we analyze a sustainable production-inventory model with a uniform production rate for items whose demand rate follows a power-time function during the inventory cycle. Shortages may occur throughout the product's management period, but these stockouts cannot be retrieved and result in lost sales. The model considers carbon emissions from production, transportation, storage and obsolescence. We study the different scenarios that configure the behavior of the inventory level, and for each of them, determine the costs of production, transportation, maintenance, obsolescence, lost sales and carbon emissions. We formulate a mathematical model to determine the optimal policy that maximizes the average profit of the sustainable production-inventory system. We develop a procedure to obtain the economic production quantity, the optimal inventory cycle, the optimal production period and the maximum average profit. Finally, we provide some numerical examples to facilitate the understanding of the theoretical results developed and the proposed methodology.

3 - The role of underlying mathematical structure in certain lot sizing problems
Celia Glass

In this paper we explore where mathematical analysis can be used to reveal the underlying structure of a problem and hence simplify the approach and extend scope for solution. In the case of Lot Steaming, problems with up to 3 or 4 machines can be solved elegantly. The question here is whether and underlying mathematical structure can be discerned and then exploited for larger problems. For variant objectives for No-Wait scheduling, the complexity of the objective functions has resulted in the use of complete enumeration and consequently restriction to no more than about 12 jobs. Again, we will show the strength of a more mathematical approach to provide insight, simplify solution method and extend the scope of application.

■ TB-31

Tuesday, 10:30-12:00 - Room: Maurice Keyworth 1.06

Robust and Distributionally Robust Optimization - Theory and Applications

Stream: Stochastic and Robust optimization
Invited session
Chair: Yannick Becker

1 - Pareto front for two-stage distributionally robust optimization problems
Filipe Rodrigues, Agostinho Agra

Two-stage distributionally robust optimization (DRO) is a powerful optimization technique to handle uncertainty that is less conservative than robust optimization and more flexible than stochastic programming. The probability distribution of the uncertain parameters is not known but assumed to belong to an ambiguity set. The size of certain types of ambiguity sets - such as several discrepancy-based ambiguity sets - is defined by a single parameter that makes it possible to control the degree of conservatism of the underlying optimization problem. Finding the values to assign to this parameter is a very relevant research topic. In this presentation, we propose an exact and several heuristic methods for determining control parameter values leading to all the relevant first-stage solutions of a DRO model. The applicability of the proposed methods is shown on instances of the scheduling problem.

2 - Integrating Global and Robust Optimisation for Non-Convex Quadratic Programs
Asimina Marousi, Vassilis Charitopoulos

State-of-the-art robust optimisation algorithms for non-convex problems typically rely on global solvers to obtain robust optimal solutions. The prevailing approach involves deriving the dual reformulation utilising a global solver, either directly or adaptively. However, the dual reformulation can increase the problem complexity, and in the case of challenging non-convex problems may only yield a robust feasible solution. An alternative approach is based on an iterative robust cutting plane algorithm. In this case, significant computational time can be spent searching for a global solution that will be deemed robust infeasible. In this work, we introduce a novel algorithm that conducts a concurrent global optimality and robustness search for continuous non-convex problems. The proposed approach integrates spatial branch-and-bound with robust cutting plane algorithms. The key idea is that, while exploring the branch-and-bound tree, we assess the robustness of nodes entailing the best-found solutions. We illustrate the performance and benefits of our proposed approach through benchmark QCQP problems utilising McCormick envelopes to obtain convex lower bounds. The performance of the RsBB algorithm is compared to state-of-the-art methods that rely on global solvers. The findings of our work highlight the efficiency of the RsBB algorithm in terms of computational time and optimality convergence and give insights to the advantages of combining robustness and optimality search.

3 - Decomposition Algorithms, and Convex approximations for Distributionally Robust optimization with Wasserstein Metric
Alban Kryeziu

When dealing with problems where both the model parameters are uncertain and their distribution is unknown, Distributionally Robust Optimization (DRO) is the popular modeling framework to solve such problems. In this paper, we focus on the DRO for the two-stage totally unimodular integer recourse models, where we propose novel approaches for solving such problems. The first two approaches are based on a modified column generation scheme where we iteratively add variables and only optimality cuts to the master problem. The first one is a standard algorithm, whereas the second one is derived

from a result we prove here, and it requires less information about the second-stage value function. The third approach is a regularization scheme where we prove that in many cases the first two methods take a long time to converge, whereas with regularization, we can ensure faster convergence. In addition, we propose a novel pragmatic approach that capitalizes on convex approximations, and we call this a pragmatic approach. We assess the performance of the solutions for these approximations. To this end, we solve a problem of a stochastic activity network and a gas network problem. As an ambiguity set, we consider distributions that lie within a chosen Wasserstein distance from the reference distribution. Our numerical experiments show that the novel pragmatic approach, when compared to the Sample Average Approximation (SAA) and the standard Wasserstein DRO for solving two-stage DRO models

4 - Regret Robust Optimization: A Generalization with Benchmarks
Yannick Becker, Pascal Halffmann, Anita Schöbel

Decision-makers face challenges due to the inherent uncertainties of real-world scenarios. Robust optimization approaches help to find good decisions across all possible scenarios. While most models require that decisions remain feasible for all scenarios, they often have limitations concerning the optimization objective. For instance, the well-known robust min-max optimization concept tends to overrepresent worst-case scenarios and relies on absolute terms. In contrast, regret robustness approaches focus on comparisons against the best decision that would have been chosen if the scenario was known.

In practice, decision-makers often compare their choices against other market players rather than fictional entities. For a more reliable representation of reality, initial approaches to parametrized regret targets exist in the literature for portfolio optimization. Based on this previous work, we generalize the min-max regret robust optimization concept. We formulate regret with benchmarks independently of any specific application by parametrizing the decision space of the regret target. We present key characteristics of benchmark regret robust solutions and compare them with the standard regret approach and min-max robustness.

This generalized approach can be applied across various domains and provides a practical, reliable framework for practitioners, enabling them to develop strategies better suited to navigate the complexities and uncertainties in decision-making.

■ TB-32

Tuesday, 10:30-12:00 - Room: Maurice Keyworth 1.09

Low- and zero-emission solutions for maritime operations-3

Stream: Maritime and Port Logistics
Invited session
Chair: *Kjetil Fagerholt*
Chair: *Peter Schütz*

1 - Wind-assisted ship propulsion technologies: operational and financial conditions to be feasible.
Cristiam Gil

Wind assisted ship propulsion technologies have attracted significant attention as sustainable alternatives to conventional marine propulsion systems. However, the appropriate selection and implementation of these technologies can be heavily influenced by a variety of factors, including their technical characteristics, environmental impacts, associated costs, inherent limitations, and operational settings. This paper presents a comprehensive and innovative financial modeling framework tailored to assess the potential economic and environmental benefits resulting from installing different wind assisted ship propulsion systems on various vessel types. The insights derived from this study provide valuable guidance for stakeholders in the maritime industry, aiding shipowners, investors, and policymakers in making informed decisions regarding the adoption and investment in wind assisted propulsion systems, thereby contributing to the advancement of sustainable shipping practices.

2 - A comprehensive review of assessment methods for green shipping corridors
Sadaf Farboodi, Michael Bruhn Barfod, George Panagakos

Sadaf Farboodi, Michael Barfod, Georgios Panagakos Department of Technology, Management and Economics, Technical University of Denmark, 2800 Kgs Lyngby, Denmark Abstract The maritime sector is transforming to align with the decarbonization targets outlined in the Paris Agreement and the International Maritime Organization's (IMO) 2023 strategy to achieve zero greenhouse gas emissions from ships by or around 2050. Green shipping corridors (GSCs) have emerged as key enablers in this transition, providing structured pathways for deploying zero-emission maritime routes. However, despite the increasing focus on GSCs, a comprehensive and systematic assessment remains underdeveloped. This study reviews existing literature about GSCs to identify the prevailing methodologies and highlight gaps in current research. Employing a systematic literature review approach, the findings from 53 peer-reviewed articles and government publications published between 2019 and 2024 are synthesized. The study examines the evolution of the GSC concept and analyzes the strategic priorities outlined. Also, it reviews assessment methods and frameworks applied to GSCs across different stages, from pre-feasibility studies to impact assessments. The insights provide a foundational step toward implementing an assessment methodology and inform researchers and industry stakeholders to develop evidence-based strategies to advance GSCs.

3 - The Hybrid Electric Aquaculture Vessel Routing Problem
Martin Augestad, Kjetil Fagerholt, Hans Tobias Slette

The aquaculture industry is one of Norway's most important export sectors, and it relies on specialized service vessels to perform maintenance and repairs at offshore production facilities. To overcome environmental challenges, there is a need for a rapid reduction in greenhouse gas emissions from the industry, including those from the fleet of service vessels. This reduction could incur significant costs, making it crucial for the industry to find cost-efficient ways to reduce emissions. This research introduces the Hybrid Electric Aquaculture Service Vessel Routing Problem (HEAVRP), which consists of routing a heterogeneous fleet of hybrid electric service vessels between fish farms to perform service tasks. These vessels can operate on both conventional diesel and electricity from installed battery packs. Charging stations allow vessels to recharge their battery packs with green power, while the conventional machinery provides flexibility in sailing range. The HEAVRP involves determining the routing of the fleet between service tasks, as well as a charging and power management plan (balancing diesel and electricity use) to minimize variable costs of performing service tasks, including penalty costs for unperformed tasks. An arc flow model formulation is proposed, and a computational study is conducted based on realistic data. In addition to a realistic current fleet of hybrid electric vessels, different potential future fleets with larger battery packs are considered.

■ TB-33

Tuesday, 10:30-12:00 - Room: Maurice Keyworth 1.31

Behavioural operations 1

Stream: Behavioural OR
Invited session
Chair: *Xuan Zhao*

1 - Refining demand accuracy for competing retailers
Meng Wu, Xiaoyin Cao, Tian Bai

With recent advancements in technology significantly boosting forecasting accuracy, more retailers are investing in enhancing their forecasting capabilities to reduce demand uncertainty. This paper examines how reducing demand uncertainty affects demand competition between two retailers in a market where competition is driven by their supply levels. Utilizing a mean-preserving approach to characterize uncertainty reduction, we derive equilibrium order quantities and profits. Our findings suggest that while reducing uncertainty can improve supply-demand matching in monopolistic settings—benefiting low and high margin products—it may deteriorate supply-demand matching for medium-high margin products, potentially resulting in profit losses. Importantly, improved demand accuracy does not always translate into a competitive advantage, which contrasts with the notion that lower demand uncertainty is always beneficial in both monopolistic markets and substitution competition.

2 - Resilience and emergency orders: An experimental investigation of newsvendor recourse
B Vipin, Mohd Mujahid Khan

This study experimentally investigates the ordering behavior of newsvendors under the recourse option in both monopolistic and duopoly markets. We design between-subject experiments to compare monopoly vs. duopoly treatments and duopoly at low-profit vs. high-profit margins. In the duopoly market setting, we consider two identical newsvendors selling the same perishable goods in a common market. We use the proportional demand allotment rule. Our results show that market orders systematically deviate from equilibrium, exhibiting a pull-to-center pattern: average orders fall below equilibrium in high-profit margin conditions and above equilibrium in low-profit margin conditions. Under the recourse option, orders in the duopoly market are significantly higher than in the monopolistic market. We also find asymmetry in ordering tendencies at different profit margins. We explain the ordering behavior using a statistical model, which accounts for all the major observations: pull-to-center effects, demand chasing, and asymmetry. Our research highlights the need to model individual and strategic behavior for supply chain resilience and offers strategies for managing supply chain disruptions, especially during costly emergency orders.

3 - Facing asymmetric supply chain disruptions: The moderating role of team familiarity
Jiatian Xie

In many supply chain disruptions, workers must manage complex and dynamic work demands despite having insufficient abilities and resources to handle the interruptions. Most existing research has examined the relationship between supply chain disruptions and operational performance. However, few studies have explored the impact of supply chain disruptions from a social performance perspective. In this paper, we examine how supply chain disruptions in railway systems affect the social performance of workers in digital control rooms. Specifically, we focus on the team level and define social performance as the distribution of task workload among team members, measured using the Herfindahl-Hirschman Index. Drawing on dynamic capabilities theory, we analyze the impact of supply chain disruptions on workload distribution, with a focus on traffic controllers, who are the primary decision-makers in our setting. Our study is based on 160,391 team-15-minute observations collected over 12 months from seven control centers at INFRABEL. We find that a higher concentration of supply chain disruptions leads to greater workload imbalance among team members. Furthermore, team familiarity serves as a moderating factor that mitigates the positive effect of asymmetric supply chain disruptions on workload distribution. Our findings highlight the social implications of supply chain disruptions and emphasize the role of team familiarity in promoting worker well-being.

4 - Transshipment with overconfidence
Xuan Zhao

This paper investigates how overconfidence affects the equilibrium of lateral transshipment systems. We find that overconfidence bias can exert a positive force on the decentralized transshipment system, in contrast to its consistent negative effect on a centralized system. Thus, contrary to intuition, overconfident newsvendors can be better off with a decentralized transshipment practice than a centralized one. Additionally, while conventional wisdom holds that coordinating transshipment prices exist to allow the decentralized system to achieve full coordination (first-best outcome), our analysis reveals that such coordination prices fail to exist when overconfidence bias is high. If this is the case, we show that newsvendors with a high (low) net profit margin benefit more from increased (decreased) transshipment prices. Our findings provide actionable insights on how overconfident newsvendors can design transshipment prices more effectively and suggest when to leverage decentralized transshipment practice depending on the newsvendors' overconfidence bias.

■ TB-34

Tuesday, 10:30-12:00 - Room: Michael Sadler LG10

Advancements of OR-analytics in statistics, machine learning and data science 3

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: *Achal Goyal*

1 - OR - More Than Just Optimisation
Joseph Brennan, Jon McLoone

Wolfram's vision of unified computation is a high-level programming language where any computation you might need is built in and designed to work together without the need for external libraries or programs. While this includes the full range of industrial scale optimization that would be in an OR tool, it extends to include Machine Learning, Time Series, and Image Analysis.

In this talk using live demos, we will show how you can produce new insights and support research workflows from computation through to deployment.

Furthermore having a unified design enables greater automation so OR Researchers can express problems at a higher level with less coding. The talk will be illustrated with examples from many domains including manufacturing, transport and resource allocation, across computations in graph theory, linear and non-linear optimization and system modeling.

2 - Neural Network Optimization using Evolutionary Computation
Ioannis Tsiligkaridis

Optimizing a network model often becomes the primary interest, and if done manually, this can take some substantial effort. Evolutionary algorithms can provide with several optimization patterns that can solve a multitude of problems. The Convolutional Neural Network (CNN) with the convolutional layer works as a filter that tends to excel at learning short sequences. A CNN architecture can be adapted using evolutionary algorithms. To this end GAs are used to encode a sequence of gene defining a CNN model for image classification. Convolutional Autoencoders (CAE) is composed of the standard AE architecture and the convolutional layers. The CAE incorporates convolutional layers to better extract features in images. The construction process for individuals that works with encoder and decoder, includes the creation of the gene sequence and can check for additional layers and provide better performance for a multitude of problems. Experiments with CAE providing the encoding of the architecture into a gene sequence shows the superiority for image classification over the CAE without using the Evolutionary Computation.

3 - Efficient Usage of Machine Learning-Based Approaches to Improve the Solvability of Linear Programming Problems
Ronit Neogy, Jitamitra Desai

Recognizing that the computational time required to solve a linear programming problem can be heavily influenced by the choice of a starting basis (referred to as "warm start"), we apply machine learning techniques to apriori decide the decision variables that are most likely to be part of the optimal basis. Using historical data, several well-known classification techniques, predicted on a detailed feature set, are utilized to determine a near-optimal basis with a negligible inference cost. Furthermore, we supplement machine learning-based prediction models with analytic methods to ensure the validity of the generated starting basis. Problem parameters and their combinations that produce the most effective feature set that can be used to generate a warm-start basis are identified, and our detailed computations show that the use of advanced machine-learning techniques can significantly improve the solvability of linear programming problems.

4 - Joint Issuing and Replenishment for Perishable Products Using Deep Reinforcement Learning
Achal Goyal, Vinay Reddy

Online grocery stores commonly sell perishable products such as bread, milk, and meat similar to brick-and-mortar stores. There is one key difference in the operations of an online retailer and a brick-and-mortar store: the online retailer gets to decide which unit to issue whereas this decision is customer-driven in the case of a brick-and-mortar store. This gives more flexibility to the online retailer as they can now issue the units in First-In-First-Out (FIFO) orders and reduce wastage. However, this could backfire as customers desire freshness. We consider a periodic review inventory model where every period the manager makes two decisions: 1) How much fresh inventory to order? 2) Which units to use to fulfil the demand? A goodwill penalty is incurred upon selling an old unit which increases as the remaining lifetime of the unit decreases. We apply Deep Reinforcement Learning (DRL) in our problem context. The major difference in our study is that the action space is high dimensional due to the presence of issuing as a decision variable. We implement two state-of-the-art policy gradient RL algorithms: Reinforce and Actor-critic. We observe that the algorithms are unstable while training because of the high dimensionality of action space. We explore transfer learning to stabilise the training process and improve performance. Overall, the DRL policy developed in this paper outperforms the existing heuristics.

■ TB-35

Tuesday, 10:30-12:00 - Room: Michael Sadler LG15

Optimization for machine learning and inverse problems

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: *Silvia Villa*
Chair: *Cesare Molinari*
Chair: *Lorenzo Rosasco*

1 - Inertial Methods with Viscous and Hessian driven Damping for Non-Convex Optimization
Rodrigo Maulen

In this work, we aim to study non-convex minimization problems via second-order (in-time) dynamics, including a non-vanishing viscous damping and a geometric Hessian-driven damping. Second-order systems that only rely on a viscous damping may suffer from oscillation problems towards the minima, while the inclusion of a Hessian-driven damping term is known to reduce this effect without explicit construction of the Hessian in practice. There are essentially two ways to introduce the Hessian-driven damping term: explicitly or implicitly. For each setting, we provide conditions on the damping coefficients to ensure convergence of the gradient towards zero. Moreover, if the objective function is definable, we show global convergence of the trajectory towards a critical point as well as convergence rates. Besides, in the autonomous case, if the objective function is Morse, we conclude that the trajectory converges to a local minimum of the objective for almost all initializations. We also study algorithmic schemes for both dynamics and prove all the previous properties in the discrete setting under proper choice of the step-size.

2 - Learning from data via overparameterization
Cesare Molinari, Silvia Villa, Lorenzo Rosasco, Cristian Vega, Hippolyte Labarrière

Solving data driven problems requires defining complex models and fitting them on data, neural networks being a motivating example. The fitting procedure can be seen as an optimization problem which is often non convex, and hence optimization guarantees hard to derive. An opportunity is provided by viewing the model of interest as a redundant re-parameterization - an overparametrization - of some simpler model for which optimization results are easier to achieve. In this talk, after formalizing the above idea, we review some recent results and derive new ones. In particular, we consider the gradient flow of some classes of linear overparamtetrization and show they correspond to suitable mirror flow on the original parameters. Our main contribution relates to the study of the latter, for which we establish well posed-ness and convergence. The results yields insight on the role of overparametrization for implicit regularization and constrained optimization.

3 - Bridging Theory and Practice in Deep Learning Optimization
Kevin Scaman

Despite the high-dimensional and non-convex nature of deep learning optimization, empirical evidence suggests that standard training procedures often succeed in minimizing the associated loss function efficiently. However, existing theoretical analyses either rely on overparameterization or make very restrictive assumptions on loss functions and network structure. In this talk, I will show that a large class of deep learning architectures allow for efficient training beyond the overparameterized regime. In particular, the analysis will rely on a natural extension to the Kurdyka-Lojasiewicz condition, one of the standard assumptions required for non-convex optimization to reach a global optimum, that is verified for a large class of objective losses and neural network architectures.

■ TB-38

Tuesday, 10:30-12:00 - Room: Michael Sadler LG19

Forecasting, prediction and optimization 2

Stream: Data Science meets Optimization
Invited session
Chair: *Ahmed Kheiri*
Chair: *Sven Weinzierl*

1 - Optimizing Forecasting Efforts: Focusing on What Really Pays Off
Johann Robette

Forecasts are central to business decision-making, and improving their accuracy is often seen as a direct path to better outcomes. Many companies pursue ever-higher accuracy, believing that "the sky is the limit." However, research shows that the link between accuracy and business impact is far from obvious. Due to decision-making mechanisms, many forecast improvements generate no tangible value — despite the significant investment they require.

This raises a key question: When is it worth improving a forecast, and when is "good enough" sufficient? Our empirical studies (Foresight Issue 74, JBF Spring 2024) and past conference presentations (ISF 2023, MOFC 2023) demonstrated that in supply chain replenishment, only a small fraction of decisions truly benefited from better forecasts.

Yet, such ex-post analysis is not directly actionable. What if we could predict, in advance, where improving forecasts matters? This would allow companies to focus their efforts, reducing costs and complexity while maximizing business impact.

Existing segmentation methods like ABC/XYZ classifications attempt this, but are they truly effective? Can we do better? And if so, is the juice worth the squeeze?

In this talk, we present findings from our 2024-2025 studies at Vekia and explore how businesses can refine their forecasting strategies and make sure to focus on what really pays off.

2 - Integrated forecasting and optimization in multi-echelon logistics

Vittorio Maniezzo, *Livio Fenga*

The increasing complexity of Large-Scale Retail Trade (LSRT) supply chains calls for efficient multi-echelon logistics optimization. The efficiency of these networks typically depends also on optimized inventory management, transportation, and demand forecasting and can benefit from predictive and prescriptive analytics for cost-effective decision making. This paper presents a novel approach that integrates predictive analytics with optimization to improve inventory allocation through customer demand forecasting. A case study of LSRT logistics is described, requiring demand forecasting, optimization of distribution center (DC) sizing and retailer allocation. The approach uses a bootstrap-based forecasting model for demand data that is seamlessly integrated with a deterministic equivalent optimization component. The analysis is extended to include integer split assignments for scenario validation. The study demonstrates the effectiveness of this combined forecast-optimization pipeline through computational analysis. The results are validated with real-world data and demonstrate practical applicability and superior accuracy and efficiency, thanks to a generally applicable approach not limited to logistics decision making.

3 - Predictive and optimization-based package consolidation for efficient e-commerce fulfillment at Trendyol

Mutlu Soruklu, *Betül Ahat*, *Mert ParÇaoĞlu*, *Fikret Batu Sagay*, *Ahmet Çınar*, *Meltem Sanisoğlu*

In traditional e-commerce fulfillment, each item is transferred individually without consolidation, leading to high shipping costs and inefficient cargo movement. This study proposes a hybrid model that integrates predictive analytics and optimization to improve package consolidation efficiency while ensuring timely delivery. The objective is to consolidate shipments up to a certain deci and price limit, thereby reducing overall logistics costs, holding costs, and partial shipment rates while improving lead times, particularly for shipments from Turkiye to international destinations. The model predicts estimated delivery times to consolidation centers and identifies shipments that might exceed delivery thresholds, preventing consolidation delays and customer dissatisfaction. By analyzing multiple factors of individual shipments such as delivery time, deci and price, the model optimally creates consolidated packages while filtering out delayed shipments. This approach enhances fulfillment efficiency, minimizes unnecessary cargo movement, and optimizes customer experience by reducing partial shipments and improving international lead times. Empirical results demonstrate that prediction-driven package consolidation significantly reduces shipment costs by more than 50% when high customs fees are considered, decreases customer lead times of affected consolidated packages by approximately 25% by filtering out delayed shipments, and ensures a more reliable and scalable fulfillment

4 - A machine learning framework for interpretable predictions in patient pathways: The case of predicting ICU admission for patients with symptoms of sepsis

Sven Weinzierl, *Sandra Zilker*, *Mathias Kraus*, *Patrick Zschech*, *Martin Matzner*

Proactive analysis of patient pathways helps healthcare providers anticipate treatment-related risks, identify outcomes, and allocate resources. Machine learning (ML) can leverage a patient's complete health history to make informed decisions about future events. However, previous work has mostly relied on so-called black-box models, which are unintelligible to humans, making it difficult for clinicians to apply such models. Our work introduces PatWay-Net, an ML framework designed for interpretable predictions of admission to the intensive care unit (ICU) for patients with symptoms of sepsis. We propose a novel type of recurrent neural network and combine it with multi-layer perceptrons to process the patient pathways and produce predictive yet interpretable results. We demonstrate its utility through a comprehensive dashboard that visualizes patient health trajectories, predictive outcomes, and associated risks. Our evaluation includes both predictive performance - where PatWay-Net outperforms standard models such as decision trees, random forests, and gradient-boosted decision trees - and clinical utility, validated through structured interviews with clinicians. By providing improved predictive accuracy along with interpretable and actionable insights, PatWay-Net serves as a valuable tool for healthcare decision support in the critical case of patients with symptoms of sepsis.

■ TB-39

Tuesday, 10:30-12:00 - Room: Newlyn LG.01

Sustainability & Infrastructure Systems

Stream: Sustainable & Resilient Systems and Infrastructures

Invited session

Chair: *Adam Abdin*

1 - Coupled hydrogen and electricity electricity system in Switzerland in 2050: a comprehensive sensitivity analysis

Giacomo Rubino

Hydrogen produced from renewable electricity could enable decarbonisation of industry feedstock and process heat, heavy-duty goods transport, shipping and aviation as well as provide long-term storage to balance volatile renewable electricity. To contribute to the investigation of how hydrogen markets could develop in Switzerland, the hydrogen system composed of power-to-hydrogen (electrolysers), hydrogen-to-power (fuel cells, gas turbines), hydrogen storage (underground caverns, steel tanks) and transport options (hydrogen grid, trucks) was coupled to the spatial-explicit Swiss electricity optimization model EXPANSE. Due to the novelty of such sector-coupled model and the well-known sensitivities of energy modeling to key assumptions, a comprehensive sensitivity analysis was conducted to ensure robustness. We analysed the sensitivity of 11 key input assumptions, including technology costs, electricity and hydrogen import costs, hydrogen demand, and electricity demand, using two distinct methodological designs. First, we used a 2-levels Plackett-Burman fractional factorial design with foldover ("edge design"), which requires 24 model runs to estimate the first-order effects of the assumptions varied. Second, 500 Monte-Carlo runs with uniform distributions were conducted ("space-filling design") to estimate Kernel density distributions and perform further statistical analyses, and to compute first-order Sobol indices. The two methods eventually complement each other.

2 - Assessing the Potential of a Multi-Layer Filtration System to Address TDS and EC Challenges in Treated Wastewater for Irrigation

Syed Muzzamil Hussain Shah

The agricultural sector faces challenges in efficient water management, particularly in arid regions experiencing severe shortages. Treated wastewater (TWW) is increasingly utilized for irrigation to conserve freshwater, offering both benefits and risks due to potential contaminants. This study assessed key water quality parameters—pH, electrical conductivity (EC), salinity, and total dissolved solids (TDS)—in

TWW samples from retention tanks in an irrigation zone in Al-Qatif. A cost-effective, multi-layer filtration system using locally available materials was then tested. The setup included sand, gravel, date palm fibers, and activated carbon, with variables such as filter depth, fiber volume, and media size evaluated over 96 hours, with effluent collected every 24 hours. The sand-gravel (SG) setup improved water quality moderately, achieving 12.8%, 15.36%, and 15.53% removal for salinity, EC, and TDS, respectively. Adding date palm fiber slightly enhanced removal to 17.52% (salinity), 18.62% (EC), and 19.14% (TDS). Incorporating activated carbon yielded the highest efficiencies, reaching 18.14% (salinity), 19.2% (EC), and 19.6% (TDS). However, overall reductions remained modest, with activated carbon providing only incremental gains.

3 - Navigating Complexity: Systems Thinking for Integrated Marine Social-Ecological System Management
Gemma Smith

The management of marine environments, characterised by their complex and adaptive nature, necessitates a robust framework that can effectively integrate natural and anthropogenic components. This research focuses on the application of Systems Thinking to marine Social-Ecological Systems (SES), acknowledging the inherent intricacy and dynamic interactions that define these environments. Specifically, this study demonstrates the application of systems tools and fundamentals. By conceptualising marine systems as shared SESs, we underscore the importance of an integrative and interdisciplinary approach. The research emphasises the application Systems approaches, alongside foundational SES frameworks and principles, to address multifaceted environmental challenges. These challenges include the reduction of complexity, the optimisation of data management, consideration of uncertainties, and the fostering of active stakeholder engagement, all of which are essential for the uptake and operationalisation of Ecosystem-Based Management. It underlines the role of Systems Thinking in navigating the complexities of marine SES, aiming to achieve a balanced and sustainable integration of conservation, societal well-being, and economic objectives. This discussion highlights the potential of a systems approach to enhance decision-making processes within marine management, providing practical guidance for addressing the multifaceted interactions within these ecosystems.

4 - Operations Research for Sustainable Space Operations: Optimizing On-Orbit Servicing Under Uncertainty
Adam Abdin

The rapid expansion of the global space industry—driven by commercialization and the rise of mega-constellations—has introduced new operational challenges for managing space assets. Emerging applications such as space logistics, on-orbit servicing (OOS), and satellite life extension require novel frameworks to optimize high-risk, high-cost operations. This provides new opportunities for operations research (OR) to adapt rigorous methodologies from mathematical programming, stochastic optimization, and combinatorial scheduling to address unique space mission complexities, including orbital mechanics, strict tolerances, and harsh environmental conditions. We illustrate OR's role in enhancing sustainability and resilience of space infrastructures, particularly through OOS logistics, where servicing vehicles (OSVs) refuel, inspect, and maintain satellites. Such operations demand multi-vehicle routing under dynamic orbital constraints and long-term fleet management. As a case study, we introduce a two-stage stochastic programming model optimizing OSV fleet deployment and operations. Strategic decisions (fleet size, depot locations) are made under budget and coverage constraints, while operational uncertainties—client demand, fuel usage, and orbital maneuvers—are managed through scenario-based routing and task scheduling. Our approach demonstrates OR's capability to deliver robust, cost-effective solutions that improve the resilience and sustainability of space systems

■ TB-41

Tuesday, 10:30-12:00 - Room: Newlyn GR.01

OR Innovations in Policy Making - II

Stream: Soft OR and Problem Structuring Methods
Invited session

Chair: Ine Steenmans
Chair: *Irene Pluchinotta*

1 - Cross-sectoral Systems Interlinkages towards Net Zero Strategic Transitions
Ke (Koko) Zhou, Nici Zimmermann, Mike Davies, Irene Pluchinotta

Moving towards net-zero emissions is essential for the UK to achieve significant emissions reductions that benefit long-term sustainability and public health. However, while monitoring frameworks have been developed to support decision-making across various sectors—such as transportation, food, buildings, and energy—there has been limited exploration of how to effectively synthesize and align co-benefits while avoiding unintended consequences. This gap in understanding restricts our ability to place health benefits at the core of decision-making. In our case study, we draw from existing literature and collaborate with the Climate Change Committee (CCC), an advisory group for the UK's net-zero emissions strategy. We mapped out cross-sectoral interdependencies within the system. We identified health-focused narratives that connect different sectors and examine their relationships to health outcomes. We discovered that integrating health equity and socioeconomic considerations into the strategic policy transitions is crucial to ensure the long-term, sustained benefits of health outcomes from such policy changes. We reflected how to engage with policymakers to understand policy narratives and design innovative monitoring frameworks.

2 - A systems approach to enable circular bioeconomy of wellbeing in the Thames Estuary: the REGENYSYS project
Matthew Hutcheson, Joanna Williams, Irene Pluchinotta

REGENYSYS aims to develop a participatory systems mapping approach to understand the challenges and opportunities for a circular bioeconomy of wellbeing (CBW) in the Thames Estuary. Working collaboratively with local stakeholders, the project will co-produce causal maps that reveal system interdependencies and leverage points for transitioning to a CBW.

Through workshops involving food producers, circular bioeconomy businesses, ecosystem managers, and young people as drivers of future transformation, REGENYSYS will map the structure and dynamics of the existing system to assess the potential for a CBW in the region. Initial workshops will generate causal maps to identify factors influencing the CBW transition, followed by validation workshops to refine these maps and deepen understanding of ecological, social, and health interactions. Final workshops aim to identify targeted interventions to drive systemic transformation.

By integrating multiple perspectives and applying systems thinking, REGENYSYS aims to co-produce effective solutions for transitioning to a CBW and support the development of policies that promote ecosystem health and community wellbeing. This research will inform the development of CBW Living Labs in the region to test interventions that foster a regenerative, socially just, and resource-resilient living system.

This talk will outline the research design of the project, highlighting key challenges encountered and sharing preliminary insights.

3 - Integrating Structural Equation Model and Agent-based Simulation for supporting Nexus Policy Design
Laura Selicato, Mohammed Armani, Evangelia Drakou, Charalampos Chalkiadakis, Raffaele Giordano

Achieving a sustainable world requires transformative systemic change at all levels of society and across sectors. The BIOTRAILS project aims to generate knowledge and develop tools to inspire and accelerate this biodiversity-relevant change, using participatory modelling approached - e.g. Participatory System Dynamic Modelling (PSDM) and Agent-based Modelling (ABM). Unraveling the behavioral drivers of change is essential to address the biodiversity-climate-society nexus and identify key pathways for transformative change. This study focuses on integrating the results of structural equation modeling (SEM), used to characterize stakeholders' behavioral intentions towards biodiversity, into agent-based modeling. The agent-based simulation is based on a model built through the classical variables of the Theory of Planned Behavior (TPB) - Attitude, Subjective Norms, and Perceived Behavioral Control - and the latent variables emerged from SEM. By incorporating data-driven variables, we seek to better understand the motivations behind the adoption of sustainable behaviors to inform effective policy design. The integration between PSDM, ABM and SEM will allow simulating and prioritizing policy intervention scenarios. The applicability of the integrated methodology has been tested in the artisanal and small-scale (ASM) Gold Mining value chain in Ghana.

4 - Using Problem Structuring Methods in UK Government to Analyse Environmental, Agricultural and Food Policy Issues
Gary Preece

Biodiversity loss and climate change continue to raise the stakes for environmental, agricultural and food policy across the globe. Issues in these policy areas can cascade across countries and across different sectors of the economy. They can also behave in ways that are complex and unpredictable, with potential solutions contested by actors with conflicting goals.

These policy areas in the UK fall under the remit of the Department for Environment, Food and Rural Affairs (Defra). The Systems Research Programme at Defra provides a dedicated team to support Defra undertake analysis to tackle some of its most complex and intractable problems. This talk will introduce Defra's approach to this analysis, highlight different techniques used and provide reflections on how they can be used to support policy and decision making in complex areas.

■ TB-42

Tuesday, 10:30-12:00 - Room: Newlyn GR.02

Sustainable supply chains III

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: Lea Franze

1 - Examining Facilitators of Social Sustainability in Multi-Tier Supply Chains: An Insight Based from the Manufacturing Sector
Saumyaranjan Sahoo

Over the past few years, Indian manufacturers have become increasingly focused on achieving social sustainability compliance across their multi-tier supply chains. The importance of identifying key enablers cannot be overstated when it comes to enhancing social compliance governance. The primary objective of this paper is thus to determine the enablers that facilitate a focal manufacturer to administer social sustainability across its multi-tier supply chain. The current investigation presents a methodological operations-research based framework for identifying and prioritizing key enablers of social sustainability in a multi-tier supply chain using the best-worst method. The analysis illustrates that the primary drivers of social sustainability in a multi-tier supply chain are extrinsic pressure from stakeholders, institutional self-adoption, and senior management commitment of the focal manufacturer. This study highlights the importance of understanding the impact of various factors on the successful implementation of social sustainability practices in manufacturing companies and their suppliers at different levels of the supply chain. By prioritizing these factors, decision-makers can gain valuable insights into how to effectively adopt and integrate social sustainability guidelines. Prospective investigators have the opportunity to broaden the scope of the current investigation by utilizing various multi-decision making techniques, such as ISM, DEMATEL, and others.

2 - A four valued neutrosophic multi-objective optimization for managing pandemics in a network of healthcare systems
Muhammad Imran, Irfan Irfan

Decision making under uncertainty has been always a challenge due to probabilistic and non-probabilistic behavior of situations. Moreover, most of the models are based on a set of assumptions and unknown parameters, making it difficult for the analyst to incorporate all of them in the decision making. The extent of literature depicts the extensive use of probabilistic models in which their deterministic form employs expected values and standard deviation while ignoring the extreme values. While non-probabilistic models such as fuzzy multi-objective optimization model incorporate extreme values based on the type of membership function used in the model. Most of the fuzzy multi-objective models engage extreme values such as best and worst solutions to cater to uncertainty. However, in addition to the uncertainty the decision-making process the analyst may face the truth, falsity, and contradiction in the results. To deal with this problem this research proposes a four valued neutrosophic multi-objective optimization model. It uses membership function for each objective and each situation such as uncertainty, truth, falsity, and contraction and its final formulation achieves the satisfaction level of each objective. To demonstrate the practical application of the model a case study of healthcare network is presented. The case study is about managing resources in a network of healthcare systems during uncertain situations such as the Pandemic Covid-19. Due to the increased numb

3 - An optimization approach for socially sustainable raw material sourcing in global supply chains
Lea Franze, Karsten Kieckhäfer, Bruna Mota, Ana Barbosa-Povoa

Due to due diligence requirements, social sustainability receives more attention in global supply chains. In the context of sourcing, companies seek sustainable supply sources, engage in supplier development, or invest in raw material mining projects to meet social standards. However, existing literature on supply chain planning rarely studies and oversimplifies socially sustainable raw material sourcing. To fill this gap, we develop a novel approach to support optimal raw material sourcing, combining social life cycle assessment, activity analysis, and multi-objective optimization. The developed multi-period model decides how much raw material to source from multiple sites with varying levels of costs and social risks. To meet social standards and fulfill demand, different measures are explored: commitment to long-term supply contracts, investment in mining projects, and implementation of social supplier development measures. The net present value of these decisions is maximized in the economic objective function, while social risks are limited by constraints or used as a second objective function. The ϵ-constraint method is applied to analyze how different objective functions impact sourcing strategies and supplier development measures in the supply chain of lithium-ion batteries. A key question is: Under which conditions is it beneficial to source from suppliers with low social risks and when to implement supplier development measures?

4 - Planning and Evaluation of Dynamic Inductive Infrastructures on Airport Aprons
Niklas Pöch

With the growing importance of sustainability in the aviation sector due to climate change, electrifying ground vehicles on airport aprons is one way to reduce emissions. Dynamic inductive charging, which charges vehicles wirelessly as they move, is particularly suitable for apron vehicles as it eliminates the downtime associated with charging electric vehicles compared to conductive charging. The design of such

an infrastructure is challenging as both technical and economic constraints need to be considered. We present a model to determine the design of the charging infrastructure while minimising the investment. In order to evaluate the charging infrastructure resulting from the solution of this strategic model, we have developed a model that depicts the operational processes of passenger buses on airport aprons. In this model, the routes of the buses are planned taking into account their battery. With a variable neighbourhood search, we evaluate different charging infrastructures of the strategic decision from the operational perspective and show e.g. the trade-off between the sizing of the charging infrastructure and the batteries of the buses.

■ TB-43

Tuesday, 10:30-12:00 - Room: Newlyn GR.07

Continuous solvers

Stream: Software for Optimization
Invited session
Chair: Julian Hall

1 - Enhancing the HiGHS solvers
Julian Hall

HiGHS has established itself as the world's best open-source software for linear optimization. However, there is still a significant gap between its performance and that of major commercial software. This talk will present work that has been done recently in two areas to reduce this gap. Firstly in interior point methods, where an entirely new solver has been written, and secondly in mixed integer programming, where multi-threading is being used to accelerate the tree search. Other advances in HiGHS will also be presented.

2 - Accelerating Linear Programming Performance: A Hardware-Software Co-Design Approach for the Simplex Method
Kristin Braun, Marcus Bednara, Martina Kuchlbauer, Carsten Sigwarth

Linear programming plays a key role in mathematical optimization, forming the basis for solving a wide range of practical problems. Many real-world applications can be directly modeled as linear programs, while more complex problems, such as Mixed-Integer Programs (MIP) and Mixed-Integer Nonlinear Programs (MINLP), often rely on repeatedly solving linear relaxations. However, CPU-based methods face limitations when targeting extremely low computation times or substantial energy reductions, particularly in edge applications such as real-time robot control.

To address these challenges, we propose a dedicated hardware accelerator for the Simplex algorithm, developed using a hardware-software co-design approach. Specifically, we introduce the Simplex Processing Unit (SXPU), an accelerator for the computationally expensive pricing step in the Simplex method. Our design seamlessly integrates with the open-source HiGHS solver, accelerating the solution of large-scale LP relaxations in MIP and MINLP contexts. The SXPU is primarily designed for ASIC implementation to maximize performance and energy efficiency but also supports FPGA-based prototyping. It achieves significant speedups over software-based approaches, demonstrating its potential for high-performance, energy-efficient optimization in mathematical programming solvers.

3 - Solving LPs using GPUs: a practical review
David Torres Sanchez

In this talk, we will explore the reality of using GPUs to solve LPs from industry problems. Newly developed First Order methods (e.g., PDHG) and the Barrier algorithm can leverage this hardware for performance, but to what extent? And should we all rush to buy the new chips?

4 - CuClarabel: GPU Acceleration for a Conic Optimization Solver
Yuwen Chen

We present the GPU implementation of the general-purpose interior-point solver Clarabel for convex optimization problems with conic constraints. We introduce a mixed parallel computing strategy that processes linear constraints first, then handles other conic constraints in parallel. This mixed parallel computing strategy currently supports linear, second-order cone, exponential cone, and power cone constraints. We demonstrate that integrating a mixed parallel computing strategy with GPU-based direct linear system solvers enhances the performance of GPU-based conic solvers, surpassing their CPU-based counterparts across a wide range of conic optimization problems. We also show that employing mixed-precision linear system solvers can potentially achieve additional acceleration without compromising solution accuracy.

■ TB-44

Tuesday, 10:30-12:00 - Room: Newlyn 1.01

Equilibrium modelling in energy markets

Stream: Energy Economics & Management
Invited session
Chair: Mel Devine

1 - Comparing Risk Measures in Stochastic Equilibrium Energy Markets
Dáire Byrne, Mel Devine

Owing to the energy transition, there is a heightened amount of stochasticity in energy markets. This causes firms to modify their behaviour to mitigate against risk, modelled with risk measures. The impact of implementing risk measures - such as conditional value-at-risk, stochastic dominance, or utility functions - into energy markets is underexplored in the literature. This work aims to address this gap for equilibrium energy markets. It considers an illustrative multi-player problem with market power. Players can purchase units at deterministic costs via a forward, or at stochastic costs from a pool. This leads to four mixed complementarity problems; one risk-neutral, one for each risk measure. The work analyses the impact of risk aversion numerically, assessing how retail prices and profits change. This provides insight into both risk aversion itself, and a lens with which to compare the risk measures. The work highlights how risk aversion interfaces with hedging instruments. Further, it provides an analysis of the computational costs associated with implementing each risk measure. Attention is paid to recasting the MCPs to equivalent convex optimization problems; computational advantages of doing so are detailed. Finally, the work incorporates real data into a related model. With energy market models informing policy and investment decisions and stochasticity continuing to heighten, it is crucial that a deeper understanding of the impact of risk aversion is developed.

2 - Modelling demand- and supply-side investment decisions in an oligopolistic electricity market
Mel Devine, Valentin Bertsch

Meeting carbon reduction targets will require investment in various green technologies, including wind energy, solar PV, and battery storage. In this work, we examine the optimal investment mix for these technologies from the perspectives of both electricity-generating firms and consumers. We develop a game-theoretic optimisation model in which generating firms maximize their profits while consumer groups minimize the cost of meeting demand. All players make hourly operational decisions alongside long-term investment choices. Generating firms may exert market power by strategically adjusting their generation decisions to increase market prices and enhance profits. The model is formulated as a stochastic equilibrium problem, with wind and solar PV uncertainty the sources of stochasticity. We apply our model to a case study of the future Irish electricity system, which is

expected to integrate a significant share of renewable energy. Our results show that market power raises electricity prices, increasing both generating firms' profits and consumer costs. However, it also drives greater investment in renewable technologies and battery storage, ultimately reducing carbon emissions. Additionally, we explore how a rolling horizon approach can assess the impact of retail premia on renewable energy investment.

3 - Risk-aversion and Capacity Remuneration Mechanisms in Electricity-Hydrogen Markets
Kenneth Bruninx, Alessio Berdin, Laurens de Vries, Aad Correljé

Hydrogen and derived fuels may act as long-term energy storage in climate-neutral energy systems. However, risk-averse investors will not invest in sufficient renewable electricity, back-up, electrolyzer and storage capacity if they are only renumerated for the hydrogen or electricity produced. We develop a stochastic equilibrium model to study whether capacity markets can restore investments to their risk-neutral levels. Our results show that the efficacy of capacity markets depends on complementary instruments to ensure the availability of renewables. If risk-averse investors build less renewables than what is societally optimal, capacity markets in the electricity and hydrogen sectors are needed to restore the overall capacity mix and limit consumer costs. If complementary instruments lift investments in renewables to their societally optimal level, a capacity market in the electricity sector suffices. In this situation, an additional capacity market in the hydrogen sector triggers a bias toward hydrogen-fired backup capacity. This illustrates that an integrated systems' perspective is required to design future energy markets.

4 - Environmental policy under risk aversion: Prices versus quantities
Trine Krogh Boomsma, Afzal Siddiqui

Mechanisms to regulate environmental externalities such as can be divided into price instruments and quantity instruments, examples being a tax and a quota system, respectively. In a deterministic setting, both instruments achieve maximal welfare (Kolstad, 2009). In the presence of uncertainty, however, the expected welfare loss may diverge (Weizman, 1974). Here, we take the perspective of a risk-averse regulator that anticipates the behavior of a perfectly competitive industry producing an externality. By establishing a bi-level mean-variance optimization problem for this Stackelberg game, we investigate the impact of risk aversion on the optimal price or quantity regulation and the resulting expected welfare and risk. Under a quantity instrument comparative statics show that the industry output is reduced with the degree of risk-aversion. Somewhat surprisingly, under a price instrument, the tax rate declines and expected output increases with risk-aversion. Furthermore, with a sufficient degree of risk-aversion the welfare loss is always less under the price instrument than under the quantity instrument. In contrast, risk mitigation is more effective under the quantity scheme than under the price scheme.

■ TB-46

Tuesday, 10:30-12:00 - Room: Newlyn 1.07

Tackling Energy Problems with ML and Scarce Data

Stream: Energy Economics & Management
Invited session
Chair: Reinhard Madlener

1 - Mapping the market diffusion of private ev charging in germany: a spatiotemporal model considering regional economic incentives
Reinhard Madlener, Kagan Yüksel, Matthias Nagel

Germany's transportation sector is responsible for roughly one-fifth of the country's greenhouse gas emissions, predominantly from passenger vehicles. Expanding electric mobility is therefore pivotal, yet growth is hindered by limited charging infrastructure—especially private stations that remain understudied due to data scarcity.Employing an Operations Research perspective, we frame the design and placement of private charging stations as a constrained resource allocation problem subject to uncertainties in demand, cost considerations, and spatial limitations. Advanced machine learning methods help address gaps in the underlying data and refine our decision-making framework. Specifically, a Spatio-Temporal Graph Convolution Network is used to integrate annual public charger data, housing characteristics, and socioeconomic factors. This approach, combined with adjacency-based cluster detection and scenario analyses (e.g., varying electricity prices and subsidies), infers private-charger adoption patterns and identifies critical drivers of growth. Results emphasize the significance of targeted infrastructure investments and supportive policies to alleviate range anxiety and spur home-based EV uptake. By yielding data-driven insights into charging station dynamics under sparse information, our study guides policymakers in designing strategies aligned with Germany's climate targets and the evolving landscape of electric mobility.

2 - Forecasting the diffusion of residential photovoltaic systems in austria: an agent-based modeling approach
Kagan Yüksel, Reinhard Madlener, Seif Marji

Austria aims for 100% renewable electricity by 2030, placing residential solar PV at the center. However, PV adoption modeling is hampered by inconsistent records and limited policy insights, leading to data scarcity. We address these issues through data augmentation and scenario-based analyses in an agent-based OR framework that accounts for financial, social, and environmental factors influencing household decisions across diverse demographic and geographic contexts. Drawing on fragmented time-series (2008-2023), our method reconstructs missing information and refines parameters, enabling robust forecasts of PV adoption from rural to urban regions through 2050. Results indicate that falling system costs and subsidy programs will expand PV uptake, though scenarios vary with shifts in subsidies and household incomes. Enhanced datasets improve predictive accuracy, particularly in underrepresented urban areas, revealing substantial opportunities as costs decline. By reconciling data gaps and evaluating multiple adoption trajectories, this framework provides actionable insights for policymakers seeking to design effective incentives and target high-potential regions. This study demonstrates how innovative OR techniques, including data augmentation under scarce conditions, deliver evidence-based guidance for energy transitions. The findings underscore the need for flexible, data-focused strategies to sustain Austria's renewable goals despite some serious market hurdles.

3 - Assessing the Environmental Kuznets Curve through Spatial Econometric Analysis
Michaela Chocholatá

Despite ambitious global sustainability goals, environmental degradation remains a pressing challenge, particularly in rapidly developing regions. The Environmental Kuznets Curve (EKC) hypothesis suggests an inverted U-shaped relationship between economic growth and environmental degradation. However, traditional EKC models often overlook spatial dependencies and interregional spillovers. Using European regional data, this paper examines local spatial patterns by testing for general spatial trends in the distribution of the variables analysed at the regional level. The analysis confirms that the spatial interactions of the regions under consideration are an important factor influencing the level of environmental degradation. Spatial autoregressive (SAR) models were estimated and spatial spillovers were calculated. Our results highlight the need for spatially coordinated policies and interregional cooperation to ensure sustainable development beyond the conventional EKC paradigm. This paper was supported by the Grant Agency of Slovak Republic - VEGA 1/0047/23 "The importance of spatial spillover effects in the context of the EU's greener and carbon-free Europe priority".

4 - Batteries without borders: Battery-as-a-Service meets energy sharing in energy communities
Sharif Khaleghparast, Somayeh Torkaman

Energy communities (ECs) coordinate energy sharing, granting participants market-free access to use local renewable generation assets while contributing to the socio-economic benefits. These benefits grow with batteries, yet their high capital costs limit investments to minimal capacity presumed to achieve high utilization. However, battery utilization generally underperforms regardless of the adopted capacity. This resource inefficiency stems from treating batteries as a product; that is, the battery capacity is strictly reserved for the battery owner's energy. Battery-as-a-Service (BaaS) is an alternative model that keeps ownership with the battery owner while making surplus capacity available to others. BaaS intensifies energy sharing by granting participants access to each other's battery capacity and letting the EC coordinate battery charging and discharging through explicit capacity sharing. However, it is still unclear how BaaS affects various performance indicators of the energy system. We evaluate BaaS against Battery-as-a-Product across EC operations under different battery scale and ownership scenarios. We employ an agent-based model comprising the EC, participants, and the grid operator to simulate the interactions, including the EC coordination in the day-ahead horizon and the energy delivery behind the low-voltage feeder. Our analysis clarifies how BaaS influences resource efficiency, collective self-consumption, financial returns, and grid congestion.

■ TB-47

Tuesday, 10:30-12:00 - Room: Parkinson B08

Avoiding Food Waste

Stream: Retail Operations
Invited session
Chair: *Sandra Zajac*

1 - Integrating perishables' shelf life into assortment optimization
Mariana Sousa, Dorothee Honhon, Pedro Amorim, Sara Martins, Maria João Martins dos Santos

Retailers' product mix selection is a key determinant of market share, profitability, and long-term success. While a broader assortment increases the likelihood of meeting diverse customer preferences, it raises inventory-related costs and stockout risks, ultimately affecting operational performance and customer loyalty. This challenge is amplified for perishable goods, where limited shelf life narrows the selling window and increases spoilage risks. Despite extensive research on assortment optimization, existing models fail to integrate perishability dynamics. The few studies that consider shelf life treat it as a constraint rather than a factor influencing substitution patterns and retailers' profitability. However, ignoring perishability can lead to suboptimal product selection, excessive waste, and lost revenue. This study introduces an assortment optimization framework that integrates remaining shelf life into decision-making. Unlike conventional models, it accounts for shelf-life-sensitive demand and substitution effects, helping retailers balance waste reduction, profitability, and service levels. Using historical data from a European grocery retailer, we assess the framework's effectiveness and quantify the profitability and waste gap. Our findings highlight the importance of shelf life in assortment planning, introduce new heuristics for perishable product selection, and offer actionable insights to improve retail efficiency, sustainability and financial performance.

2 - Joint Pricing and Ordering to Reduce Food Waste Considering Strategic Consumers Behavior
Geun Ho Yang, Byung Do Chung

Retailers in the food supply chain struggle to manage inventory efficiently due to perishability and short shelf life. Dynamic pricing is one of the alternatives to address this challenge, as it helps control demand by considering the decreasing valuation of the product. However, overlooking strategic customer behavior in dynamic pricing may lead to significant losses for retailers. Accordingly, this study addresses the problem of joint three-period pricing and inventory management considering the strategic customer. To the best of our knowledge, this study is the first to address this problem under endogenous stochastic demand. Given the potential non-concavity of the problem, we propose a heuristic algorithm to improve computational efficiency. In numerical experiments under various scenarios, the proposed algorithm demonstrates faster computation and comparable optimal profit relative to an exhaustive search-based algorithm. Furthermore, our findings confirm that the joint pricing and inventory management approach effectively improves profit and reduces food waste.

3 - Impact of pricing and replenishment decisions on food waste at stores and households
Bouchra Bacha, Yann Bouchery, Mohamed Zied Babai, Zied Jemai

A strategy often used by retailers to reduce in-store waste of perishables consists of discounting the less fresh products. However, this strategy can lead to excessive purchase of less fresh products, which ends up in household waste disposal. The perishable inventory literature often ignores this phenomenon, i.e., the waste at households, by considering only in-store waste. In this article, we investigate the impact of the selling price and ordering decisions on food waste at the store and in households for perishable products with fixed lifetime. We consider a periodic order-up-to-level (OUTL) inventory control policy where the demand is modeled using customer choice behavior derived from a utility function that incorporates household waste. The selling price and OUTL are determined with the objective of maximizing the expected profit. Through a numerical investigation, we show that setting the right order-up-to level and pricing increases the profit by 4% and reduces the total food waste by 21%. Moreover, we show that raising consumer awareness of food waste has a positive impact on the store profit, which increases by 17%, and on consumer consumption, with a 34% reduction in household waste, and on the environment, with a 12% decrease in the total waste.

4 - Spoiling a Surprise to Reduce Spoilage? The Impact of Partial Disclosure of Surprise Bags Contents
Ilgin Efe Senyuva, Bram De Moor, Zumbul Atan

Surprise bags — opaque bundles of perishable products sold at a fraction of their regular price — are widely used by retailers to generate revenue from near-expired items and reduce spoilage. Traditionally, retailers only disclose the discounted price and the original retail value of these bags, leaving consumers unaware of the specific contents. The composition of surpise bags may significantly influence consumer satisfaction. A well-balanced bag with complementary items may be preferred over a higher-value bag that contains a single product or substitutes. Dissatisfied consumers may ultimately discard undesired items, transferring store waste to households and reducing long-term customer retention. To maintain sustainable revenue streams and effectively minimize waste, retailers must ensure consumer satisfaction. If the consumer does not make a completely blind choice, and has an idea about the contents of the bag, the informed choice will lead to a higher satisfaction and a better match between the consumer and the retailer. This study explores the impact of disclosing partial information about the contents of surprise bags, thereby improving the match between consumer preferences and available products. We compare retailer profitability and waste reduction against a scenario where no information is revealed and analyze the conditions under which disclosure is beneficial — or not.

■ TB-49

Tuesday, 10:30-12:00 - Room: Parkinson B10

Analytics and the link with stochastic dynamics 2

Stream: Analytics
Invited session
Chair: Gerhard-Wilhelm Weber
Chair: *Ulrike Leopold-Wildburger*
Chair: *Helper Zhou*

1 - Data-Driven Prediction of Heating Cable Degradation: A Case Study on Trace Heating Systems

Jyrki Savolainen, Ahsan Muneer

Industrial trace heating systems provide freeze protection in cold climates and maintain constant temperatures for liquid transport. However, heating cables degrade over time, leading to high-impedance, low-current faults and leakages. This study presents a data-driven approach to detecting early signs of cable degradation using an industrial dataset, consisting of five years of data with around 150 million rows for each year, recorded at intervals of few seconds, covering 694 active heating circuits and 50 variables per circuit. This study conducts two analyses based on cable type. First, degradation detection for Mineral Insulated (MI) cables is performed using K-means clustering and Isolation Forest to identify faults that occur when current is switched on after prolonged use, potentially causing overheating or insulation breakdown. The performance of both methods is compared. Second, temperature lag analysis for self-regulating (SR) cables is conducted using eXtreme Gradient Boosting (XGBoost) to detect abnormal correlations between applied current and temperature response, indicating broken cables. To the best of our knowledge, this is the first application of predictive maintenance techniques for trace heating systems. The results demonstrate that data-driven analytics can effectively identify early signs of degradation, offering industrial operators a practical approach to reducing downtime and maintenance costs.

2 - Forecasting Automobile Demand: Spatiotemporal and Hierarchical Modeling, Life Cycle Dynamics, and User-generated Online Information

Tom Nahrendorf, Stefan Minner

In the automotive industry, accurate demand forecasting is crucial for informed medium-term decisions on volume planning and optimized pricing strategies. This study forecasts monthly car demand in a multi-product, multi-market environment, focusing on product life cycles, spatiotemporal correlations across regions, and the complex hierarchies in demand data. We employ machine learning-based multi-step time series forecasting methods, including a hybrid of exponential smoothing and recurrent neural networks, as well as LightGBM ensembles with various pooling strategies. We also provide stochastic forecasting extensions using quantile regression and apply optimization-based hierarchical reconciliation. These methods are benchmarked against traditional statistical models. We collected data from a leading German car manufacturer and evaluate forecast error using the weighted root mean squared scaled error, along with a prescriptive evaluation for a newsvendor problem. Our methods achieve an 8.55% improvement over the company benchmark. We find that life cycle curves exhibit exponential growth and decline phases, with multiple peaks during maturity, challenging classical product life cycle models. Weighted life cycle features are identified as key demand indicators, along with product stock information and configurator website visits. These findings highlight the effectiveness of the demand forecasting approach and offer a robust framework for optimizing supply chain decisions.

3 - Sequential adaptive exponential smoothing

Alisa Yusupova

Exponential smoothing remains one of the workhorses of business forecasting. ES models used in practice implicitly assume that the characteristics of the time series are constant over time. This is not necessarily true as the disruptions caused by the COVID pandemic and the war in Ukraine have illustrated. This has caused renewed interest in developing models that optimally adapt to events such as persistent or transient changes, while making best use of available historical data. In this work we introduce a state-space based ES formulation in which events can occur at each time-step. The model is recursively estimated using ideas from sequential Monte Carlo (SMC), which allows the continuous updating of estimated parameters, and favors models that can explain better the observed data. It combines the benefits of using maximum likelihood to obtain estimates of the smoothing parameters, and the benefits of MC to infer quantities like the probability of an event at a given time point.

■ TB-51

Tuesday, 10:30-12:00 - Room: Parkinson B22

Multiobjective discrete optimization

Stream: Multiobjective and vector optimization
Invited session
Chair: Clemens Thielen

1 - Lagrangian Relaxations for Multi-Objective Discrete Optimization Problems

Mariagrazia Cairo, Lavinia Amorosi, Dell'Olmo Paolo, Serpil Sayin

The majority of the algorithms for Multi-Objective Discrete Optimization (MODO) problems relies on scalarizations of the problem and investigations in the objective space. Although branch and bound techniques are highly effective in single-objective optimization, Multi-Objective Branch and Bound (MOBB) methods have only emerged recently. Bounding is one of the most challenging aspects in MOBB where the classic single-objective concept of a bound is substituted by the concept of a bound set [2]. Lagrangian relaxation is a technique that is known to outperform linear programming-based bounds in single objective branch-and-bound methods. Recent studies have shown that Lagrangian relaxation has the potential to provide tighter bound sets than linear programming relaxations also for MODO problems. This is due to their ability to reach the interior of the feasible region. An appropriate choice of the lower bound set is important for the performance of MOBB methods: improved lower bound sets reduce the area where possibly new non-dominated points could be found [1]. This talk investigates the potential and effectiveness of Lagrangian relaxation within a MOBB setting. The results of preliminary computational experiments are discussed. [1]Bauß, J., et al., Adaptive improvements of multi-objective branch and bound, arXiv:2312.12192 preprint, 2023 [2]Dunbar, A., et al., Relaxations and duality for multiobjective integer programming, Mathematical Programming, 207(1):577-616, 2024

2 - The Evolution of Exact and Approximate Linear-Parametric Optimization and Its Connections to Multi-Objective Optimization

Alina Wittmann, Levin Nemesch, Stefan Ruzika, Clemens Thielen

In linear-parametric optimization, multiple objective functions are combined into a single objective function using linear combinations with parameters as coefficients. The goal is to find a set containing an optimal solution for every possible combination of parameter values. For more than 60 years, linear-parametric optimization has been an important research area with numerous links to adjacent fields in optimization and a wide range of application areas. Among other relations, the optimal solution set of a parametric optimization problem can be characterized as the set of non-dominated extreme points of the corresponding multi-objective optimization problem. In the multi-objective literature, the parameter set is called the weight set. Hence, concepts

from one field can be applied to the other. In this talk, we present our literature review of theoretical developments and exact and approximation algorithms for linear-parametric optimization problems. While existing overviews on parametric optimization are mostly concerned with parametric mixed integer linear programming, the focus of our literature review is on general, problem-agnostic approaches and results for parametric variants of specific problems, in particular, well-known combinatorial optimization problems. We compare these methods with important results from related fields to point out that some algorithms were preceded by similar algorithms from linear-parametric optimization.

3 - Beyond monolithic solvers: Solving multidisciplinary optimization problems in a cooperative fashion
Dimitri Rusin, Manuel López-Ibáñez, Joshua Knowles, Ali Hassanzadeh

High-stakes applications of multiobjective discrete optimization often require that a system be fully optimized without knowing its full formulation. Instead, the formulation is fragmented into two or more components that depend on each other, yet must be optimized consecutively or in parallel.

Such applications can be formulated as multidisciplinary optimization models, also known as interwoven systems, which can be naturally decomposed into (at least) two components. We seek a set of solutions that is Pareto optimal with respect to both components.

Two components interact: On the one hand, the first component can propose a baseline solution that will allow the second component to be optimized independently. On the other hand, if the first component slightly tweaks its baseline solution, the second component's optimized solution can become suboptimal.

In this talk, we study this interaction in the context of the Travelling Thief Problem. The Travelling Thief Problem famously models an interaction between the Travelling Salesman Problem and the Knapsack Problem. Even if we can solve both of these individual single-objective problems efficiently, it is not obvious how to integrate these efficient solvers into an efficient solver of the aggregated multiobjective optimization problem.

We present first results of our study of the relationship between the number of interaction rounds and the achieved Pareto efficiency gap.

■ TB-53

Tuesday, 10:30-12:00 - Room: Liberty Moot Court

New Trends in Game Theory V

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Prem Prakash Mishra*
Chair: *Mauro Passacantando*

1 - Emergent Behaviour in Stochastic Queueing Systems
Geraint Palmer, Vincent Knight

Motivated by students attempting different strategies when trying to find study spaces in our university mathematics building across different floors, we present a queueing system where customers jockey and renege according to some strategy that they have chosen. In a system where customers can adapt and change their strategies according to the outcomes of the population they interact with, we are interested in finding emergent behaviour, that is a stable population of strategies. First we present a novel queueing model that described the process of finding study spaces in the building. We then present an efficient tool for finding emergent behaviour in stochastic, simulatable systems, called Discrete Event Population Updates (DEPU), that combine discrete event simulation with game theoretic tools. We then apply DEPU to the queueing scenario, demonstrating how DEPU finds emergent behaviour.

2 - Zero-Sum Deterministic Differential Games Involving Continuous and Impulse Controls"
Hafid Lalioui

This paper investigates a new class of deterministic differential games (DDGs) in which an optimal switcher competes against a controller-stopper over a finite time horizon. These games are motivated by real-world scenarios in advertising and stock management, with potential applications in operations research. Several examples with numerical tests are provided. We primarily derive the corresponding Hamilton-Jacobi-Bellman-Isaacs dynamic programming equation (DPE) and establish the viscosity characterization of the two value functions as the unique viscosity solutions to this equation. We then extract an equilibrium strategy using a convergence result for an approximate value function, which serves as the unique solution to an approximate DPE. Consequently, we develop a policy and value iteration-based computational algorithm derived from these theoretical results.

3 - Mean-variance payoff applied to Stackelberg games
Alberto Pinto

The novelty consists in using the usual mean-variance payoff in mathematical finance, instead of the usual expected value payoff in game theory. We completely characterize the best response of the leading firm, uncertain in the intersect demand, depending of the risk aversion parameter of the payoff. We prove the existence of a threshold value, such that for less risky firms do not enter in dumping for uncertain small intersect demands.

4 - Will Competitors Give Hands? A New Role of Physical Publishers in the Anti-Digital Piracy Deadlock
Xiaotong Du

Digital piracy significantly challenges online sellers and digital platforms, incentivizing them to combat piracy. However, under competition from physical publishers, online sellers and digital platforms may pass the buck on antipiracy actions due to disagreement in profit-sharing, leading to an antipiracy deadlock. We examine the impact of antipiracy actions by online sellers or platforms on stakeholders and analyze how this can be leveraged to resolve such the deadlock. We construct a Stackelberg game model, wherein the physical publisher first determines physical product output, followed by the online seller's digital product output decision, to explore the interactions between antipiracy action and the firms' profits. Our study finds that, in a market with antipiracy action, the increased competitiveness of digital piracy (digital products) does not uniformly harm (enhance) the profits of the online seller and platform. When antipiracy deadlock arises, under low (high) commission rates, the physical publisher, either individually or jointly with the platform (online seller), subsidizes the online seller (platform) to combat piracy and resolve the deadlock. Under moderate commission rates, insufficient cooperative subsidies from the physical publisher and online seller may fail to incentivize platform-led antipiracy action; in turn, the platform has both the incentive and ability to subsidize the online seller individually, which also can resolve the deadlock.

■ TB-54

Tuesday, 10:30-12:00 - Room: Liberty 1.08

Stochastic Models and Simulation

Stream: Stochastic modelling
Invited session
Chair: *Lidia Malizia*

1 - Simulation-based evaluation of well-being practices in Public Administration
Lidia Malizia, Pasquale Legato, Rina Mary Mazza

Occupational safety and health is a concern for employers and employees worldwide. Many countries have defined acts, fixed requirements and/or developed national standards for this purpose that apply to all sectors of activity, both public and private. Evaluating the responsiveness and commitment to improving workplace safety and health is also a key issue. With respect to this matter, we pursue a simulation-based approach meant to assess the impact of introducing interruptions in the daily work schedule of the employees in an Italian public administration. The focus is on the practices of a public university in compliance with the related EU and national legislative framework. Specifically, voluntary breaks of window tellers are investigated via a what-if analysis. The aim is to evaluate how break occurrence, in terms of both frequency and duration, affects process quality and overall system performance. Model calibration is carried out under the random arrival of service requests, while accounting for the teller's vigilance decrement. The latter is based on a leaky integrator logic that mimics (human) resource depletion-replenishment. We report on our current experience and discuss preliminary numerical results.

2 - Using GANs for the hourly shapping of renewables in Monte-Carlo simulations
Geoffroy Chaussonnet, Andreas Eppler

In this paper we applied generative adversarial network (GAN) to shape the hourly production of solar and wind power in Germany for mid-term Monte-Carlo simulations. In Monte-Carlo simulations with a forecast horizon up to the liquid horizon (ca. 3 years), renewable production is usually expressed by the ratio of production normalized by the installed capacity. This gives the advantage of choosing different trajectories for the renewable production market shares. In a stochastic approach, the daily renewable production ratio can be easily mimicked by simple distributions, which constitute a first step of modeling. To model the hourly granularity, there are two major caveats. First, hourly shapes cannot be easily described by simple distributions to match the moments and the autocorrelation. Second, as the hourly shape is also a ratio, multiplying the hourly shape by the daily ratio can lead to production ratio above one. To solve these two points, a GAN is employed as a shaping engine. It takes renewable daily ratios and behavioral features (dates and holidays) as input and produce multiple hourly shape for each technology. It is shown that this approach generates realistic hourly shapes, in terms distribution, autocorrelation and technology cross correlation.

3 - An Accelerated Static Hedging Method for the Analytic Valuation of American Options
Lung-fu Chang, Jia-Hau Guo, Mao-Wei Hung

This article proposes an accelerated static hedge portfolio (SHP) method for evaluating American options based on stochastic volatility and double jump processes. Our proposed model is a generalization of the static hedge portfolio approach of Derman, Ergener, and Kani to evaluate American options by utilizing the Richardson extrapolation. Numerical results demonstrate that the numerical efficiency of our accelerated static hedge portfolio approach is comparable to the least-squares Monte Carlo simulation method. Numerical results reveal that our proposed method is efficient and accuracy in evaluating American options with stochastic volatility and double jump processes.

■ TB-55

Tuesday, 10:30-12:00 - Room: Liberty 1.09

Robust and Stochastic Models in Disaster Management

Stream: Humanitarian Operations
Invited session
Chair: Kamran Sarmadi

1 - Capacitated Relief Provision Planning for En Route Refugees with Probabilistic Movements
Eda Yücel, Amirreza Pashapour, Dilek Gunnec, Sibel Salman

The number of refugees enduring international displacement has alarmingly doubled over the past decade, reaching nearly 37.9 million individuals by 2024. Massive refugee movements force them into dire living conditions with severe inaccessibility to essential services and resources. Humanitarian organizations are pivotal in alleviating the migration adversities of en route refugees through relief aid provisioning interventions, an area where academic approaches are seldom explored. We aim to address the cost-efficient fulfillment of recurring needs for geographically dispersed refugee groups migrating toward safe destinations. Here, capacitated mobile facilities are tasked with delivering relief aid to refugee groups periodically to ensure equitable service frequency. We introduce this problem as the Capacitated Mobile Facility Location Problem with Uncertain Mobile Demand (CMFLP-UMD). We model CMFLP-UMD as a Markov decision process (MDP) with probabilistic refugee movement behaviors. To solve this problem, we develop an approximate policy iteration algorithm. For decision-makers in relief organizations, we also present a state-dependent variable threshold policy that quickly attains high-quality relief provision plans. Our proposed methods are tested on the recent Syria-Türkiye migration crisis case study instances. The findings reveal the managerial benefits of adopting our approaches and provide guidelines for future refugee migration crises.

2 - Integrating Heterogeneous Suffering in Disaster Response: A Robust Estimation and Optimization Framework
Yuxin Hong, Ning Zhu

The increasing frequency and severity of natural disasters present significant challenges for effective humanitarian logistics, especially in the aftermath of the disaster. In this paper, we propose a joint vehicle routing and supply allocation model that integrates an extended area-level Deprivation Cost Function (DCF) to mitigate human suffering. Moreover, we incorporate regression residuals to capture heterogeneity in suffering, thereby providing a nuanced assessment of population-level impacts and enhancing resource prioritization for vulnerable communities.To address estimation uncertainties inherent in data collection and the potential ambiguity in residual distribution,we propose a robust satisficing model that accounts for these uncertainties and approximates it as a finite-dimensional program. Leveraging the structure of the cost function, we develop an efficient L-shaped method and introduce a conservative approximation to enhance computational scalability. Extensive numerical experiments validate the algorithm's efficiency and demonstrate the model's robustness in mitigating estimation errors and distribution ambiguities.The comparison of different strategies reveals that accounting for heterogeneous suffering leads to more balanced and effective relief operations. Additionally, strategically prioritizing aid to less resilient areas, even at the cost of moderate distribution imbalances, significantly reduces extreme suffering without compromising overall fairness.

3 - The Canadian Traveler Problem with Drone Reconnaissance
Joris Wagenaar

In this paper, we explore cooperative routing of a truck and drone under uncertain infrastructure environments, a novel problem in humanitarian logistics relevant to disaster management. Road network statuses are often initially unknown and revealed incrementally post-disaster, impacting first-responder aid distribution. The objective is for a truck to arrive as fast as possible at its destination to provide humanitarian supplies. Similar to the Canadian Traveler problem, each edge's traversal time is known, but whether it is blocked becomes clear only when the truck or drone visits an adjacent node. We propose policies for both, leveraging a drone's reconnaissance to scout road conditions and update the truck's path.

Three policies are developed for the truck: the Shortest Path policy, assuming all edges are unblocked; the Travel Alternative Diversity policy, incorporating backup paths; and the Shortest Path Waiting policy,

balancing route selection with drone updates. Drone policies vary in scouting order—following the truck's route, prioritizing edges near the destination, or focusing on network-critical edges.

Computational results show significant reductions in truck travel time using drone-assisted routing across simulated and real-world networks. Our findings highlight how network characteristics and disaster scenarios influence policy performance, demonstrating the benefits of drone-assisted routing for disaster response under limited information.

4 - A Distributionally Robust Approach for Urban Search and Rescue Location-Routing Problem
Kamran Sarmadi, Mehdi Amiri-Aref

We address a multi-period location-routing problem under uncertain demand and travel times in disaster management. Our proposed optimisation model integrates strategic facility location with dynamic routing to guide search-and-rescue teams post-disaster. We use a distributionally robust optimisation framework with joint chance constraints to enhance tractability via Bonferroni's inequality and constraint approximation. The methodology is tested on a case study in Santa Cruz County, California, a region prone to earthquakes. Numerical results highlight how our method aids decision-makers in optimising facility placement and team deployment to maximise rescue rates in uncertain environments

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■ TB-56

Tuesday, 10:30-12:00 - Room: Liberty 1.11

Multi-Period Vehicle Routing Problems

Stream: Vehicle Routing and Logistics
Invited session
Chair: Leonor S.Pinto

1 - Smarter demand allocation: Improving our VRP solver by redistributing demand between depots and delivery days
Michael Sutherland, Louisa Sober, Ying Tan, Jessica McQuade, Adil Rahman

In this presentation, we explore two key extensions to our ALNS-based vehicle routing optimiser, enhancing its flexibility while maintaining efficiency and scalability. These extensions—depot volume balancing and delivery day balancing—allow logistics networks to adapt dynamically to fluctuating demand.

The depot volume balancing extension addresses peak demand periods where depot capacity is exceeded. To manage this, we developed methods for reallocating customers between depots, ensuring a more balanced order distribution. While the primary goal was feasibility, empirical results showed cost reduction in certain depot pairs, suggesting even their well-established assignments can benefit from optimisation.

The delivery day balancing extension investigates whether adjusting customer delivery days within a weekly schedule can improve routing efficiency. Unlike depot balancing, this extension is embedded within the core ALNS framework, leveraging parallelisation to explore a vast solution space efficiently. Experimental results for this extension were promising, demonstrating cost savings across a variety of different depots.

These extensions improved both feasibility and cost-effectiveness, demonstrating how targeted optimisation enhances logistics performance. This talk will provide insights into the methodologies, challenges, and impact of these approaches, offering practical takeaways for large-scale routing problems.

2 - Choice-driven periodic vehicle routing and pricing
Chenghua Yang, Jie Gao, Bilge Atasoy

This study addresses the tactical decision-making challenges faced by Logistics Service Providers (LSPs) that are periodically supplying heterogeneous business customers (e.g., restaurants, hotels, cafes). Customers exhibit distinct preferences for delivery service characteristics, such as price, frequency, time of day, and time window length. LSPs aim to maximize their profit and their profitability relies on personalized service recommendations and reasonable pricing to attract customers while maintaining cost-efficient operations. Leveraging customer information at a disaggregated level enhances the accuracy of service customization and pricing strategies. To this end, we propose a choice-driven optimization framework that integrates advanced discrete choice models into the Periodic Routing and Pricing problem to optimize the system across multiple objectives.

We formulate the problem as a stochastic bi-level optimization model, where the LSP (leader) anticipates customer (follower) reactions based on a random utility maximization model. To handle the random term in the utility function, we apply a sample average approximation and reformulate the problem as a single-level mixed-integer linear program. Experimental results demonstrate that explicitly considering customer behavior at the disaggregated level prevents profit overestimation and helps improve service levels and overall profitability.

3 - A Periodic Vehicle Routing Problem with Delivery Workers and Service Choice
Antonia Ilabaca, Germán Paredes-Belmar, Giovanni Campuzano

Urban logistics is increasingly challenged by the growing demand for e-commerce, traffic congestion, and sustainability concerns. Efficient last-mile delivery is crucial for reducing operational costs, enhancing service levels, and minimizing environmental impact. This study examines a real-world distribution issue based on a food delivery company in Viña del Mar, Chile, where vehicle capacity, work shifts, and urban accessibility restrictions limit deliveries. We extend the Periodic Vehicle Routing Problem with Service Choice by incorporating multiple delivery workers who complete the final segment of deliveries on foot from designated parking locations. To optimize the weekly distribution schedule, we propose an integer linear programming formulation and develop a Two-Step Black Widow Optimizer to effectively solve large-scale instances. Preliminary results indicate that our approach significantly reduces total distribution time while improving coordination between vehicles and delivery workers.

4 - A multi-trip vehicle routing with release dates and interrelated periods
Leonor S.Pinto, Raquel Bernardino, João Janela, Carlos Lúcio Martins, Cândida Mourão, Filipe Rodrigues

A new vehicle routing problem (VRP) variant is presented, motivated by a car components distribution to repair centers (warehouses). The problem is named the multi-trip VRP with release dates and interrelated periods (MTVRP-RDIP). The routes may start at different predefined periods and may have different durations. Thus, two routes that start at different periods may be active at the same period, leading to the so-called interrelated periods. Moreover, the availability of a vehicle to start a route at a period depends on the existing vehicles but and on the active routes at that period. The clients are classified according to their importance and represent warehouses that require car components that are made available throughout the time horizon, leading to the release dates. Delays in satisfying client orders and not serving orders in the time horizon result in penalty costs that must be minimized. The objective to minimize also includes routing and vehicle utilization costs. Two metrics are defined to compute an order's delay, each leading to a different model. Computational results showed that only one model is suited to address the smallest instances. A rolling-horizon matheuristic that iteratively solves the better model was designed. The matheuristic provides feasible solutions for all test instances in an efficient manner that are, on average, better than the ones provided by the model in most of the compared key performance indicators.

■ TB-58

Tuesday, 10:30-12:00 - Room: Liberty 1.13

Inventory Routing

Stream: Vehicle Routing and Logistics
Invited session
Chair: Amira Dems

1 - Adaptive Policies for the Stochastic Dynamic Multi-Period Inventory-Routing Problem
Francisco Maia, Gonçalo Figueira, Fábio Moreira

The Stochastic Dynamic Inventory-Routing Problem (SDIRP) is a fundamental problem within supply chain operations that combines inventory management and vehicle routing while addressing the dynamic and stochastic nature of customer demands. This research aims to provide new insights into resolving an SDIRP, focusing on a central warehouse that periodically distributes homogeneous goods to geographically dispersed customers. Decision-making involves a three-step policy: calculating a delivery priority for each customer, determining delivery quantities based on an (s, S) inventory rule, and computing a vehicle route with an exact method. A simulator was developed to replicate the problem's dynamics and enable policy training and evaluation across various scenarios. The priority rule is computed as a combination of key features extracted from the problem instances. The way those features are combined into the policy is determined by two evolutionary methods: Genetic Programming and Genetic Algorithms. Our policies were evaluated on instances with up to 50 customers and 20 periods, considering multiple demand uncertainties, holding and shortage costs, and vehicle capacities. The results highlight a competitive performance in total cost reduction compared to several myopic and direct lookahead benchmarks, enhancing stock balance and minimizing travel distances.

2 - Multi Product Inventory Routing in Hospitality Deliveries
Lukas Seeholzer, Pieter Vansteenwegen

The multi product inventory routing problem with pickup and delivery is based on a case study in the hospitality industry. Multiple suppliers need to deliver their products to multiple customers over several time periods. Optimization opportunities arise when cooperations between the stakeholders enable the consolidation of deliveries to reduce the total number of delivery routes, km travelled, and vehicles used. Simultaneous inventory management at the customers offer additional room for optimization in the time dimension. A mathematical model is presented as well as experiments showing its limitations even on very small instances. For more practical applications, a variable neighborhood search is presented. The option to combine deliveries both over different vehicles as well as over time makes this an inherently challenging problem and asks for smart local search moves that take advantage of the problem structure. Preliminary experiments show promising results for instances of realistic sizes.

3 - The Distributionally Robust Cyclic Inventory Routing
Menglei Jia, Albert Schrotenboer, Ahmadreza Marandi, Feng Chen

This study addresses the cyclic inventory routing problem (CIRP), where the proposed cost-optimal solution on joint inventory replenishment and vehicle routing is cyclic, enabling repetitive execution over an infinite planning horizon. We allow ambiguity in the probability distribution of the stochastic demands faced by retailers, leading to a min-max expectation structure for inventory cost optimization and chance constraints structure that ensures the delivery plan in each period is feasible with a given probability. To solve this challenging problem, we perform exhaustive mathematical analysis to simplify the structures, enabling a tailored nested branch-and-price framework that decomposes the problem into mixed-integer linear subproblems solvable with standard optimization techniques. Within this nested framework, we propose three service policies that unify existing CIRP approaches and extend state-of-the-art inventory policies from the inventory management literature. Extensive experiments validate the effectiveness of our distributionally robust CIRP using both synthetic datasets and real-world data from an industry partner.

4 - Inventory Routing with Heterogeneous Vehicles and Backhauling
Amira Dems, Farzad Avishan, Yossiri Adulyasak, Okan Arslan, Jean-François Cordeau

Motivated by a real-world problem faced by Hydro-Quebec, a large Canadian utility, this study investigates an inventory routing problem involving the efficient distribution of commodities to sites and the backhauling of materials from these sites to the depots. We provide a mathematical formulation, introduce valid inequalities, and solve the resulting model using a branch-and-cut algorithm. To tackle large-size instances, a two-phase decomposition matheuristic is developed that solves the assignment and routing problems iteratively. This study is the first to consider multiple depots, split delivery, heterogeneous vehicles, multiple products, and backhauling in a single model, presenting both exact and heuristic solution methods to solve the problem. The heuristic algorithm solves the synthetic instances in less than two hours with an average optimality gap of less than 2%. Finally, a case study is conducted on the Hydro-Quebec commodity distribution and hazardous material backhauling network to demonstrate the real-world applicability of the model. We show how the company may benefit from integrating the delivery and backhauling networks. Our proposed model reduces the total routing costs by 21% compared to the case where backhauling is not integrated and split delivery is not allowed.

■ TB-59

Tuesday, 10:30-12:00 - Room: Liberty 1.14

Transportation applications

Stream: Transportation
Invited session
Chair: Alberto Tamburini

1 - Optimizing the transport supply planning of a metro line
Alexandre Orhan

Optimizing automated metro line transport is crucial for balancing efficiency and service quality. When supply and demand misalign, passenger comfort, environmental sustainability, and costs suffer. Automated metros can flexibly adjust to actual passenger flow, enhancing network performance. Previously, a major European transport operator planned supply (schedules, intervals, time periods) using standardized or historical assumptions that didn't reflect real-time demand. This created imbalances like overestimating off-peak needs or peak overcrowding, leading to resource waste or poor passenger experience. The challenge was modeling passenger flow and integrating predictions into optimized supply plans while respecting constraints like train capacity and time-period transitions. The solution used two steps: First, passenger flow modeling utilized historical data with exogenous variables (day of week, events) and lagged variables (station dependencies), capturing temporal and spatial variations with improved accuracy on nominal days using median-based typical profiles. Second, transport supply optimization considered train intervals across peak, off-peak, and transition periods. Using simulated annealing over a full day, this approach produced operational solutions maximizing comfort while maintaining density thresholds, with computation times suitable for real-time implementation.

2 - Distributed Workforce and Machine Rostering: A Multi-Criteria Approach
Daniel Miodowski, Martin Scheffler, Aron Lange

Companies in the German railway construction industry face the challenge of coordinating machines and workers across different construction sites. Motivated by operational practice, we present two mathematical formulations to address an integrated machine routing and worker rostering problem. Given a set of construction orders distributed across multiple locations, our primary objective is to maximize the number of completed orders within a fixed planning horizon. Each order consists of multiple shifts, requiring the assignment of a worker and machines. All shifts within an order must be covered with the required resources to be considered complete. Beyond the primary objective, we account for secondary goals, such as minimizing transport distances, reducing worker travel times, and assigning workers to shifts with their preferred machines. To tackle this problem, we introduce a network flow model based on traditional routing and flow formulations and an assignment-based model commonly used in rostering problems. Both serve as the foundation for constraint programming approaches. Our comparative analysis demonstrates that the assignment-based formulation outperforms the network flow formulation in maximizing the number of completed orders. When incorporating secondary objectives in a two-step multi-objective approach, constraint programming for the assignment model yields higher-quality solutions, whereas the mixed-integer programming model provides tighter bounds.

3 - Enhancing Efficiency in Extra-Port Depot Logistics Chains to Reduce Demurrage Costs
Astrid Oddershede, Cexcilia Montt, Luis Quezada, Pedro Palominos, Felisa Cordova

This study examines the logistics of empty container management in a company with the goal of reducing demurrage costs and maintaining client confidence. Delays in container delivery often stem from inefficiencies across the logistics chain, beginning with a vessel's arrival at port and extending through land transportation and deconsolidation at off-dock facilities. The objective is to redesign these processes to minimize demurrage charges, enhance customer service, and promote sustainability by optimizing land transport and reducing unnecessary trips and vehicle idling. A thorough diagnosis of the current workflow was conducted using simulation and Business Process Management (BPM) methodologies to pinpoint inefficiencies in container reception and dispatch. The proposed process redesign focuses on improving planning, coordination, and information flow across the supply chain. As a result, the system is expected to achieve more efficient logistics management, reducing empty container delivery delays from 5.6% to 2%.

4 - A bi-objective tramp ship routing and scheduling problem to accelerate shipping sustainability transition
Alberto Tamburini, David Pisinger, Aurore Wendling, Nina Lange

We consider a bi-objective Tramp Ship Routing and Scheduling Problem in which we plan routes for a fleet of tramp shipping vessels using a rich model. The two objective functions are maximizing profit and minimizing greenhouse gas (GHG) emissions. The rich model can handle speed optimization, chartering costs, and bunker planning. The single-objective model is efficiently solved using column generation, where the columns represent the possible routes of a vessel, while the master problem keeps track of the binding constraints. The pricing problems are solved using time-space graphs. The bi-objective model is solved iteratively using the [U+03F5]-constraint method. The mathematical model is mainly composed of perfect matrices. We use this property to design an efficient solution method. We compute the Pareto front for 10 different historical scenarios between 2021 and 2023, showing that emissions can be reduced on average by more than 10% with less than a 2% profit decrease and by 20% with a 5% profit decrease. Then, we compute the Pareto front with alternative fuels-engine combinations, obtaining emissions reduction of over 40% with less than a 5% profit decrease. For smaller vessels, we tested wind-assisted and wind-propelled alternatives. Finally, we compare the results with GHG tax levies, showing that these solutions are strongly dominated by the Pareto fronts we compute.

■ TB-60

Tuesday, 10:30-12:00 - Room: Western LT

DEA under uncertainty

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: *Aliasghar Arabmaldar*

1 - Fuzzy measures for fuzzy hierarchical data envelopment analysis
Shiang-Tai Liu

Data Envelopment Analysis (DEA) is an effective method for evaluating the performance of decision-making units (DMUs). Many enterprises have units under their jurisdiction that may include further subunits, using inputs allocated by their parent units to produce various outputs. The sum of all sub-unit outputs constitutes the parent unit's output, indicating a hierarchical relationship between units. Such systems can be referred to as hierarchy systems. In a DEA model, estimating data in practical applications is sometimes necessary due to difficulties in precise measurement. In such cases, fuzzy values can replace the input and output items. Therefore, how to calculate the efficiency scores of fuzzy hierarchical DEA under fuzzy conditions is a worthy topic for research. When both input and output values are fuzzy, the developed fuzzy hierarchical DEA efficiency scores will vary with changes in the efficiency frontier. In calculating the fuzzy hierarchical efficiency scores, it is essential to consider the relationship between the simultaneous changes in input and output values. This paper aims to derive minimum and maximum efficiency scores under varying observational values, allowing the computation of fuzzy hierarchical efficiency scores' membership functions at multiple levels. The fuzzy hierarchical DEA efficiency scores obtained in this study will also be fuzzy numbers, which align more intuitively with problem-solving and provide more information for decision-making.

2 - Enhancing Robust Efficiency Assessment in Data Envelopment Analysis Under Uncertainty
Aliasghar Arabmaldar

This paper introduces two novel robust data envelopment analysis (DEA) models to enhance efficiency assessment under uncertainty. The first model employs a correlated budgeted uncertainty set, capturing dependencies among uncertain parameters for more realistic evaluations. The second model leverages order statistics uncertainty, improving robustness by considering worst-case scenarios based on ranked data. A theoretical analysis establishes the properties and advantages of these models, demonstrating their effectiveness in addressing different uncertainty structures. To validate their performance, a comparative example benchmarks the proposed models against the conventional budgeted uncertainty set approach. The results highlight their strengths in providing more reliable and adaptable efficiency assessments. By integrating correlated dependencies and ranked uncertainty considerations, the proposed models advance robust DEA methodologies, offering valuable insights for decision-makers in uncertain environments.

3 - Measuring the Malmquist Productivity Index Incorporating Probabilistic Variations in Data
Yu Zhao

The Malmquist Productivity Index is a widely used tool for evaluating productivity growth. In this study, we address the probabilistic variations present in input-output data and propose a forest-based sampling approach to account for the statistical properties of efficiency scores when constructing the Malmquist Productivity Index. To capture the underlying probability distributions, we classify observed decision-making units (DMUs) into clusters and optimize information gain within each cluster using a Gaussian-based entropy function. Additionally, we discuss the decomposition of the Malmquist Productivity Index into catch-up and frontier-shift components, along with the construction of confidence intervals for these components. The effectiveness of the proposed method is demonstrated through both simulated and empirical datasets.

4 - Nonconvex centralized allocations with multiple technologies
Giovanni Cesaroni

Until recently, the literature on centralized resource allocations (CRA) within non-parametric methods was mainly characterized by the assumption of a common convex technology shared by a set of decision-making units (DMUs) under control of a given planner/manager, and determined by means of the Data Envelopment Analysis (DEA) technique. On one hand, the seminal contribution of Fang (2013), and that of Lozano (2014), extended this convex approach by considering the existence of multiple technologies in the set of DMUs under analysis. On the other hand, Cesaroni (2024) introduced an explicit solution for the CRA of a set of DMUs sharing a common nonconvex technology, such as the free disposal hull (FDH). The purpose of the present work is extending the nonconvex CRA to the case of multiple technologies. Besides determining the aggregate technology in the presence of multiple FDH technologies, we develop the optimization program as a MILP problem, which is simpler and allows to substantially reduce the number of binary decision variables when compared with the approach of Fang (2013) and Lozano (2014). We perform computations on a data set describing a multi-input and multi-output technology relating to Italian local public transit. In particular, following Lozano (2014), we compare the results and the computational features of nonconvex CRAs obtained under either a common or multiple technologies.

■ TB-61

Tuesday, 10:30-12:00 - Room: Maurice Keyworth G.31

Addressing behavioral issues of real-world problems 2

Stream: Behavioural OR
Invited session
Chair: Judit Lienert

1 - Communicating model uncertainty for decision support in seasonal climate forecasting services
Andrea Taylor

Climate information services aim to support organisations in making choices about how to manage climate variability and change. At seasonal timescales climate forecasts might be used to inform a range of preparedness decisions across different sectors. However, uncertainty arises in this information due to both the probabilistic nature of the forecasting models themselves, and the fact that forecasting models do not perfectly reflect physical systems. As forecast models sometimes underperform historical observations as an indicator of future conditions, it is important that users understand both forecast probabilities and model performance ('skill'). We report on findings of experiments with engaged climate information users (n=84) and European decision makers in climate sensitive sectors (n=122), exploring different approaches to communicating forecast likelihood and forecast skill. Participants were presented with visualisations with probabilities represented using map icons, tables, violin plots and bar graphs, and forecast skill with numeric values, verbal categories and colour-saturation. Objective understanding, perceived usefulness, preference and familiarity were assessed. We find that 1) tables are best understood with respect to likelihood information, 2) preference is positively associated with familiarity but not understanding, and 3) non-specialists struggle to interpret low-skill forecasts. We discuss practical implications for communication.

2 - Behavioural dimensions of avalanche forecasting
Ian Durbach

Public avalanche forecasts are published daily during winter in many countries. These forecasts are made by a team of expert forecasters who combine daily field observations about the current snow conditions with a range of other information, including the output of mathematical models. In this talk I describe a collaborative project with the Scottish Avalanche Information Service that aims to develop new statistical models to better understand the judgemental processes behind avalanche forecasts; to understand how avalanches, when they occur, affect later forecasts; and to use this understanding to design interventions that improve forecasting practice.

3 - Towards participatory decision support for decarbonisation planning
Valentin Bertsch

Climate change is one of the most pressing challenges of our time. To support energy-related decarbonisation decision-making and limit the effects of climate change, researchers have developed and used highly sophisticated energy system models (ESMs) for decades. Most prominently, (mixed-integer) linear optimisation models are used to identify cost-minimal energy systems that meet the energy demand and a number of further constraints such as decarbonisation targets. Real-world systems, however, are typically characterised by a multitude of heterogenous actors, uncertainties, many criteria beyond costs playing a role, and indeed identifying and implementing a global cost optimum is neither necessary nor realistic. ESMs are therefore being extended to offer multi-objective optimisation (MOO) and modelling to generate alternatives (MGA) to handle multiple criteria, such as resource constraints, supply risks or equitable distribution beyond costs and emissions. However, such methods are typically not yet applied in a truly participatory way, i.e. engaging stakeholders from beginning to end. To achieve this goal, combining ESMs with approaches from MCDA can help support structured interaction with stakeholders and elicit their preferences in practice. This work provides an overview of the state-of-the-art in this field and addresses research requirements, including the consistent consideration of uncertainties and the needs for interfaces to link these models and methods.

4 - A review indicates low stakeholder participation and use of behavioral OR in MCDA applied to environmental problems
Judit Lienert

Aim of this critical review of 118 articles was to gain an overview of the state of the art of multicriteria decision analysis (MCDA) applied to environmental problems. The articles stem exclusively from Operational Research (OR) and Management Science (MS) journals. Here, I will focus on participatory stakeholder processes and aspects especially relevant to behavioral OR. Although most articles addressed a practice case, around one third did not document any interaction with stakeholders in a real-world case, but used data from earlier cases, or fictitious data. Interactions were with only a few experts in many articles, and not with a broader, representative group of stakeholders. Adequate problem structuring in the early MCDA steps was generally neglected, or possibly not well documented. Main focus of preference elicitation was on weights, and less on other preference parameters. Often, it was unclear how weights were elicited and from whom. Only around one quarter of the 69 publications with real-world interaction mentioned behavioral aspects such as learning, preference elicitation, people's cognitive limitations, or biases. Documentation of post-MCDA processes such as giving feedback or policy implementation were also rare. I will conclude with some discussion points concerning a possible future research agenda, which includes strengthening behavioral OR in application cases, and joining efforts across disciplines to develop protocols and standards of documentation.

Tuesday, 12:30-14:00

■ TC-01

Tuesday, 12:30-14:00 - Room: Great Hall

Francesca Maggioni

Stream: Keynotes
Keynote session
Chair: Milos Kopa

1 - Bounding large-scale optimization problems under uncertainty
Francesca Maggioni

Many real world decision problems are dynamic and affected by uncertainty. Stochastic Programming provides a powerful approach to handle this uncertainty within a multi-period decision framework. However, as the number of stages increases, the computational complexity of these problems grows exponentially, posing significant challenges. To tackle this, approximation techniques are often used to simplify the original problem, providing useful upper and lower bounds for the objective function's optimal value.

This talk explores methods for generating bounds for a wide variety of problem structures affected by uncertainty. We begin by discussing bounds based on scenario grouping under the assumption that a sufficiently large scenario tree is given but is unsolvable, both in the context of stochastic programming and distributionally robust optimization. Next, we extend these techniques to address more complex problems, including multi-horizon stochastic optimization and decision-dependent stochastic optimization.

Finally, the talk introduces the integration of these bounding methods with Benders' decomposition, demonstrating how this combination can substantially reduce computation times and enhance the stability of the algorithm.

By exploring these approaches, the talk aims to inspire further advancements and innovative solutions in tackling large-scale optimization problems under uncertainty

■ TC-04

Tuesday, 12:30-14:00 - Room: Rupert Beckett LT

ORS Meet the Editors Session

Stream: OR Journals
Invited session
Chair: Thomas Archibald
Chair: Konstantinos Nikolopoulos

1 - UK OR Society Journals - Meet the Editors
Thomas Archibald

This session, hosted by the Chair of the OR Society's Publication Committee, brings together Editors from across the OR Society journal portfolio. Each editor will briefly introduce their journal's scope, what makes it distinctive, and the types of papers that would be successfully published. They'll also highlight emerging themes, current trends, and offer practical advice on what makes a strong submission and common pitfalls to avoid. The Editors will also dive into how people can get involved with the journals, such as joining the editorial teams or as reviewers. They will also give guidance on what they look for when reviewing a manuscript. A short overview from Taylor & Francis will cover key author support services, open access options, and how they help increase visibility for published work.

The session will conclude with a panel Q&A and discussion, offering attendees the chance to ask questions and raise broader issues, such as the role of Generative AI in peer review.

2 - EiC Journal of Business Analytics
Dursun Delen

EiC Journal of Business Analytics

3 - EiC Applied Operations and Analytics
John Fowler

EiC Applied Operations and Analytics

4 - EiC Journal of the Operational Research Society
Martin Kunc, Konstantinos Nikolopoulos

EiC Journal of the Operational Research Society

5 - EiC Health Systems journal
Daniel Gartner

EiC Health Systems journal

6 - EiC Journal of Simulation
Navonil Mustafee

EiC Journal of Simulation

■ TC-07

Tuesday, 12:30-14:00 - Room: Clarendon GR.01

Portfolio Risk Management

Stream: Risk Management in Commodities and Financial Markets
Invited session
Chair: David Neděla

1 - Applicability of intraday entropy for high-frequency trading eliminating overnight anomaly
David Neděla, Aleš Kresta

This paper investigates the application of entropy on intraday data of stocks within the S&P 500 index to aid in preselecting assets for portfolio construction. In particular, we propose a new performance ratio incorporating intraday entropy, which is also used as a preselection tool. By analyzing the entropy performance ratio, we aim to identify stocks that exhibit desirable characteristics for portfolio inclusion, using a simple naive portfolio scheme to achieve a balanced allocation. Furthermore, we evaluate portfolio performance statistics to assess risk-return profiles. To ensure the robustness of our approach, we analyze the impact of different entropy computation settings and assess the marginal contribution of preselected assets to portfolio performance. These supplementary analyses demonstrate the adaptability and reliability of entropy-based preselection in diverse market conditions.

2 - Exploring Determinants of Dynamic Stochastic Dominance Ratios: A Causal Approach Using Explainable AI
Jurgita Cerneviciene, Audrius Kabasinskas, Milos Kopa

Various financial ratios are recognised as elements that determine investment decisions, making it essential to identify what factors influence these ratios. The calculation of a ratio is often depicted as a relationship, often in the form of a fraction or percentage, and demonstrates the frequency with which one item is included inside another. The limitations of causal relationships that are derived from observational data are, however, frequently disregarded. We employ structural causal modelling to ascertain the inherent relationship between performance and risk metrics and the dynamic stochastic dominance ratio, as well as how this causal framework influences investment product selection. The dynamic stochastic dominance ratio is an attractive tool for ranking assets with respect to basic stochastic dominance principles. The findings indicate that the extreme Gradient Boosting

(XGBoost) technique outperforms the quantile regression method in predicting the dynamic stochastic dominance ratio. To interpret the significance of features, the Shapley Additive Explanations (SHAP) method is employed. The results substantiate the causal importance of dynamic stochastic dominance ratio elements and show the significance of distributional characteristics (Kurtosis) and risk metrics (Max Drawdown and Expected Shortfall) in determining the stochastic dominance ratio. Our research is essential for linking stochastic dominance theories with empirical validation beyond mere correlation

3 - Optimizing high and low ESG portfolios with DCC-GARCH models and graph theory
Pilar Gargallo, Manuel Salvador, Jesús Miguel, Luis Lample

This study proposes a network theory-based approach to portfolio optimization, combining advanced statistical techniques with graph analysis. To achieve this, we use VAR-DCC-GARCH models to capture the dynamic correlations between assets and construct an undirected graph where connections reflect significant relationships. Additionally, we apply the Granger causality test to generate a directed graph that identifies predictive links between assets. The combination of both approaches results in a directed and weighted graph, on which we implement filtering and clustering techniques to select the assets that will compose the portfolio based on their ESG values. The weights of the selected assets are assigned using the Minimum Variance Portfolio model, allowing for risk minimization without compromising expected returns. Furthermore, we compare the performance of portfolios with higher and lower exposure to ESG assets to assess whether investments with strong sustainability criteria yield better risk-return outcomes. Finally, we analyze the temporal evolution of the networks and their impact on portfolio composition, evaluating performance through financial metrics.

■ TC-08

Tuesday, 12:30-14:00 - Room: Clarendon SR 2.08

MCDM for project portfolio problems

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Maria Barbati

1 - Portfolio selection in blockchain environments
Grzegorz Miebs, Jonas Gehrlein, Matteo Brunelli, Milosz Kadzinski

We consider a problem arising in proof-of-stake blockchain environments where agents called nominators are actively engaged in the selection of validators (the agents called to run the physical infrastructure of the blockchain). In an incentive system, nominators' revenues are related to the performance of validators that they selected, and in this setting, the nominators are faced with a portfolio selection. In fact, it is a multicriteria portfolio of portfolios problem. Firstly, the validator evaluation itself is multicriteria regarding criteria like the commission rate, cluster size, self, stake, etc. Then nominators' are supposed to nominate selected validators. Finally to diversify multiple stashes with different fractions of the total stake might be created by a single user, each with a different subset of validators. We propose a two-stage solution, the first one based on a pairwise comparison scheme is used to learn preferences regarding the evaluation of a single validator. The second utilizes a multicriteria optimization to find the best portfolio of portfolios regarding the quality of validators and diversification of the funds.

2 - Balancing Priorities: MCDA for Sustainable Coastal Tourism Development
Maria Zulfaqar, Cristina Maxim, Alexandros Paraskevas

Coastal regions are globally recognized as prominent and economically vital tourist destinations, significantly contributing to local and national economies. Coastal tourism has become integral to the livelihood of many coastal communities, prompting research into challenges such as overcrowding, natural resource protection, human well-being, and long-term economic viability. The UK's coastal regions face challenges like economic decline, air pollution, and land contamination, necessitating economic, social, and environmental interventions. Sustainable tourism planning requires a strategic, long-term approach and the involvement of multiple stakeholders. Our proposal advocates for establishing a multi-stakeholder forum, comprising local communities, government agencies, the corporate sector, and civil society, to collaboratively develop sustainable tourism strategies. By employing portfolio selection and multi-criteria decision analysis (MCDA), we demonstrate evaluation and prioritisation of various tourism development options, ensuring balanced consideration of economic, social, and environmental factors. This is a work in progress showing interim findings along with future plans for further modelling and validation.

3 - A Stochastic Supplier Portfolio Model Utilizing Conditional Value-at-Risk
Garima Mittal, Nitin Sahu

Supplier selection and order allocation represent critical decision-making processes in supply chain management. These tasks are inherently challenging due to the presence of uncertainties that can significantly affect both efficiency and reliability. Addressing these complexities requires an approach to account for possible risks, thus enhancing the robustness of the supply chain. In this study, we propose a bi-objective supplier selection model under stochastic uncertainty. Specifically, we use an important financial risk management concept, Conditional Value-at-Risk (CVaR), to address the risk associated with the attainment of two objectives, namely total profit and quality levels of the supplier portfolio. The model also integrates several practical constraints expressed as chance constraints to address the uncertainty in parameters. The proposed stochastic model is solved by formulating its deterministic equivalent. The proposed model addresses the operational risks while enhancing the resilience, efficiency, and sustainability of supply chain operations. It further provides a strategic methodology for making resilient supplier selection and order allocation decisions under uncertainty. A numerical illustration highlighting the practical applicability of the proposed model and approach is also provided in the study.

4 - A Multi-Objective Portfolio of Portfolios Problem with Qualitative Performance Assessments
Maria Barbati, Salvatore Greco, José Rui Figueira

We introduce a multi-objective decision-aiding model for selecting a portfolio of projects along with a specific allocation of resources to each project. This model optimizes a set of objectives, with the projects contributing to these objectives in diverse ways. The resources considered for the portfolios are evaluated using both qualitative and quantitative criteria. Projects are eligible for inclusion in the portfolio only if they satisfy established criteria based on threshold values. Our model is flexible enough to accommodate temporal factors and uncertainty, making it applicable to various real-world scenarios. To find solutions to our portfolio problem, we adopt an interactive multi-objective approach that combines the selection of projects and resources. After the initial selections, we engage the Decision Maker (DM) to assess the portfolios. From the preference information provided by the DM, using Dominance-based Rough Set Approach, we induce "if ..., then ..." decision rules expressed in natural language, that, after approval by the same DM are used in an interactive multiple objective optimization procedure permitting to select the most preferred solution. We demonstrate the effectiveness of our model with a case study that highlights its practical applications.

■ TC-09

Tuesday, 12:30-14:00 - Room: Clarendon SR 2.01

ESG investing and sustainable finance

Stream: OR in Finance and Insurance
Invited session
Chair: *Hayette Gatfaoui*

1 - Do Commodity Prices Reflect ESG and Sustainability Factors? An Empirical Analysis and Implications for Investors
Hayette Gatfaoui

This paper explores the intersection of commodity markets, sustainability, and environmental, social, and governance (ESG) factors. The study evaluates the potential impact of ESG considerations on commodity prices and their implications for commodity investing and related investment strategies. Additionally, the impact of geopolitical and climate risks on commodity markets is examined. By analyzing historical data and current trends, the paper measures the relevance of sustainable commodities, such as renewable energy sources and organic agricultural products, in relation to long-term environmental and social goals, for investors. The study also investigates whether incorporating ESG factors into commodity investments can enhance portfolio resilience, thereby contributing to the broader objective of sustainable development. This paper provides valuable insights for investors and policymakers interested in promoting sustainability within the commodity markets.

2 - Sustainable Diversified Portfolios
Francesco Cesarone

The search for a portfolio maximizing an appropriate measure of diversification has recently gained popularity in portfolio selection due to favourable empirical results documented in the literature. At the same time, an increasing number of investors are looking to align their financial goals with a desire to positively contribute to the environment and society. This trend has led to developing portfolio selection models that incorporate sustainability objectives. We propose a novel bi-objective portfolio optimization model aiming at maximizing both portfolio sustainability and diversification. More precisely, our approach seeks to simultaneously maximize the portfolio ESG (i.e., Environmental, Social, and Governance) score and a diversification ratio based on general risk measures, which extends the diversification measure introduced by Choueifaty and Coignard for volatility. We conduct an extensive empirical analysis using real-world data from major stock markets to evaluate the out-of-sample performance of this sustainable diversification approach. Additionally, we assess how integrating sustainability influences financial performance by comparing ESG-diversification strategies with ESG-risk strategies across various risk metrics. The overall trend emerging from our analysis indicates that the out-of-sample performance of the ESG-diversification strategies surpasses that of the corresponding ESG-risk strategies for each risk measure considered.

3 - Reaction of rates of returns on ESG ratings - greenwashing problem
Patrycja Chodnicka-Jaworska

The aim of the study was to examine the impact of changes of environmental, social and governance (ESG) measures and their data greenwashing on changes of rates of returns of non-financial companies. As an effect of the literature review, the following hypothesizes are proposed: The reaction of rates of returns of non-financial companies' changes on ESG measures varies, considering the type of sector, period of implementation regulations, geographical locations and ESG measures. The data greenwashing has got the significant impact on rates of returns changes. An analysis was conducted for non-financial companies that are listed on stock exchanges on all over the world. Data were collected from Refinitiv (Thomson Reuters database) and the World Bank. The analysis was prepared for enterprises for the years 2010-2024. Pursuant to the Directive on non-financial reporting, only a few groups of entities had to present the above-mentioned data. To the analysis were used machine learning models like LASSO and 2LASSO. The received results suggests that it is noticed the data greenwashing phenomenon that has got the significant impact on the stock market. There are noticed geographical, sectoral, time biases.

4 - Portfolio optimization integrating financial and ESG risks
Valentina Piantoni, Sergio Ortobelli Lozza, Denise Mirabella

This article examines portfolio optimization strategies that address both financial and ESG risks. First, portfolios are optimized to minimize financial risk using different coherent risk measures that capture extreme market losses. After identifying portfolios with reduced financial risk, a second optimization is applied to further lower ESG risks, ensuring alignment with sustainability goals. By integrating both financial and ESG considerations, the approach produces portfolios that offer strong financial performance while meeting responsible investing criteria. Results show that ESG-coherent portfolios not only meet sustainability objectives but also exhibit competitive, resilient financial outcomes. This dual optimization process provides investors with portfolios that balance risk management with ethical investment principles.

■ TC-10

Tuesday, 12:30-14:00 - Room: Clarendon SR 1.06

Pairwise comparisons and preference relations 1

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: *Jiri Mazurek*
Chair: *Konrad Kułakowski*
Chair: *Matteo Brunelli*

1 - Theoretical study of characteristic polynomial of 4th order PCM in AHP
Shunsuke Shiraishi, Tsuneshi Obata

We have demonstrated that we can obtain the maximum eigenvalue of pairwise comparison matrices of general order using Newton's and the secant method. Among classical root-finding methods, the remaining challenge is proving the theoretical convergence of the bisection method. To show the bisection method's convergence, we must show that there is only one eigenvalue greater than n. In this talk, we provide a theoretical proof that this property holds for n=4. For an inconsistent pairwise comparison matrix of order 4, precisely two real eigenvalues generally exist. It can be shown that the larger one is greater than 4, while the smaller one is less than 4. Therefore, since only the largest eigenvalue exists in the region greater than 4, the bisection method can determine this maximum eigenvalue by choosing an appropriate initial value. We also demonstrate the convergence of the bisection method for higher-order pairwise comparison matrices through simulations.

2 - Size independence of the consistency index for pairwise comparison matrices in AHP
Tsuneshi Obata, Shunsuke Shiraishi

In the Analytic Hierarchy Process (AHP), pairwise comparisons play a crucial role. Various consistency indices have been proposed to assess inconsistency in these comparisons. Among these, the Consistency Index (CI) proposed by Saaty is defined using the principal eigenvalue of the pairwise comparison matrix. In our previous research, we introduced an alternative index based on the relationship between a coefficient of the characteristic polynomial and the consistency of comparisons. Saaty proposed a fixed threshold of 0.1 for CI as a guideline for an acceptable level of consistency, regardless of matrix size. However, whether this threshold represents an equivalent level of consistency across different matrix sizes, i.e., different numbers of evaluation criteria, remains unclear. In this study, we analyze the relationship between

consistency and matrix size by examining pairwise comparison matrices constructed from a subset of evaluation criteria. Based on this analysis, we propose a fundamental property that a size-independent consistency index should satisfy. Furthermore, we refine our previously proposed index to ensure that it satisfies this property and demonstrate that it coincides with an existing consistency index. Finally, we visualize the relationship between matrix size and consistency index values using randomly generated pairwise comparison matrices, providing insights into the impact of matrix size on consistency evaluation.

3 - A comparison of prioritization methods in pairwise comparisons with respect to a priority vector quality
Jiri Mazurek

Pairwise comparisons (PCs) constitute a fundamental part of many multiple-criteria decision-making methods designed to solve complex real-world problems. The methods' input has a form of experts' judgments (pairwise comparisons of alternatives, criteria, etc.) usually arranged into a PC matrix. The methods' output is a priority vector - the vector of weights of all compared objects. When pairwise comparisons are inconsistent, different methods yield different results (vectors), and these results do not always satisfy a set of natural properties such as coherency, consistency, intensity, or efficiency. The aim of this paper is to compare selected prioritization methods with respect to the satisfaction of the desirable properties by numerical examples and Monte Carlo simulations for different matrix sizes, different levels of inconsistency of an input PC matrix, and also with respect to an incomplete information (missing PCs). The examined methods include, among others, the AHP (the eigenvector method), geometric mean method (GMM), simple tree method, Best-Worst method, Weighted Least Squares Method, Simple Column Sum Method Rank, or AHP-Express. Our results indicate that the AHP and GMM (without missing matrix elements) perform the best.

4 - An MCDM process integrating human judgments and AI-facilitated objective decisions
Andrej Bregar

AI and big data have become heavily utilized in business and production processes, services, and information systems, especially in Industry 4.0 and 5.0. Although autonomous decisions can substitute human judgments and may directly trigger actions, many issues arise related to ethics, bias, transparency, lack of expertise, ability to express subjective preferences correctly, etc. We introduce an MCDM process that aggregates holistic AI-facilitated objective decisions with subjective judgments and knowledge of human decision-makers to guarantee unbiased actions. The process is aligned with the principles of Industry 5.0 and includes phases of data processing and prediction, synthesis of decision-making knowledge, specification of objective and subjective preferences, and consolidation. It incorporates personal constraints on value functions, preference mappings, and a convergence mechanism. We demonstrate the process with a use case from the energy domain. We conduct a simulation study to show the efficiency of human-centric decision-making that complements and enriches autonomous decisions. We examine how subjective judgments enhance the objectively inferred recommendations through several factors, including the consistency of judgments, richness of discriminating information, and extremeness of preferences. We generate pairwise comparison matrices to approximate human reasoning with slightly inconsistent preferences and compare the inferred decisions with consistent ones.

■ TC-11

Tuesday, 12:30-14:00 - Room: Clarendon SR 1.03

Emergency care and services

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Lei Liu

1 - A Markov Chain-Based Relocation and Districting Model for Optimizing Emergency Medical Services
Lei Liu, Yiwen Hu

Ambulance relocation is a critical strategy in Emergency Medical Service (EMS) systems, aimed at repositioning idle ambulances to enhance coverage in high-priority areas. Compliance table policies are commonly used in EMS systems to optimize ambulance deployment. To further enhance the efficiency of EMS call responses across large geographic regions, we propose a novel relocation model that combines a Markov chain framework with sub-region-based repositioning. This approach enables the EMS system to allocate resources more effectively to high-priority areas while reducing the time spent on ambulance relocations. The model's effectiveness and practical applicability are demonstrated through numerical results derived from real-world EMS operations in a Chinese city with a population of over 9 million.

2 - Information design for volunteer emergency response
Giulia Montagna, Pieter van den Berg, Caroline Jagtenberg, Rob van der Mei, Brian Overbeek

Community first responder systems expand the traditional emergency services with trained volunteers that can be dispatched by an app. Volunteers can accept or decline alerts to provide first aid at an emergency until professional services arrive. The decision to accept may depend on the expected impact on patient health outcomes. Usually, volunteers are only informed about their distance to the incident. However, additional information, such as the distance of other volunteers, might influence the acceptance probability. This study investigates how providing more information to volunteers could lead to the most valuable volunteers accepting the request. The value of a volunteer indicates how much the patient would benefit if they accept. It can be measured by the reduction in time to CPR or increase in survival probability. This value depends on the location of all available volunteers, their acceptance probabilities and possibly their skill or equipment. Given the relationship between the believed value of a volunteer and their acceptance probability, we explore how sharing more information can nudge the highest value volunteer to accept the alert. How would sharing more information with volunteers impact the response time? How much information would you need to share? How does this depend on the relationship between the acceptance probability and the expected value?

3 - Evaluating the Cost-Effectiveness of Transitioning from Metered-Dose Inhalers to Dry Powder Inhalers for Asthma Management: A System Dynamics Approach
Armando Vargas-Palacios

Abstract Objectives: This paper aims to reduce CO2 emissions by evaluating the cost-effectiveness of replacing Metered-Dose Inhalers (MDIs) with Dry Powder Inhalers (DPIs) for asthma management in the UK. This involves assessing the impact on direct and indirect healthcare costs and patient outcomes across the asthma care pathway.

Methods: A System Dynamics (SD) model built to simulate the transition from MDIs to DPIs, considering parameters like disease severity, treatment adherence, symptom control, and healthcare resource use. The cost-effectiveness analysis concentrated on direct costs, such as medication and hospitalisations, excluding indirect costs like CO2 emissions and lost productivity.

Results: Switching from MDI to DPIs may result in a potential loss of symptom control. While the base scenario (0% loss in symptom control) shows an additional cost of ’0.29 per unit of CO2 saved by using DPIs, and no extra medical expenses. However, a 10% loss in symptom control raises the cost to ’0.33 per CO2 unit saved, leading to a loss of 0.002 QALYs per patient and adds ’72.41 to annual treatment costs per patient.

Conclusion: The model shows that economic, environmental, and patient factors affect the cost-effectiveness of switching from MDIs to DPIs. While DPIs may provide long-term savings and environmental benefits, a successful transition requires managing higher initial costs and potential temporary loss of symptom control for some patients.

4 - A Multi-Criteria Approach for Patient Stability Assessment in Emergency Care: Integrating PFS and TOPSIS
Antonio Sergio da Silva, Marcos dos Santos, Carlos Francisco Simoes Gomes

This study introduces a multi-criteria approach for assessing patient stability in emergency care by integrating the PFWA operator with the PFS-TOPSIS framework and the MPSI-MARA technique for weight assignments. By utilizing Picture Fuzzy Sets, this model provides a nuanced classification of patient conditions, overcoming the limitations of traditional triage systems with a more flexible, data-driven assessment. Applied to simulated data, the model effectively prioritizes patients based on critical vital signs, including respiratory rate, oxygen saturation, and heart rate, aligning closely with clinical expectations for risk stratification. The findings indicate that this approach could significantly impact patient outcomes by enhancing the accuracy and consistency of triage decisions in emergency settings. Future research should focus on validating this methodology with real-world data and investigating its applicability across various healthcare contexts, ultimately influencing patient flow, resource allocation, and quality of care in high-demand environments.

■ TC-12

Tuesday, 12:30-14:00 - Room: Clarendon SR 1.02

Application of scheduling models

Stream: Scheduling and Project Management
Invited session
Chair: *Taho Yang*

1 - An implementation framework for digital lean production and case studies
Taho Yang

Lean and Industrie 4.0 (or smart manufacturing) are two approaches, but they have one common goal: the pursuit of zero waste. The lean approach can be systematically connected with the new opportunities of digitalization and Industrie 4.0. We called it Lean 4.0—reaching the next level of excellence through digitalization. There is a significant amount of literature on either Lean or smart manufacturing. However, practical applications for Lean 4.0 are rare. This paper proposed a Lean 4.0 implementation framework—JIT-Jidoka Cycle (JJC). It is based on the two pillars of the TPS house—JIT and Jidoka, and a continuous improvement cycle. When automation technologies are adopted, Toyota-style factories tend to be conservative economically and technologically. It is a so-called low-cost or semi-automatic system with just enough functions. JJC adopts the same philosophy when adopting digitalization technology. We may coin this concept as a Low-cost Smart System (LCSS), which became the implementation framework of Lean 4.0. The proposed JJC approach has been applied to various applications with promising results. It has been used in die mold development. It resulted in an 80% decrease in development lead time. The application to textile manufacturing increased its on-time delivery rate by 33%. The effectiveness of the proposed JJC approach is justified through a series of practical applications.

2 - Machine leasing management for welfare-oriented companies using improved invasive weed optimization
Chunfeng Liu, Emrah Demir

In service-oriented manufacturing, equipment manufacturers can extend their role beyond leasing by offering optimized production scheduling to improve equipment utilization and customer satisfaction. This study focuses on leasing strategies for welfare-oriented companies, where the objective is to maximize the participation of disabled operators in production while minimizing leasing costs. To address this, we propose a bi-objective nonlinear programming model that determines optimal equipment selection, production scheduling, and operator assignment to balance the interests of both lessors and lessees. Given the complexity of the problem, we develop a Discrete Invasive Weed Optimization with a Priority rule-based heuristic (DIWOP) to efficiently generate high-quality solutions. The performance of DIWOP is evaluated against Discrete Invasive Weed Optimization (DIWO) and the Non-dominated Sorting Genetic Algorithm II (NSGA-II) using three metrics to assess the Pareto solution set. Extensive numerical experiments and statistical t-tests confirm that DIWOP achieves superior convergence, better diversity, and higher solution quality within the same computational time compared to DIWO and NSGA-II. The findings offer valuable insights into optimizing machine leasing management for welfare-oriented companies, demonstrating the potential benefits of integrating advanced algorithms into service-oriented manufacturing.

3 - A Dantzig-Wolfe Reformulation for Automated Aircraft Arrival Routing and Scheduling
Roghayeh Hajizadeh, Tatiana Polishchuk, Elina Rönnberg, Christiane Schmidt

Air traffic volumes have increased over the years. This growth increases environmental impact and challenges air traffic controllers, particularly in Terminal Maneuvering Areas (TMAs), where congestion and noise are significant. Therefore, it is essential to provide improved arrival procedures. We consider the problem of computing aircraft arrival routes in a TMA while ensuring automated scheduling of arrivals within a given time interval. Moreover, all aircraft follow continuous descent speed profiles and are separated along the arrival routes based on wake-turbulence categories.

Our contribution is a Dantzig-Wolfe reformulation of a previous mixed-integer programming model for optimizing arrivals. This reformulation significantly improves computational efficiency, in a way that is necessary for real-time applications. Our approach computes solutions for low-traffic scenarios at Stockholm Arlanda Airport in a few seconds, compared to 1.58 hours with the previous model, and for high-traffic scenarios in under one hour, compared to 40.9 hours. Additionally, it successfully handles full-hour, high-traffic scenarios that the previous model could not solve at all.

4 - A Simulation Approach Risk Mitigation and Procurement Scheduling in Dairy Supply Chain
Pratik Maheshwari, Yashoda Devi

This research aims to identify the challenges dairy industries face due to fluctuating demand, uncertainty of raw material providers, perishability, supply chain disruptions, and lack of cold-chain logistics network. The literature provided insides for effective process scheduling to manage seamless operations, minimize costs, and ensure agility and resilience of the supply chain. However, the literature review is evident that most of the studies either based on procurement process optimization or simulation or risk assessment independently but fewer studies have to establish the setup for stress-test of the supply chain in the given scenario. To test the robustness of the procurement schedule, we introduce stress-testing scenarios, including Supplier Disruptions, Logistics Bottlenecks, and Demand Surges. The proposed model is built and conceptualized using AnyLogistix simulation software. We validated the process using Mixed Integer Linear Programming with Python as the solution approach. Additionally, we conducted further sensitivity analysis and contributes to Systems Theory and Supply Chain Resilience Theory. This research aligns with UN SDG 12 by optimizing procurement scheduling to minimize waste, enhance resource efficiency. The proposed procurement schedule determines the optimal quantity of raw materials to order, the supplier allocation, and the precise order timing for each cycle.

■ TC-13

Tuesday, 12:30-14:00 - Room: Clarendon SR 1.01

AI in healthcare

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Rui Xu*

1 - AI-Enhanced Image-Based Bacterial Differentiation via Volatile Compound Detection
António Cardoso, Felipe Tetsuo Yamada, Flávia Barbosa, Luis Guimarães

Healthcare-associated infections (HCAIs) represent a serious global health threat exacerbated by antimicrobial resistance. Traditional detection methods, such as culturing and molecular techniques, have limitations, including low sensitivity and high costs. An alternative strategy is the detection of volatile organic compounds (VOCs) emitted by bacteria, which serve as a unique fingerprint for bacterial identification. This study presents a novel bacterial detection method using a wavelength-multiplexed photoionization detector (PID) to generate distinct ionization current patterns specific to different bacteria based on the VOCs they emit. These patterns are transformed into image representations, which are then analysed using Few-Shot Learning (FSL), and a machine learning approach designed to work effectively with limited labelled data. To extract robust features from the image-based data, a pre-trained Convolutional Neural Network (CNN), specifically ResNet-18, is employed. Prototypical Networks (PN) are then applied to classify bacterial species by comparing query samples to prototypes representing each class. This AI-driven methodology offers a promising solution for real-time bacterial detection, particularly in clinical diagnostics and infection control, where limited data poses a significant challenge.

2 - Artificial Intelligence Model Using Deep Learning for Operating Room Time Prediction
Luís Lapão

Introduction: Efficient management of surgical centers requires optimizing operating room time while minimizing team idle time. This study presents a deep learning-based tool designed to predict operating room time and patient destination, initially implemented for scheduling coordinators at ICHC-FMUSP (Central Institute of the Hospital das Clínicas, Faculty of Medicine, University of São Paulo) to enhance scheduling efficiency and reduce idle time. Methods: A non-parametric deep learning model was developed using a multilayer perceptron approach (using Python libraries), with anonymized variables for privacy purpose and addressing GDPR. Surgical data from 2016 to 2021 was used. After exploratory analysis and the exclusion of combined procedures and non-elective surgeries, a total of 31,090 elective surgeries (70% of the dataset) were used for model training. Results: The weighted average between the current OR time prediction method and the deep learning model resulted in an algorithm with an accuracy of 0.78, according to Lin's concordance correlation coefficient. Predicted and actual times showed no significant difference (Hosmer-Lemeshow test: $\chi' = 12.45$, $p = 0.052$). Conclusion: The artificial intelligence (deep-learning) model improved operating room time prediction accuracy, demonstrating potential benefits in optimizing surgical scheduling, resource utilization and reducing inefficiencies.

3 - Investigating the Role of Generative AI in Revolutionizing Online Health Operations: A Case Study
Rui Xu

Online health plays a crucial role in addressing population aging and extending quality healthcare to the underprivileged. Generative AI (GenAI) has the potential to revolutionize online health operations and redefine the way individuals engage with healthcare services. However, existing research mainly focuses on GenAI's impact on general healthcare systems or clinical applications, overlooking its role in online health operations. To address the gap, this study adopts a grounded theory methodology to examine Good Doctor, a leading online health platform in China that operates within advanced GenAI and large-scale online health markets. Data will be collected through document analysis and semi-structured interviews with key stakeholders, including the company's founders and technical staff. Data analysis will be conducted in three main steps: open coding, axial coding, and selective coding. The results will be analysed through the lens of the Technology Acceptance Model 2 from three perspectives: the supply side (i.e., healthcare professionals), the demand side (i.e., patients or users), and the platform side (i.e., platform managers). GenAI is expected to have a systematic and transformative impact on online health operations. This research will offer insights into obstacles, nuances, and effective strategies for managing socio-technical online health systems characterized by the implementation of GenAI.

4 - Real-Time Optimization of Intra-Hospital Transportation: A Deep Q-Learning Approach
Hossein Torkinezhadirani, Sibel Salman, Ali Hassanzadeh, Ozgur Araz

Intra-hospital transportation is necessary for maintaining efficient hospital operations and ensuring timely and effective delivery of treatments in large healthcare facilities. This study investigates the Real-Time Intra-Hospital Transportation Problem (RIHTP), which seeks to improve the operational efficiency and responsiveness of the hospital transportation systems by optimizing the management of transporters (porters and service robots with different capacities). The goals are cost reduction, increased service, and equitable task distribution among staff. The static version of the problem, where all requests are known to the system, is modeled using the Dial-A-Ride Problem (DARP) framework. For the dynamic version, we utilize a two- phase approach that decomposes the problem into the assignment and routing problems. In the first phase, the assignment problem is solved. Transportation requests are dynamically assigned by a Deep Q-Learning (DQL) employing a Bayesian Neural Network (BNN). Subsequently, in phase two, the routing problem is solved. The route for the assigned transporter is reoptimized through a heuristic approach (Best Insertion combined with Variable Neighborhood Search). Based on the preliminary computations, our two-phase approach demonstrates significant improvements in solution quality and computational efficiency compared to the benchmarks.

■ TC-15

Tuesday, 12:30-14:00 - Room: Esther Simpson 1.08

Heuristic Search 3

Stream: Combinatorial Optimization
Invited session
Chair: Anna Martínez-Gavara

1 - A heuristic approach for disaster response - matching and scheduling unaffiliated spontaneous volunteers
Martina Sperling, Guido Schryen

In large-scale disasters, such as natural or man-made catastrophes and pandemics, the shortage of resources and personnel can limit the effectiveness of rescue efforts. At the same time, many civilians are eager to help their communities. Unaffiliated spontaneous volunteers play an important role in improving disaster response, but coordinating them is a major challenge for relief organizations (e.g., Red Cross, fire departments). Effectively managing these volunteers requires careful planning, clear communication, and a good understanding of available resources, all of which can significantly influence the outcome for those affected. Coordinating spontaneous volunteers using exact methods can be computationally challenging due to the NP-hard complexity of our problem. While exact methods provide high-quality solutions, they often lack the runtime efficiency needed in urgent scenarios. We propose a greedy heuristic, which balances runtime efficiency with solution quality. Using data from a real-world flood scenario, the approach is compared to an exact method using the Gurobi solver. The results show that the heuristic is a viable alternative for relief organizations, offering a good balance between speed and solution quality.

2 - Urban Waste Collection Planning: From Flexible Scheduling to Data-Driven Tour Improvements
Christina Hess, Alina-Gabriela Dragomir, Karl Doerner

Efficient solid waste collection is critical for urban sustainability, yet operational challenges persist due to variability in waste generation and logistical constraints. In collaboration with a practical partner, our research aims to generate actionable insights for real-world waste

collection operations. In our real-world problem, waste must be collected periodically from several thousand locations which have different types. In the first phase of our project, we conducted a computational study on flexibility both in the scheduling of collection visits and the utilization of intermediate facilities where vehicles need to unload whenever they are full and at the end of each tour. We solve the underlying operational problem, which is modelled as a Periodic Vehicle Routing Problem with Intermediate Facilities, with an Adaptive Large Neighborhood Search. Additionally, we leverage fill-level sensor data collected over an extended period to improve decision-making. We address sensor errors and use forecasting models to predict bin fill levels. In ongoing work, we aim to integrate these forecasts into planning. The proposed methods offer practical improvements in waste collection efficiency and adaptability, and contribute to cost reduction, service reliability, and sustainability in urban waste management.

3 - Multiparent Path Relinking for the Power Dominating Set problem
Raúl Martín-Santamaría, *Anna Martínez-Gavara*, *Ana Dolores López-Sánchez*, *Manuel Laguna*

Path Relinking (PR) is a trajectory-based metaheuristic originally introduced as a long-term memory mechanism within Tabu Search (TS). It explores trajectories that connect elite solutions identified during the search process. PR has also been used as an intensification strategy in hybridizations with the Greedy Randomized Adaptive Search Procedure (GRASP) and as a combinatorial method in Scatter Search (SS). In this talk, we present an extension of PR known as Multi-Parent Path Relinking (MPR), initially proposed by Glover et al. (2000) but, to the best of our knowledge, not yet implemented in practice. We introduce a reference framework for integrating MPR into GRASP and SS, demonstrating its potential to enhance solution quality. To evaluate its performance, we focus on the Power Dominating Set Problem (PDSP), which seeks the minimal set of nodes in a network to achieve complete system monitoring. The complex structure of the PDSP presents a challenging test bed for assessing various metaheuristic strategies. Through extensive computational experiments, we analyze the contributions of each component within our MPR implementations, demonstrating its effectiveness in improving metaheuristic performance.

Glover, F., Laguna, M., Martí, R.: Fundamentals of scatter search and path relinking. Control and Cybernetics 29, 653-684 (2000)

■ TC-16

Tuesday, 12:30-14:00 - Room: Esther Simpson 2.07

Sustainable Agriculture

Stream: Sustainable Food & Agroforestry
Invited session
Chair: Shaina Jain

1 - Channel Selection in Agricultural Supply Chains: Managing Yield Uncertainty, Aesthetic Requirements, and Producer Information
Mirjam Meijer, *Nina Mayer*, *Sandra Transchel*

Direct-to-consumer (D2C) channels, where farmers sell directly to end-consumers, are gaining attention in agri-food supply chains due to increasing consumer interest in product origin and sustainability. However, farmers face complex decisions when choosing between D2C and traditional retail channels, especially considering yield uncertainty and esthetical requirements of retailers. This study analyzes farmers' channel choices and pricing decisions, considering demand uncertainty and yield uncertainty, regarding both quantity and esthetics. We explore the viability of a dual-channel strategy, selling through both retail and D2C channels, and its impact on contractual agreements with retailers. We develop a game-theoretical modeling framework to examine the optimal channel choice of a farmer and, if applicable, the associated wholesale-price contract between farmer and retailer. We develop conditions under which a dual channel choice is viable, highlighting the importance of using the opportunity in the D2C channel to share additional information on the product and its background. We demonstrate that a dual channel choice can lead to a coordinated equilibrium where both the farmer and the retailer have positive expected profits. However, in a decentralized supply chain, this coordinated equilibrium is not attained. Despite this, the dual channel option can benefit the farmer. However, increased yield uncertainty significantly reduces profits and increases food waste.

2 - Sustainable Management of Paddy Waste: A Data-driven Analysis of Value Chain Constraints
Shaina Jain

Sustainable paddy waste management is vital for resource efficiency and environmental sustainability. However, limited research exists on the specific challenges faced by value chain participants in effectively utilising paddy by-products, leading to economic losses and environmental concerns. This study examines challenges faced by key value chain participants—300 farmers, 100 traders, and 100 processors—in handling paddy waste and by-products such as rice husk, rice bran, broken rice, and paddy straw. A structured survey in Punjab, India, utilised mixed sampling-convenience for farmers, snowball for traders and processor and Likert-scale responses. Data analysis using descriptive statistics, one-sample t-tests, and exploratory factor analysis identified major challenges. Farmers struggle with high production costs, market access issues, and lack of infrastructure. Traders face financial constraints, pricing volatility, and weak logistics, while processors encounter high input costs, limited technology, and supply chain inefficiencies. Addressing these requires policy interventions, better infrastructure, and technological innovations. Promoting alternative uses of paddy waste, improving financial access, and enhancing market linkages can transform waste into valuable resources, benefiting both the economy and the environment.

■ TC-17

Tuesday, 12:30-14:00 - Room: Esther Simpson 2.08

Service Network Design: challenges and opportunities

Stream: Combinatorial Optimization
Invited session
Chair: Maria Grazia Scutellà
Chair: *Giacomo Lanza*

1 - How to mitigate natural disaster-based disruptions affecting urban rail transit networks: devising cost-effective strategies via bi-level programming
Annunziata Esposito Amideo, *Stefano Starita*, *Maria Paola Scaparra*

Railway systems are considered critical infrastructures, as their malfunction, whether due to natural or man-made disasters, can have far-reaching adverse effects on entire communities. Therefore, the ability to assess railway system vulnerabilities and devise cost-effective protection strategies is of paramount importance. This work-in-progress aims to advance the state of the art in optimization for railway infrastructure protection by proposing a novel bi-level program in which a natural disaster affects an urban rail transit network and its components (i.e., stations and/or tracks), and the network operator must implement protection strategies to effectively mitigate the consequences of resulting disruptions. We also propose two additional variants of this model: (i) one with demand windows and (ii) one that is time-dependent with time windows. These models were designed with floods in mind as the natural disaster of interest; however, they can be adapted to other types of natural disasters. We present preliminary experimental results on grid-based generated test networks and extend our testing with a case study on the Central London Tube.

2 - Stochastic Multicommodity Network Design: A Synergistic Approach Using Machine Learning and Optimization
Fatemeh Sarayloo, Mahya Hemmati, Teodor Crainic, Walter Rei

This paper introduces a novel Machine Learning (ML)-guided matheuritics for the stochastic multicommodity capacitated network design problem (SMCND), with broad applications in service network design, transportation, and beyond. Our approach synergistically integrates machine learning and optimization to address both demand uncertainty and computational complexity. We propose an iterative framework that employs Artificial Recourse Problems (ARPs) defined across various scenario combinations to generate a rich dataset, including features related to promising arcs, paths, and costs, which are used to train ML models capable of predicting key solution structures. We explore various algorithmic strategies that facilitate an iterative exchange of information between ML and optimization, guiding the search process toward high-quality solutions. Extensive experiments highlight the gains over traditional methods, especially for large-scale instances.

3 - Planning Express Lines in a Line Network: Reducing Travel Time and Energy Consumption
Sarah Roth, Anita Schöbel

While an expansion of the public transport system facilitates the shift from individual transport to public transport and hence saves energy, also the public transport system itself consumes a non-negligible amount of energy. Both of these aspects can be improved by introducing express lines that skip some of the stops. This enables people to travel faster between their origins and their destinations, which makes the usage of public transport more attractive. Further, each skipped stop means that the vehicle avoids an acceleration process, and, hence, consumes less energy than a vehicle on a normal line on the same route. However, skipping a stop might lead to higher travel times for the passengers who want to board/alight at that stop. Further, the introduction of new lines might increase the energy consumption of the transport system if it results in a higher number of vehicles. Therefore, the decisions where express lines are implemented and which stops are skipped are essential to its practical effect. In this talk, several MIP models for the implementation of express lines in a line network are presented and their differences are analyzed. The problem is considered in a bicriteria setting, minimizing the passengers' travel time as well as the usage of energy of the transport system. First solution approaches are presented and examples illustrating an optimal solution structure are shown.

4 - Robust Service Network Design under Uncertain Travel Times
Giacomo Lanza, Maria Grazia Scutellà, Mauro Passacantando

Service network design is a fundamental problem that freight carriers face at the tactical level when planning a consolidation-based transportation network. The objective is to define a transportation plan - including the selection and scheduling of services as well as routing policies for freight - that meets estimated demand while achieving the carrier's economic and service quality targets. However, uncertainty in the system (e.g., demand or travel times fluctuations) poses a significant challenge in decision-making, impacting both operations and service reliability, potentially leading to additional costs. In this work, we propose a robust formulation of the problem that explicitly accounts for uncertainty in travel times. The goal is to determine a cost-efficient transportation plan that ensures selected services operate as scheduled and freight arrives at its destination within the agreed-upon delivery time, even under worst-case travel time scenarios defined within a given uncertainty set. We present a min-max mathematical formulation for this robust optimization problem and an implementor-adversary resolution approach, based on the proposed formulation. We discuss preliminary computational results on medium-sized instances, aiming to assess the algorithm's efficiency, and examine the structural differences between robust and deterministic solutions.

■ TC-20

Tuesday, 12:30-14:00 - Room: Esther Simpson 2.11

Exact algorithms for combinatorial optimization

Stream: Combinatorial Optimization
Invited session
Chair: *Diego Delle Donne*

1 - MILP Models for the Planar p-Median Problem: An Evaluation of Different Linear Approximation Techniques of Euclidean Distances
Fabian Wilschewski, Alf Kimms, Christin Münch

The planar p-median problem consists of locating a given number of facilities in the plane in order to minimize the sum of Euclidean distances from given demand points to its closest facility. As the problem has various applications, it has already received a lot of attention and many variants of the problem have been addressed. A major part of proposed solution methods are iterative approximation algorithms and heuristics. However, these methods are often closely related to a specific problem variant, whereby minor changes to the problem definition or new conditions may render an algorithm completely unusable or require a lot of effort to adapt it appropriately. In contrast, model-based approaches are typically more flexible, so that additional conditions can often be easily implemented. In order to utilize this advantage, we present different approximation techniques that enable the use of MILP model formulations. Moreover, we evaluate the performance of the proposed techniques in terms of solve time and approximation accuracy within the framework of MILP model formulations for the planar p-median problem. The results may also be valuable for related problems or other applications including Euclidean distances.

2 - On the Rank-1 Chvátal-Gomory inequalities for the knapsack problem with generalized upper bounds
Junyoung Kim, Kyungsik Lee

In this talk, we examine rank-1 Chvátal-Gomory (CG) inequalities for the knapsack problem with generalized upper bounds (GKP). We first analyze the properties of non-dominated rank-1 CG cuts for the GKP. Based on these results, we propose efficient exact and heuristic algorithms for the separation problem, along with an analysis of their computational complexity. We then conducted computational tests on benchmark instances for the multi-dimensional multiple-choice knapsack problem. The results demonstrate that the proposed algorithms generate the CG inequalities that are more effective in strengthening the linear programming relaxations than existing valid inequalities for the GKP, within a short computation time.

3 - Using Column Generation with Neighbourhood Pricing to solve the Generalized Assignment Problem
Basile Blayac, Andrew J Mason, Andrea Raith

In the context of column generation, Neighbourhood Pricing is a novel column pricing strategy that narrows the search for new columns to the neighborhoods of existing ones. Neighbourhood Pricing can be used as a Very Large Scale Neighborhood (VLSN) search matheuristic, where it replaces the standard Pricing problem to only explore neighborhoods of feasible integer solutions. It can also be used in Branch and Price as a pricing heuristic. Our study focuses on the Generalized Assignment Problem (GAP), a well-known and challenging scheduling problem in which tasks must be assigned to a set of heterogeneous agents with capacity constraints, with the goal of minimizing the total assignment cost. We introduce two variants of Neighbourhood Pricing for the GAP problem and develop algorithms to use these efficiently. We evaluate the impact of Neighbourhood Pricing approaches on solving GAP instances at the root node and their integration into heuristic methods, and compare these approaches with existing techniques. Finally, we discuss intriguing aspects of the concept, such as the reduction in "fractionality" of solutions during the column generation process.

4 - An incremental exact algorithm for the hyper-rectangular clustering problem with axis-parallel clusters
Diego Delle Donne, Javier Marenco, Eduardo Moreno

Given a set of points in the d-dimensional space, a hyper-rectangle clustering is a partition of the set of points into groups called clusters, where each cluster is determined by the smallest hyper-rectangle containing the points in the cluster. We address the problem of finding a hyper- rectangle clustering of minimum size. Previous exact approaches to this problem are mostly based on integer programming formulations and can only solve to optimality instances of small size. In this work we propose an adaptive exact strategy which takes advantage of the capacity to solve small instances to optimality of previous approaches. Our algorithm starts by solving an instance with a small subset of points and iteratively adds more points if these are not covered by the obtained solution. We prove that as soon as a solution covers the whole set of point from the instance, then the solution is actually an optimal solution for the original problem. We compare the efficiency of the new method against the existing ones with an exhaustive computational experimentation in which we show that the new approach is able to solve to optimality instances of higher orders of magnitude.

■ TC-21

Tuesday, 12:30-14:00 - Room: Esther Simpson 2.12

Innovative Metaheuristic Approaches

Stream: Metaheuristics
Invited session
Chair: David R Penas

1 - From TSP to VRP with deep learning
Adrien Pichon, Alexandru Olteanu, Marc Sevaux, Christine Solnon

In this work, we investigate converting solutions from the Traveling Salesman Problem (TSP), into solutions suitable for Vehicle Routing Problems (VRPs). VRPs extend the TSP by adding restrictions such as limited vehicle capacities, heterogeneous fleet of vehicles or specific delivery schedules (time windows), dramatically increasing its complexity. Due to the impracticality of exact optimization methods for large-scale problems, researchers typically employ heuristic approaches (like nearest neighbor or Clarke-Wright) or more advanced metaheuristics (such as Genetic Algorithms or Tabu Search) to obtain solutions close to the optimal. Our approach integrates deep learning techniques into the well-known Hybrid Genetic Search (HGS) framework, for which a solution is encoded as a giant tour (a TSP) and is decoded by the SPLIT method to obtain VRP solutions. We introduce a neural regression model to predict VRP solution costs directly from existing TSP solutions, thus allowing to bypass the SPLIT computations, which is especially beneficial for complex VRP variants. Inspired by advanced Graph Neural Networks (GNNs), our proposed method, named DeepHGS, efficiently captures graph structures and enables fast inference using GPU acceleration. This novel combination significantly improves computational speed, demonstrating strong potential in tackling large and intricate vehicle routing scenarios.

2 - Ant colony based feature selection for stacking ensemble in diagnostic applications
D Jinil Persis

Quick-response decision support is vital to deal with the changing behavior of dynamic systems. Early signs and accurate failure prediction would pave the way for corrective actions and enable the continuum. This study explores the ant colony feature selection algorithm to shortlist the relevant predictors for quick modeling of the stacking ensembles, offering diagnostic support for various applications. This methodology is used on various medical datasets and the computational and predictive performance of the diagnostic models are presented.

3 - Parameter estimation in computational systems biology: a new adaptive hybrid method
David R Penas, Julio R Banga

Large-scale dynamic biological models in systems biology typically have many unknown, non-measurable parameters that need to be estimated. This task, known as parameter estimation, can be formulated as a global optimization problem, where the cost function is the goodness of fit between simulations and real data. However, the dimensionality and multimodality (non-convexity) in the search space lead to NP-hard complexity. As a result, local optimization methods often fail to locate the global optimum, returning suboptimal solutions that can lead to incorrect conclusions. In this way, evolutionary strategies are well-suited to handle this type of problem, providing solutions close enough to the global optimum.

This study adapts the Success-History based Adaptive Differential Evolution (SHADE) algorithm to address parameter estimation challenges, incorporating features such as logarithmic space search, exploration-exploitation strategies, refined hyperparameter adaptation mechanisms, and hybridization with local methods (gradient-based or derivative-free). We rigorously tested our proposal across different system biology benchmarks, including epilepsy whole-brain network modeling, microbial metabolic pathway optimization, gap gene network identification, and full cell cycle models. The results demonstrate superior convergence rates and solution quality compared to baseline methods, establishing our approach as a robust tool for complex biological system parameterization.

4 - A Matheuristic for the Traveling Salesman Problem with positional consistency
Mafalda Ponte, Luís Gouveia, Ana Paias

We propose a matheuristic for the Traveling Salesman Problem with positional consistency constraints, where we seek to generate a set of routes with minimum total cost, in which the nodes visited in more than one route (consistent nodes) must occupy the same relative position in all their visits. The matheuristic is an Iterated Local Search-based algorithm that uses a restricted version of the problem under study, where the positions of consistent nodes are fixed, to significantly improve the quality of local optima found by the local search. Computational results show that, for instances with 48-76 nodes and 5 routes, or 96-171 nodes and 10 routes, the matheuristic can obtain, in short computational times, significantly better solutions than an exact method in 10 hours, obtaining optimal or near optimal solutions for instances where the optimal solution is known.

■ TC-23

Tuesday, 12:30-14:00 - Room: Esther Simpson 3.01

OR Challenges for Developing Countries 1

Stream: OR for Societal Development
Invited session
Chair: Yu-Hong Dai

1 - OR in China: Challenges and Opportunities
Ya-xiang Yuan

In this talk, I will briefly review the history of OR in China, and discuss the current situation of OR education, research and application in the country, in cluding the activities of the OR Sociey of China, the major OR related projects supported by the National Natural Foundation of China, and OR education in China. I will also discuss the opportunities and challenges of the OR community in China due to the rapid development of AI and data science.

2 - OR, in Europe and worldwide, for Development and Developing Countries, yesterday, today and tomorrow
Gerhard-Wilhelm Weber, Nina Kajiji, Gordon Dash, Jinal Parikh, Sarah Fores

EURO Working Group on Operational Research for Development (EWG-ORD) was established within the Association of European Operational Research Societies (EURO) during EURO 2006 in Iceland. Its aim is to promote and facilitate communication links among European and other researchers working in areas of operational research (OR) for development. EWG-ORD has organized annual workshops, e.g., ICORD workshops with IFORS, to promote the importance of OR in improving the lives of people in developing and developed countries, as well as streams at EURO, IFORS and other conferences. From the beginning, EWG ORD was very international and global, which led to numerous developmental impulses worldwide. This enriched IFORS itself, its regional groupings, numerous national OR societies, other EWGs and further groups, universities and organizations, sciences and disciplines, and always the lives of the local people. IFORS has a dedicated section "Developing Countries online resources" which serves as a platform to provide widespread access to free and publicly-available OR materials for development to the entire OR community, including researchers and practitioners in the Developing Countries (DCs). It has now reached 1 million visitors. Among the many collaborators and supporters were E. del Rosario, S. Merchant, L. White and H. Smith. We would like to thank them all very much. This presentation provides details, examples and future challenges of OR for Development.

3 - Energy consumption Decomposition and Decoupling Analysis in Developing countries with specific reference to India
Jinal Parikh, Gerhard-Wilhelm Weber

India targets net-zero emissions by 2070 and a 45% cut in GDP emissions intensity by 2030. However, balancing growth with emission reductions is challenging. In 2023, carbon emissions rose by 190 million tonnes due to strong GDP growth and a weak monsoon, though per capita emissions remain low. With a 9% growth target and a $5 trillion economy goal by 2024-25, managing greenhouse gas (GHG) emissions is increasingly complex. Aligned with SDGs 7 and 13, boosting energy efficiency is crucial for climate resilience. However, India's diverse states and union territories show varying emissions due to differences in industrialization, resources, and demographics, requiring region-specific strategies. This study examines economic growth and carbon emissions decoupling using panel data, the Tapio index, and the LMDI model. While emissions growth has slowed, full decoupling remains unachieved, particularly in industrial hubs like Maharashtra and Gujarat and coal-dependent states such as Jharkhand and Chhattisgarh. To achieve decoupling, India must restructure industrial economies, transition to clean energy, expand renewables, and enhance efficiency. This study explores decomposition analysis methods to assess emission drivers and support sustainable growth. Keywords: OR for Societal Development, Sustainability, Decomposition Analysis, Decoupling Analysis, Tapio Index, LMDI, Energy

4 - Job assignment for the inclusion of people with disabilities
Hector Cancela

We discuss job assignment for persons with disabilities, as related to a case study pertaining the Internships project within the Citizen Services in the Municipality of Montevideo, Uruguay.

Labor inclusion of persons with disabilities depends on adapting physical spaces, improving communications, and the access to information and to technological tools needed to perform the task, as well as having enough flexibility to reinterpret the tasks and to generate an environment of respect and continuous learning for all parts involved.

During this project, we worked together with the Disabilities Secretary of the Municipality of Montevideo, to perform a job assignment for a group of interns with disabilities, taking into account their preferences. The assignment task was modeled using mathematical programming, including the definition of different alternative objective functions. The model included a number of hard constraints on the match between persons and jobs, as well as some desirable aspects, and can be extended to other scenarios.

The results for the mathematical programming models were compared against the manual assignment, showing better results, improving the satisfaction of the interns as well as the fit of the assignment (measured as the fit of the persons assigned to the needs defined for each job). Exploring different objective functions also allows to put into evidence the compromises between the different stakeholders, and supports decision making

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■ TC-24

Tuesday, 12:30-14:00 - Room: Esther Simpson 3.02

Tutorial: How can the partitioning of elective surgeries benefit the inpatient operating theater?

Stream: Tutorials (and Workshops)
Tutorial session
Chair: Florian Jaehn

1 - How can the partitioning of elective surgeries benefit the inpatient operating theater?
Erik Demeulemeester

Based on an extensive literature review, we found that in many hospitals the surgery activities in an outpatient setting could be planned and scheduled quite effectively, whereas it would be challenging to plan OR capacity in the more uncertain and complex inpatient settings. In this presentation, we therefore propose a promising and robust variation on the multistage scheduling process of ORs and surgeries in the inpatient operating theater. It consists of partitioning elective surgeries into two homogeneous groups, i.e., the more predictable surgeries (MPS) group and the less predictable surgeries (LPS) group, and then the MPS surgeries are scheduled in separate ORs from the LPS and the emergency surgeries. Using Markov decision process (MDP), linear programming (LP) and simulation models, we comprehensively investigate whether, how and where such a partitioning can be beneficial regarding a variety of performance measures. The analysis is performed for both a real university hospital and a stylized model. Important findings and insights are deduced from this analysis.

■ TC-26

Tuesday, 12:30-14:00 - Room: Maurice Keyworth 1.33

At the heart of things: OR in the UK Government and National Health Service-England

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: Jane Parkin

1 - Making a difference in UK Government
Tony O'Connor

Making a difference in UK Government Tony O'Connor CBE FORS. Head of the Government OR Service.

UK Central Government has had long history of using Operational Research in developing and delivering policies, and the Government OR Service (GORS) now has around 1500 professional OR analysts

working in 30 different Government Departments and agencies. From Health to Welfare, Education to Transport, Policing to Energy, and Business to Taxation, GORS supports many aspects of Government policy, helping Ministers to deliver better outcomes to UK citizens.

This session will show how OR has made a difference to Government, some examples of where OR has influenced policy, and how it has impacted on the lives of millions of UK citizens.

2 - Operational Research in NHS England
Stephen Lorrimer

The National Health Service (NHS) in England provides free-at-the-point-of-access healthcare to the population of England. Its budget of around ’179bn is funded through general taxation.

NHS England is the body that leads and manages the NHS. It oversees the budget, planning, delivery and operations of the NHS in England. NHS England has a large Data & Analytics directorate in which operational research analysts and operational research techniques are well represented.

Dr Stephen Lorrimer is head of Analysis and Insight for Finance at NHS England. He has over thirty years’ experience in the UK public sector, originally working on the physics modules of weather forecasts before moving into operational research in welfare benefits and then health. He is also one of the two Vice-Presidents of the OR Society.

In this session Stephen will illustrate the impact of operational research on NHS England’s decision making process, discussing a number of projects drawn from across the range of our work.

■ TC-28

Tuesday, 12:30-14:00 - Room: Maurice Keyworth 1.03

Multicriteria Decision Analysis and Optimization for Complex Decision-Making

Stream: Decision Support Systems
Invited session
Chair: Nikos Tsotsolas

1 - PLIAS: A Multi-Criteria Decision-Making Tool for Assessing the Performance of Urban Vehicle Access Regulations (UVARs)
Theodoti Kerama, Konstantinos G. Zografos

The increased demand for the transportation and distribution of goods in urban areas, coupled with existing traffic congestion and the associated Green House Gas (GHG) emissions, has led city authorities to introduce measures aiming to improve the urban environmental quality and the sustainability of urban logistics operations. These measures include Urban Vehicle Access Regulations (UVARs) such as low and zero emissions zones, time-windows for deliveries, regulated loading-unloading bays. However, different choices of UVARs impact differently the performance of the city’s mobility and logistics system. Therefore, there is a need for city authorities to have available tools to: i) decide which UVAR(s) should be selected, for implementation, from a set of available UVARs, (ex-ante analysis), and ii) assess the impact of implemented UVAR(s) on the performance of the mobility and logistics system (ex-post analysis). In this presentation, we introduce a Multi-Criteria Decision-Making (MCDM) tool called PLIAS (Policy Logistics Impact Assessment) that can be used by city authorities to perform ex-ante and ex-post analysis for assessing the performance of UVARs. The proposed tool is based on the Analytical Hierarchy Process (AHP) and can be used for group decision making, and allows the user to perform sensitivity analysis regarding the importance assigned to the various assessment criteria.

2 - Framework for Evaluating Educational Quality in Public Schools in Brazil: An Approach Using the CoCoSo Multicriteria Decision Support Method
Fabio Bentes, Marcos dos Santos, Daniel Pereira, Anderson Monteiro, Thais Leite

According to the 2023 Brazilian Official School Census, 59.4% of municipal schools in Rio de Janeiro presented a quality index below the average of 5, a criterion defined by the Brazilian Ministry of Education to rank the quality of schools. This has raised questions about the sufficiency of the current Brazilian educational quality measurement system, which considers only a limited number of educational indexes. This study proposes a new approach to evaluate educational performance in Brazilian public schools, using the CoCoSo method, a multicriteria decision-making technique that combines compromise solutions and reconciles conflicting evaluation criteria. The analysis covered 997 schools and 6 criteria, such as school dropout rate, student failure rate, teacher retention index, and other relevant educational indexes. The results enabled a fairer ranking of schools, offering a new perspective on their quality and reality. This work contributes to the debate on improvements in the Brazilian educational system, offering a valuable tool in the decision-making process, and facilitating the understanding of the complexity of Brazilian educational inequalities. For future research, the inclusion of other educational indexes is suggested.

3 - Measuring social media customer engagement with brands based on information entropy: an application case of luxury brand
Siwei Xiao, Xiaoyu Chen

Customer engagement (CE) within social media has emerged as a focal point in marketing research due to its significant impact on brand and firm-related outcomes. However, effective measurement methodologies for CE behaviours remain underexplored in this context. Building upon the existing concept of CE behaviour proposed by Brodie et al. (2013), and the CE cycle theory, this paper introduces an operational definition that supports an entropy-based CE behaviour measurement framework, offering a nuanced reflection of social media dynamics. The proposed measurement approach, among the initial attempts to integrate the multi-criteria decision-making (MCDM) weighting method into brand marketing analytics, ensures a reliable and rigorous assessment of CE performance with brands. Additionally, a range of analytical methods, including regression modelling using dummy variables, sentiment analysis, and hierarchical clustering algorithm, were synthesised to assist the objective evaluation of brands’ impacts on CE behaviour outcomes. A peer group of six luxury brands were chosen to analyse their impacts on engagement performance independently. Key findings from this application demonstrate the approach’s ability to compare the engagement performance of different brands, offering a significant tool to differentiate engagement behaviour levels while providing actionable insights for brand marketing initiatives.

■ TC-30

Tuesday, 12:30-14:00 - Room: Maurice Keyworth 1.05

Supply chain management

Stream: Advanced Lot Sizing and Inventory Strategies
Invited session
Chair: Bram De Moor

1 - On the Value of Predictive Spare Parts Printing as the Second Supply Mode
Ipek Tanil Can, Collin Drent, Rob Basten

We investigate the use of additive manufacturing (AM) for predictive spare parts printing, leveraging sensor data to optimize decision-making in spare parts provisioning. AM enables the production of

spare parts with a short lead time, offering a faster supply than regular replenishments. The former is, however, more expensive than the latter, which leads to a trade-off. We examine this trade-off within the context of spare parts provisioning for a partially observable degrading system. We consider a system with embedded sensors providing classification data on the condition of a critical component. We propose a Bayesian procedure to infer from this data and the confusion matrix whether the component is nearing failure. Using this procedure, a decision maker sequentially decides whether to predictively print spare parts, replenish spare parts from the regular supplier, or do nothing. To analyze this decision problem, we formulate a partially observable Markov decision process. Through a numerical study, we explore the optimal conditions under which printing or replenishment is preferred, and analyze the impact of input parameters on the decisions. Moreover, we derive sensor guidelines based on the performance measures obtained from the confusion matrix, providing insights into the integration of sensor data in spare parts provisioning. This study contributes to the understanding of AM's value in spare parts management in environments where condition monitoring is available.

2 - All Aboard! Capacity Pooling in Collaborative Rail Shipping
Bram De Moor, Hannah Yee

The freight transport sector faces increasing pressure to improve efficiency and sustainability. A modal shift from truck to rail transport can lower carbon emissions and alleviate road congestion, but rail's inflexibility — requiring advance bookings and fixed capacity — hinders its competitiveness against trucking. To address this challenge, we propose a collaborative shipping strategy where multiple shippers jointly book and allocate rail capacity. We model this problem as a two-tier decision-making process: (1) a strategic decision on fixed capacity booking and (2) operational decisions on the periodic replenishment orders for all shippers, given the fixed capacity booking. We analyze the structure of the optimal collaborative replenishment policy and find that it consists of reactive orders (based on inventory levels) and proactive orders (anticipating future capacity constraints). Given the complex nature of the optimal policy, we propose a more practical replenishment heuristic. A numerical study reveals that collaboration reduces the total capacity requirement compared to a non-collaborative scenario, leading to lower transport costs and improved utilization rates. Moreover, a pooling effect lowers inventory mismatch costs and addresses the inherent inflexibility of rail transport, improving its efficiency and making it a viable alternative to truck transport.

3 - Closed Loop Supply Chain, Hybrid Distribution Centres, Integrated Network Design
Adrian Garnier Artinano, Mahdi Doostmohammadi, Ashwin Arulselvan, Mehdi Amiri-Aref

Traditional supply chains follow an open-loop system with a forward flow of goods. To address sustainability and supply chain efficiency, Closed-Loop Supply Chains (CLSC) integrate reverse logistics, collecting used products for recycling or remanufacturing. The model is inspired by the return-to-retail model. In this scenario, customers return the products or waste to a retailer and this one sends it to be recycled or remanufactured through the network. We are exploring using hybrid distribution centres to mediate the flow of the returned products. The resulting model is a single-product, multi-period, multi-echelon CLSC model, integrating the facility location problem and a lotsizing problem. The first set of variables is not time-dependent, covering the selection of hybrid distribution centres, the allocation of capacity for product and return, the expansion of a facility's capacity, and the allocation of retailers to distribution centres. Meanwhile, the second set of variables optimises the production, transportation, storage, backlog, and disposal of goods. The key aspects of the model are the use of integer variables to represent multiple sizes of vehicles per arc, having backlog and disposal to give the model full recourse, and having the storage allocation in the distribution centres to allow the selection of a percentage of the capacity as storage for products or return.

4 - How to manage inventory for a perishable product with two-period shelf life when a vendor faces the oversupply penalty and takes advantage of the responsible buyer market
Li-Ming Chen

This study considers a supply chain problem that an upstream vendor, when facing the oversupply penalties, uses the two-bin supply strategy of selling a two-period shelf life produce to two types of downstream buyers. The freshly replenished items are placed in the primary bin and sold to a responsible buyer (RB), and the fresh surpluses are then allocated to the secondary bin in which old and fresh goods follow the FIFO issuing policy to sell goods to the price-sensitive mainstream buyers (MBs). We developed a profit-maximizing dynamic programming model and investigated the structural properties associated with the joint decisions on the vendor's replenishment quantity and its management for the MBs demand. We also conducted the numerical experiments to explore the effect of the interplay among the oversupply penalties, the supply to the RB market, and the length of shelf life to the vendor's profitability and disposal management. The numerical results revealed that the two-bin supply strategy combined with the two-period shelf life, as the formulated model addressed in this study, possesses an excellent control on disposal amount and at the same time brings the profit improvement.

■ TC-31

Tuesday, 12:30-14:00 - Room: Maurice Keyworth 1.06

Optimization under uncertainty in Scheduling and Manufacturing

Stream: Stochastic and Robust optimization
Invited session
Chair: Monika Matoušková

1 - Robust optimization approach for Human-robot collaboration assembly line balancing problem
Sihu An, Byung Do Chung

As technology advances, the goal should not be to replace humans but to find ways for technology to coexist with them. The traditional Assembly Line Balancing Problem (ALBP), a long-standing challenge in manufacturing, is evolving to incorporate Human-Robot Collaboration (HRC-ALBP) in response to the expanding cobot market. HRC-ALBP considers human-cobot collaboration and simultaneously addresses task allocation and scheduling. However, human workers inherently exhibit task time uncertainty, which can lead to line stoppages and worker reallocation, resulting in significant cost implications. This study models HRC-ALBP under task time uncertainty using the robust local search approach, integrating a general cobot system with a widely studied ALBP framework. Furthermore, through experiments, this study examines how cobots enhance assembly line productivity and to what extent they can mitigate task time uncertainty for human workers.

2 - Approaches to Master Production Scheduling with Pricing Decisions and Demand Uncertainty
Muhannad Alturk, Christoph Schwindt

Abstract: Master production scheduling (MPS) is concerned with the mid-term planning of production quantities for a portfolio of final products, which are manufactured in series production mode. The objective consists in maximizing the total contribution margin generated from meeting forecasted demands subject to limited production capacities over a multi-period planning horizon. In this talk, we present a brief review of selected MPS papers focusing on approaches that including pricing decisions or demand uncertainty. Despite their practical relevance, these aspects have been considered only rarely in the MPS literature. Based on a first conceptual model, we explain how pricing decisions and demand uncertainty can be formulated within the framework of stochastic mathematical programming. Computational results for a two-stage stochastic formulation containing standard price-demand functions like a linear demand curve indicate that a relatively simple

two-stage sampling approximation approach can provide noticeable improvement as compared to deterministic standard master production scheduling.

3 - Location and capacity planning of charging stations for coupled transportation and power distribution networks
Wenjie Hu, Yang Wang, Wei-Neng Chen, Jin-Kao Hao

The rapid growth of electric vehicle (EV) adoption presents significant challenges for charging station deployment, which impacts both the fulfillment of EV charging demand in urban transportation network (TN) and load management in power distribution network (PDN). In this research, we study the location and capacity planning problem of charging stations that couples TN and PDN features. We focus on incorporating three critical aspects into the optimization problem modeling: a multi-period decision horizon, uncertainties on EV charging demand, and load balancing in the PDN. Our objective is to determine the optimal locations and capacities for charging stations, along with the necessary grid expansions at each time period, with the aim of minimizing the total investment budget. To model the problem, we propose a multi-stage stochastic integer programming approach that uses a scenario tree to capture uncertainties in EV charging demand. To tackle computational complexity in large problem instances, we develop an iterative adaptive kernel search algorithm (IAKSA), a heuristic framework for solving mixed-integer linear programming problems by identifying a promising subset of decision variables as a "kernel" and iteratively expanding this kernel to find improved solutions. Computational results demonstrate that IAKSA outperforms conventional branch-and-cut algorithms and other meta-heuristics in solution quality and convergence efficiency.

4 - Fixed Interval Scheduling with Random Delays: Distributionally Robust Approach
Monika Matoušková

Fixed Interval Scheduling (FIS) problems arise in many practical applications, including transportation and logistics, where jobs must be assigned to machines with predefined start times and fixed durations. However, real-world scheduling is often affected by random delays, making it crucial to account for uncertainty while ensuring feasibility.

We analyze an operational FIS problem where job completion times are subject to random delays with a known dependency structure modeled using Archimedean copulas. We focus on assessing the worst-case probability that a given schedule remains feasible under stress conditions on a proportion of marginal delay distributions. A key reformulation of this problem reveals connections to widely used risk measures, allowing for an efficient decomposition-based solution approach. We present computational results for the problem.

A motivating application for the model is the gate assignment problem at airports, where incoming flights must be assigned to gates while accounting for uncertainty in arrival delays. The heterogeneous nature of aircraft-gate compatibility and the possibility of uncertain arrival delays make this a compelling test case.

■ TC-32

Tuesday, 12:30-14:00 - Room: Maurice Keyworth 1.09

Container Stacking and Yard Planning-1

Stream: Maritime and Port Logistics
Invited session
Chair: *Christopher Expósito Izquierdo*
Chair: *Israel López-Plata*

1 - Smart stacking import containers in multiple yard blocks at container terminals
Yuanjun Feng, Liqun Liu, Dongping Song, Ying Xie

Efficient storage planning for newly arriving containers is a critical decision-making challenge at container terminals. This decision is typically structured hierarchically at two levels: (1) the yard block level, which determines the number of containers allocated to each block, and (2) the yard slot level, which assigns each container to a specific storage location within a block. In import container operations, block-level planning often prioritises vessel handling efficiency during the stacking process while overlooking future retrieval efficiency. At slot-level planning, the smart stacking strategy has been shown to improve retrieval efficiency for import containers in a single block by creating relocation-free stacks. This study applies the smart stacking strategy to a multi-block setting, where the block-level planning has been addressed yet the selection of individual containers for each block remains undetermined. Given a predetermined number of import containers unloaded from each vessel to each block, we optimise the assignment of individual containers to blocks and their storage slots, aiming to minimise the container retrieval time while maintaining vessel handling efficiency. We formulate the problem as a mixed-integer programming model and develop a heuristic algorithm to generate efficient solutions. Computational experiments demonstrate the effectiveness of the proposed model and the efficiency of the algorithm.

2 - Multi-objective container stacking to enhance productivity and reduce energy consumption at terminals
Cihan Butun, Afshin Mansouri, Ran Wang

Efficient container stacking in terminal yards requires careful planning to minimize unproductive activities and optimize cargo flow between vessels and customers. This study explores a multi-objective container stacking problem, focusing on operational productivity and the energy efficiency of yard equipment. A scattered stacking policy can reduce container reshuffles and enhance service efficiency but may increase fuel consumption due to longer travel distances for yard cranes and trucks. Conversely, consolidating containers in a smaller area and stacking them higher can lower fuel consumption but may increase reshuffles, negatively impacting service quality. To address this trade-off, we employ two procedures, an archive-based algorithm and an evolutionary algorithm, to generate a diverse set of non-dominated solutions. We compare the effectiveness of these methods and analyze their impact on fuel efficiency and the reduction of unproductive movements using real-world data from a container terminal in Spain.

3 - The influence of instance-specific information on solution approach design - A case of storage space allocation
Jana Ries, Rosa G. González-Ramírez

With ports being a strategic hub in the global systems of transport and operations, yard management continues to be a highly sensitive component. This includes a number of optimisation problems, with the container space allocation problem being at the heart of it. In solving this, scientific advances continue to seek capturing elements of agility into the methodological design of solution approaches to improve performance.

The work aims to investigate problem-specific information for the container space allocation problem that facilitate the design of solution approaches with instance-specific information in mind. Particular focus will be drawn towards the consideration of contextual information and port characteristics such as infrastructural information that may influence the performance of solution designs. Relevant gaps for future research are presented.

4 - The stack loading problem with load-bearing limit
Xinbo Zhang, Minming Li, Zhou Xu, Yingchao Zhao

The stack loading problem has been studied in recent years for its great impact on the container loading and unloading operations. Among different objectives of the problem considered, minimizing the total number of unordered stackings and minimizing the total number of used stacks are the two important ones, which ensure efficient loading and unloading schedules, as well as reduce storage costs, respectively. The load-bearing setting, where each container has its own weight and bearing weight, is frequently considered in box packing operations but rarely in the existing studies on the stack loading problem. However, the load-bearing constraint on containers is very important for stack loading, because safety is of paramount importance. This paper is the

first study on the stack loading problem with the load-bearing constraint with an aim to minimize the number of stacks and the number of unordered stackings. We show that this problem is strongly NP-hard even when the number of stacks is given and equals 2. For the case where the number of stacks is given and jobs on the bottom tiers are fixed, we show that the problem can be solved by dynamic programming in pseudo-polynomial time. For the general problem, based on a two-index integer linear programming formulation and a tabu search heuristic, we develop a binary-search based matheuristic. Our experimental results demonstrate the efficiency and effectiveness of the newly developed matheuristic.

■ TC-33

Tuesday, 12:30-14:00 - Room: Maurice Keyworth 1.31

Behavioural operations 2

Stream: Behavioural OR
Invited session
Chair: Melvin Drent

1 - Managing supply disruptions for risk-averse buyers: Diversified sourcing vs. disruption prevention
Xin Chen

Diversified sourcing has traditionally been a popular approach for managing supply risk compared to disruption prevention. However, COVID-19 crisis has emphasized the critical importanceof disruption prevention. Additionally, the economic fears arising from the crisis have led managers to adopt a more risk-averse stance. Despite the growing importance of risk aversion, existing studies have primarily focused on examining the impact of risk aversion on a specific approach, disregarding its influence on the selection of different approaches. As companies recognized the importance of investing in reliability to prevent disruptions, this research aims to investigate how risk aversion affects the selection of approaches to mitigate supply disruptions. Within a framework where both diversified sourcing and disruption prevention offer equivalent payoffs for risk-neutral buyers, our study unveils that risk-averse buyers, particularly when the level of disruption risk is relatively low and their risk aversion is relatively high, prefer to "mitigate but retain the risk of disruption" through diversified sourcing or partial prevention. This stands in contrast to risk-neutral buyers who consistently make choices between completely avoiding risk or accepting all risk through sole sourcing or no/complete prevention. More interestingly, the adoption of diversified sourcing and partial prevention yields distinct payoffs for risk-averse buyers.

2 - Maximizing customer retention in multi-stage training services: Model and solution algorithm
Qiuwei Guo, Yifu Li, Lindong Liu, Lifei Sheng

Training is an important business in the service sector. Although performance-enhancement training programs receive considerable attention from operations management researchers, the literature lacks guidance on designing maintenance training programs. We close this gap by investigating the modeling and optimization of a maintenance training program, considering the behavior that a customer may abandon the program if the training experience is too stressful. We formulate the maintenance training program design problem (MTDP), which maximizes overall service retention across all training sessions through activity scheduling. Customers make their participation decisions about their next training program based on the remembered holistic utility of past training activities. By our analysis, MTDP is a 0-1 constrained exponential sum problem (0-1 CESP), which is proven to be NP-hard. To resolve MTDP, we introduce a novel geometric branch and bound (GB&B) algorithm that searches for the optimal solution by resolving a series of subproblems. Our GB&B algorithm is proven to be efficient through our computational studies, and it has the potential to resolve other 0-1 CESPs that cannot be efficiently solved by traditional branch and bound algorithms due to difficulty in computing the bounds directly.We contribute to the literature by discussing a mathematical model, a solution method, and managerial insights for maintenance training program design.

3 - A newsvendor model with multiple reference points: Target-setting for aspirational newsvendors
Tian Bai

Prospect theory suggests that the classification of outcomes as gains or losses depends on reference points, significantly influencing individual decision-making. Reference points can include both external targets and internal aspirations (self-goals). While growing evidence highlights the simultaneous impact of multiple reference points on decision-making, this phenomenon has received limited attention in operations management literature. This study investigates the influence of an external target as a reference point on the decisions and profitability of newsvendors who also possess a well-defined self-goal reference point. Two types of newsvendors are identified: balanced newsvendors, who harmonize personal needs with target achievement and are influenced by dual reference points, and focused newsvendors, who prioritize target realization and are guided solely by the target reference point. The findings reveal that the effects of target-setting on expected profits for both types of newsvendors depend on the specific value of their self-goal. Target-setting can yield advantages or disadvantages, contingent on the self-goal, with balanced newsvendors more likely to benefit. Additionally, scenarios where a newsvendor's self-goal is updated demonstrate potential for further performance improvement among balanced newsvendors.

4 - When alarms fall silent: Human-adaptive maintenance optimization
Melvin Drent, Bas van Oudenhoven, Collin Drent, Rob Basten, Philippe van de Calseyde

Sensors that monitor equipment may predict a problem unnecessarily. If this happens more often, service engineers may ignore the warnings. We perform an experiment to test people's reactions to warnings. Using our findings we improve the timing of warnings and perform a second experiment to confirm improved performance.

■ TC-34

Tuesday, 12:30-14:00 - Room: Michael Sadler LG10

Advancements of OR-analytics in statistics, machine learning and data science 4

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: Olabode Adewoye
Chair: Cem Iyigün
Chair: Gerhard-Wilhelm Weber

1 - Risk Assessment of Condition-Based Maintenance Contracts
Stijn Loeys, Melvin Drent, Robert Boute, Collin Drent, Katrien Antonio

We assess the financial risk incurred by maintenance service providers responsible for delivering preventive and corrective maintenance under a fixed upfront fee agreement. Preventive maintenance is optimized based on operational condition data to minimise maintenance costs. Operational data allows the explanation of machine heterogeneity in the failure behaviour, however, this data is only accrued during the contract. We propose a method to jointly estimate the failure distribution and optimize the preventive maintenance policy using operational data revealed during the contract. We incorporate machine heterogeneity via Bayesian updating of the failure distribution's parameters. Bayesian updating is used to sequentially estimate the contract's

maintenance costs and hence estimate its risk. The posterior distributions of the failure parameters allow us to quantify the parameter uncertainty at each moment in the contract by building a maintenance cost distribution. By performing an extensive simulation study, we show that including operational data revealed during the joint estimation of the failure distribution and optimization of the preventive maintenance policy, the contract's expected maintenance costs are more accurate, and more competitive compared to a one-size-fits-all approach.

2 - Spatial-Temporal Prediction Models and Grid Resilience Study Using National-Scale Electricity Outage Datasets
Feng Qiu

Electricity outages are becoming increasingly costly as society grows more dependent on electricity, with U.S. losses reaching $150 billion annually. Modeling and mitigating outage risks are critical for grid resilience, yet traditional physics-based simulations require extensive circuit data and computing power, limiting their scalability. Furthermore, the risk modeling and mitigation need to be more closely integrated for more agile and actionalable disaster response planning.

This talk explores data-driven approaches for outage risk modeling using a national-scale electricity customer outage dataset (95% of U.S. counties, 15-minute resolution). First, we introduce a non-homogeneous multivariate Poisson process hybridized with a deep neural network to predict outages based on forecasted weather, providing spatial-temporal interpretability and insights for resilience planning. Second, we present a neural Ordinary Differential Equation (ODE) model to capture outage occurrence and recovery. We integrate this with a predict-all-then-optimize-globally (PATOG) framework, ensuring coherent, efficient decision-making for outage mitigation.

Finally, we will introduce a real-time outage forecasting web application developed by Argonne National Lab, which predicts U.S.-wide outages 48 hours in advance.

3 - An interpretable machine learning approach to day-ahead extreme electricity price forecast with imbalanced data
Jingchuan Ma, Yu-wang Chen, Fanlin Meng

In recent years, the frequency and magnitude of extreme electricity prices have increased due to the growing share of renewable energy and external market dynamics, challenging market participants. Accurate forecasting of such extremes is crucial for market stability and risk management. To address this, we first introduce a Dynamic Weighted Threshold method for extreme price identification, enabling adaptive threshold adjustments based on market conditions.

Furthermore, we propose a Weighted-XGBoost model to predict extremely high and low electricity price occurrences in an imbalanced data context. Compared to baseline models, it demonstrates superior predictive performance. To enhance interpretability, SHAP (SHapley Additive exPlanations) is used to analyse feature contributions. Results indicate that extremely high prices are driven by complex interactions among supply-demand conditions, fossil fuel prices, and historical market behaviors. In contrast, extremely low prices are primarily influenced by forecasted residual load, highlighting a more deterministic supply-demand relationship.

By integrating dynamic extreme price identification, advanced forecasting, and explainability techniques, this study improves understanding of extreme price dynamics. The proposed approach is adaptable to various electricity markets, offering valuable insights for market operators and participants aiming to enhance risk management and forecasting accuracy.

4 - Value-oriented forecast reconciliation for renewables in electricity markets
Honglin Wen, Pierre Pinson

Forecast reconciliation is considered an effective method for achieving coherence and improving forecast accuracy. However, the value of reconciled forecasts in downstream decision-making tasks has been mostly overlooked. In a multi-agent setup with heterogeneous loss functions, this oversight may lead to unfair outcomes, hence resulting in conflicts during the reconciliation process. To address this, we propose a value-oriented forecast reconciliation approach that focuses on the forecast value for individual agents. Fairness is ensured through the use of a Nash bargaining framework. Specifically, we model this problem as a cooperative bargaining game, where each agent aims to optimize their own gain while contributing to the overall reconciliation process. We then present a primal-dual algorithm for parameter estimation based on empirical risk minimization. From an application perspective, we consider an aggregated wind energy trading problem, where profits are distributed using a weighted allocation rule. We demonstrate the effectiveness of our approach through several numerical experiments, showing that it consistently results in increased profits for all agents involved.

■ TC-35

Tuesday, 12:30-14:00 - Room: Michael Sadler LG15

Recent trends in zeroth order and simulation-based optimization: 1

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: *Silvia Villa*
Chair: *Cesare Molinari*
Chair: *Lorenzo Rosasco*

1 - An Efficient Network-aware Direct Search Method for Influence Maximization
Matteo Bergamaschi, Francesco Rinaldi, Francesco Tudisco, Sara Venturini

Networks play a crucial role in understanding real-world scenarios by revealing patterns, key nodes, and predicting information, disease, or innovation spread. The Influence Maximization problem, a significant challenge in network analysis, targets identifying influential individuals for various domains like marketing, public health, and social media. In this talk, we introduce a more comprehensive model for information propagation on networks, catering to a broader range of dynamics. Then we introduce Network-aware Direct Search (NaDS), a new direct search method tailored for the Influence Maximization problem. Unlike conventional methods, our approach guarantees good performances in diverse settings where traditional approaches falter, even in large-scale networks with thousands of nodes.

2 - Variance Reduced Gradient Tracking for Distributed Zeroth-Order Optimization
Yujie Tang, Huaiyi Mu, Zhongkui Li

In this talk, we investigate distributed zeroth-order optimization for smooth nonconvex problems. We propose a new variance-reduced gradient estimator, which randomly renovates one orthogonal direction of the true gradient in each iteration while leveraging historical snapshots for variance correction. By integrating this estimator with the gradient tracking mechanism, we address the trade-off between convergence rate and sampling cost per zeroth-order gradient estimation that exists in current zeroth-order distributed optimization algorithms, which rely on either the 2-point or 2d-point gradient estimators. We also derive convergence rate results for the proposed algorithm under the smooth and nonconvex setting, showing that our algorithm achieves comparable performance with its first-order counterpart. Numerical simulations comparing our algorithm with existing methods further confirm the effectiveness and efficiency of the proposed algorithm.

3 - A derivative-free algorithm based on resilient positive spanning sets
Sébastien Kerleau

Positive spanning sets (PSSs) are sets of vectors spanning the Euclidian space using non-negative linear combinations. They can also be defined as sets properly approximating any given direction in the space and as such they prove very useful in derivative-free optimization algorithms. Optimization methods based on PSSs typically favor those with the best cosine measure, as this implies that the elements of the PSS are well spread. However, this metric does not fully account for the structure of the PSS: in particular, it does not reflect the spanning capabilities of a given subset of the PSS vectors. In this talk, I will focus on a particular subclass of PSSs, called positive k-spanning sets. A positive k-spanning set (PkSS) remains positively spanning when some of its elements are removed. After formally defining the positive k-spanning property, I will provide a simple method to construct PkSSs whose subsets possess a large cosine measure. Using such sets, I will introduce a derivative-free algorithm based on parallel computing, that will prove to be resilient to stragglers or even failures of parallel evaluations.

■ TC-38

Tuesday, 12:30-14:00 - Room: Michael Sadler LG19

Forecasting, prediction and optimization 3

Stream: Data Science meets Optimization
Invited session
Chair: Bahman Rostami-Tabar

1 - Good intentions, unintended consequences: Exploring forecasting harms
Bahman Rostami-Tabar

Organizations worldwide that rely on data-driven approaches regularly employ forecasting methods to enhance their planning and decision-making processes. While extensive research has examined the harms associated with traditional machine learning applications, relatively little attention has been given to the ethical implications of time series forecasting. However, forecasting presents distinct ethical challenges due to its diverse organizational applications, varied objectives, and unique data processing, model development, and evaluation workflows. These distinctions complicate the direct application of existing machine learning harm taxonomies to common forecasting scenarios. To address this gap, we conduct multiple interviews with industry experts and academic researchers, systematically identifying and analyzing under-explored domains, use cases, and potential risks associated with forecasting. Our objective is to develop a novel taxonomy of forecasting-specific harms. Drawing inspiration from Microsoft Azure's taxonomy for responsible innovation, we integrate a human-led inductive coding approach with AI-driven analysis to extract key categories of harm in forecasting.

2 - Optimizing Promotional Product Distribution in Retail with Machine Learning: A Decision Support Approach
Eslem Guler Kose, Fatih Mehmet Yilmaz, Ebru Özcan, Ridvan Taylan

Efficient product distribution is crucial in retail, impacting customer satisfaction and business profitability. Traditional methods often rely on assumptions and manual opinions, leading to error-prone processes, resulting in stockouts or overstock issues, which negatively affect customers and businesses. This study addresses these challenges by leveraging advanced machine learning algorithms. The primary objective of the research is to increase sales of promotional products by reducing stockouts and overstocks, preventing unexpected holding costs, and optimizing distribution. By analyzing multidimensional datasets, such as previous promotion data, risk profiles, transactional data, and product similarities, this research aims to develop a system that accurately predicts the future distribution of each product to allocated stores and provides decision-support recommendations. Various machine-learning algorithms were employed during the estimation process. Among them, the XGBoost algorithm, which uses bagging to train multiple decision trees and then combines the results, was chosen as the primary model due to its high accuracy. Implementing this strategy has already streamlined distribution efforts by a factor of ten, ultimately maximizing the effectiveness of delivering promotional products to relevant stores. By discovering these patterns, we aim to direct products towards the most efficient distribution channels, enhancing operational efficiency and increasing turnover.

3 - A Predict-then-Optimize Framework for Traffic Allocation in Local Commerce Recommendation Systems
Yani Ji, Yang Nan, Ran Ao, Yanting Jin, Ning Zhu, Zhu Meng, Jie Chen, Yun Long

With the surging trend of users utilizing local commerce platforms to search for nearby in-store services, these online platforms require to perform local searches more efficiently and more accurately. This study introduces a data-driven predict-then-optimize framework for determining the optimal impression structure of supply assortments. Our approach leverages a multilayer perceptron (MLP) to estimate conversion rates by dissecting and modeling the interdependencies amongst user attention distribution, the positional distribution of category proportions, and quality stratification (e.g., price and distance segment distributions). The MLP extracts latent patterns from these multifaceted inputs, while a Gaussian Mixture Model (GMM) further captures the complex interplay among them. Building on these predictions, we formulate a nonlinear programming model (NLP) designed to maximize overall conversion rates and develop a tailored heuristic algorithm that obtains the impression structure of supply assortments. We test our approach on a real-world dataset from the online food service sector. The results reveals that our framework not only enhances the precision of conversion rate predictions but also achieves a 7% improvement in conversion rates over existing strategies, underscoring its practical applicability in enhancing the performance of local commerce recommendation systems.

4 - A Quantum and Binary Incremental Learning Procedure for Categorical and Ordinal Classification
Yueh Lin, Luis Perez, Stefano Nasini, Martine Labbé

This paper explores mathematical programming approaches for categorical and ordinal classification, leveraging decision tree and disjunctive normal form representations. We analyze the equivalence conditions of these formulations and develop an incremental learning procedure that solves a sequence of reduced problems. We examine both linear (MILP) and quadratic (QUBO) formulations, solving the latter using quantum adiabatic/variational techniques. Our incremental learning approach strategically reduces problem size by iteratively refining feature selection, enabling efficient solutions while preserving classification accuracy. Computational experiments demonstrate that our method significantly accelerates convergence while achieving optimal (or near-optimal) classification accuracy across benchmark datasets. Moreover, our results reveal that quantum adiabatic/variational methods can outperform traditional branch-and-bound and feasibility pump algorithms for small to medium-sized instances. These findings lay the foundation for a unified, optimization-driven approach to statistical classification, bridging classical and quantum computational paradigms.

■ TC-39

Tuesday, 12:30-14:00 - Room: Newlyn LG.01

Resilient Infrastructure System

Stream: Sustainable & Resilient Systems and Infrastructures
Invited session
Chair: Jack Thompson

1 - Resilience assessment of cross-border freight transport networks considering cascading failure
Tonglaga Wang

As the Belt and Road Initiative advances, cross-border railway projects like the China-Europe Railway Express enhance regional connectivity. However, deglobalization and geopolitical conflicts increase network uncertainties. Disruptions such as natural disasters, failures, or attacks can trigger cascading failures, where local faults spread, causing systemic collapse, service disruptions, and economic losses. The 2022 Russian railway explosion highlighted network vulnerabilities. This study applies hypernetwork theory and the coupled map lattice (CML) model to analyze the network's topology (degree distribution, node importance) and simulate cascading failures under random and targeted attacks. Key findings include (1) Border ports like Alashankou and Khorgos are the most vulnerable. (2) Targeted attacks on high-degree and high-betweenness nodes cause greater damage than random attacks. (3) The topological coupling coefficient strongly influences failure propagation. (4) As flow coupling increases, impact shifts from high-strength to high-degree nodes. This study provides strategies to enhance network resilience. (1) Use redundancy design to optimize topology and mitigate power-law effects at key nodes. (2) Prioritize resources for failed nodes; pre-allocate to congestion-prone nodes and transfer-limited nodes. (3) Strengthen safeguards for high-degree and high-betweenness hubs, establishing dynamic risk monitoring.

2 - Formulation and solution of a tri-level MILP for the resilient design of operational water distribution networks
Aly-Joy Ulusoy, Ivan Stoianov

We consider the design problem which consists in installing new links to improve the resilience of water distribution networks (WDN). The problem is formulated as a so-called defender-attacker-defender problem, where the defender first installs new links, the attacker then selects the worst-case pipe failure scenario for the given design and, finally, the defender adopts an optimal incident response strategy maximizing total satisfied customer demand. The resulting tri-level MINLP features non-convex energy conservation and pressure-dependent water demand constraints in its lower-level problem. These constraints are linearized to improve tractability, transforming the problem into a tri-level MILP with binary variables in its upper and middle-level problems, and mixed-integer recourse variables. A tailored nested column-and-constraint generation algorithm is developed to solve the relaxed WDN design problem. The algorithm is shown to provide an upper bound on the total satisfied customer demand under the worst-case pipe failure scenario. The method is applied to optimize the expansion of the Anglian Water Newmarket operational network for different numbers of new valve installations. The true resilience of computed tri-level MILP solutions is evaluated a posteriori by performing a critical link analysis. This, in turn, provides an attainable solution to the original tri-level problem and a lower bound on the total supplied demand under the worst-case pipe failure scenario.

3 - Multilevel Modeling and Clustering of Risk Perceptions of Climate and Severe Weather and Natural Hazard Preparedness Across Countries to Inform Disaster Risk Communicatio
Jack Thompson, Suraje Dessai, Sarah Jenkins, Yim Ling Siu, Barbara Summers, Andrea Taylor

Understanding factors that shape public risk perceptions of climate and severe weather events, and their levels of preparedness, is essential for crafting effective disaster risk communication and reduction strategies. Prior research examines individual-level factors, such as personal experience, in isolation, focusing on their influence on risk perceptions and preparedness at a moment in time. This approach is limited, as it neglects the potential role of country-level factors, like governance, and the way the dynamics vary over time. Here we address this gap, exploring the influence of individual and country-level influences using data from the Lloyd's Register Foundation World Risk Poll, gathered every 2 years since 2019 from 143 countries, and integrating country-level indicators on natural hazards, climate trends, governance quality, and economic status. Our multilevel models indicate that individual experiences with severe weather and projected increases in flood risks are among the strongest predictors of heightened risk perceptions. We also find that effects of factors like age and urbanicity vary across countries. To make our findings actionable, we group countries using cluster analysis into six distinct clusters based on preparedness, affluence, and severe weather concern. The results offer valuable insights for tailoring risk communication, enabling agencies to effectively design interventions, and ultimately enhancing preparedness and resource allocation.

4 - Extended Goal Programming Surveillance Scheduling for Undersea Infrastructure Safety and Security
Banafsheh Khosravi, Tsz Yu Suen, Dylan Jones, Ashraf Labib

This study presents a novel approach to allocating surveillance assets to proactively protect undersea cables within offshore wind farms. The objective is to optimise surveillance operations across different levels, including sea surface and undersea, by maximising coverage while minimising operational costs and completion time. To achieve this, the problem is formulated as a combination of Extended Network Goal Programming and a Modified Open-Shop Scheduling (ENGP-MOSS) model, which helps to understand the performance and behaviour of trade-offs and achieving balance across objectives, network, layers and nodes, and addressing conflicting objectives. Another novel feature of the proposed approach is the incorporation of a Fibonacci weighting scheme, which prioritises network layers based on their relative importance, determined by the number of cables connected downstream. Computational experiments on a UK wind farm case study are conducted to evaluate the performance of the model, along with sensitivity analysis on weight parameters within ENGP and objective functions.

■ TC-41

Tuesday, 12:30-14:00 - Room: Newlyn GR.01

Evolution, Design, and Application of GSS in Structuring Complex Problems

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: Isabella Lami
Chair: *Mike Yearworth*

1 - Conceptualising an intangible form of GSS based upon multiple tangible elements
Eleanor Reynolds

We might typically expect a GSS to be tangible. A tool that we use, a model that we produce or have produced, through a process that may be supported with technology and could be delivered by a facilitator. Within a community of practice, preferences might be established concerning the form that GSS should take, along with expectations about participant roles and behaviours. We might also expect that GSS are targeted to structure a specific complex or wicked problem. This talk considers what we might see when explicit models are absent, conceptualising Collective Prior Appreciation (CPA) as an intangible form of GSS that is based upon a communal appreciation of multiple tangible elements. Empirical examples are given to illustrate how Collective Prior Appreciation (CPA) might be applied across multiple situations and how this application might be interpreted as the means of maintaining and evolving this intangible, community GSS.

2 - Argumentation schemes for urban decision support
Beatrice Mecca, Isabella Lami, Marta Bottero, Gabriella Pigozzi, Alexis Tsoukias

Decision-making in urban planning and design is inherently complex, involving a plurality of actors, interests, dimensions and uncertainties. In this context, evaluation assumes a crucial role in supporting decisions, guiding priorities based on data obtained from analysis, measurement and estimation. The paper explores the potential benefits of argumentation theory, which offers specific tools to manage the complexity of information and knowledge related to the situation under

consideration. Argumentation-based approaches not only facilitate the identification of the most justified choice but also make it possible to formulate a final recommendation through a logical formalism, graphically represented and easily understood by all actors involved. In this sense, the research explores the application of argumentation theory to the urban and architectural context through the analysis of an emblematic case study of the city of Turin, which has seen numerous actors, interests and critical points in its decision-making process, proposing some argumentation schemes a posteriori. The intention is to observe the potentialities and criticalities of this approach in decision support in the urban context and to abstract potential recommendations with respect to future skyscraper projects.

3 - How does software support decision-making processes in the group dynamic?
Elena Todella, Isabella Lami

Navigating today's interconnected world demands decision-making methodologies that balance diverse perspectives while leveraging digital tools. This study examines whether decision-support software fosters new affordances within group dynamics by analyzing a specific software, Multi-Values Appraisal Methodology (MuVAM), which integrates the Strategic Choice Approach with the Analytic Hierarchy Process via cloud technologies. MuVAM allows synchronized and connected use, digitally and also in asynchronous mode. Data from eight sustainable urban development workshops, conducted over 15 months across four European countries in three languages, were analyzed. Interestingly, the participants were quite diverse, with a varied experience in terms of educational level and background. Feedback from the workshops was collected through a report or a Google survey, through a series of questions covering both group dynamics and individual choices. Findings indicate that software promotes knowledge exchange and the emergence of a "Plural Subject" on the social level, while technically acting as a transitional object for interactive analysis. These insights enhance understanding of how digital artifacts shape the social and technical dimensions of collaborative decision-making.

■ TC-42

Tuesday, 12:30-14:00 - Room: Newlyn GR.02

Regulations in sustainable supply chains

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: Jean-Pierre Kenne

1 - Carbon Emissions Reduction in Competitive Supply Chains under Carbon Cap-Sharing Mechanism
Chang Lyu, Songsong Liu

The conventional carbon quota allocation system often imposes disproportionate emission reduction burdens, leading to inefficient surplus allowance utilization. The carbon cap-sharing mechanism promotes efficient carbon asset utilization by facilitating internal quota trading at lower prices and using external trading to address any remaining imbalances. This study develops a Stackelberg game model under the cap-and-trade policy, with the supplier as the leader and manufacturers as followers. One manufacturer faces a shortage of carbon quotas due to high emissions, while the other has a surplus due to low emissions. Three scenarios are analyzed: (i) external carbon trading only, (ii) horizontal carbon trading between manufacturers before external trading, and (iii) vertical carbon trading between the supplier and a manufacturer before external trading. Results show that horizontal carbon trading improves cost efficiency and reduces reliance on external markets, while vertical carbon trading enhances coordination between the supplier and manufacturers. Comparative analysis shows that centralized decision-making leads to better emission reduction outcomes, while sensitivity analysis indicates that market competition, consumer preference for low-carbon, and carbon pricing affect strategic decisions. These insights can guide policymakers and supply chain managers in optimizing environmental and economic performance through cap-sharing mechanism.

2 - Green upgrades under emission cap regulation
Zhiyuan Cao, Jianxiong Zhang

Driven by emission regulations and the growing trend of environmental awareness, manufacturers are increasingly motivated to implement green upgrades in their products and production processes. However, the lack of market information to these upgrades creates uncertainty about the returns, as manufacturers typically lack direct market access and expertise in demand forecasting. This paper examines how the emission regulation—specifically focusing on emission cap—and asymmetric information about market demand influence manufacturers' green upgrade and pricing decisions. We develop a game model involving a manufacturer and a retailer, where the retailer holds private information about market demand, resulting in a signaling game. Our findings show that the impact of the emission regulation on the manufacturer's upgrade decisions is non-monotonic. Under perfect information, when the emission regulation is strict, a moderate relaxation of the regulation can promote green upgrades, with this effect further amplified under asymmetric information. Additionally, we find that the retailer's private information benefits the manufacturer. When the retailer observes low market demand, they are incentivized to lower the marginal price to avoid being mimicked. Finally, we observe that asymmetric information increases both consumer surplus and social welfare compared to the symmetric scenario, particularly when the emission regulation is relatively lenient.

3 - Carbon Emissions Reduction and Fresh-Keeping Strategies of Fresh Food Supply Chain under Heterogeneous Carbon Tax Policies
Songsong Liu, Mingxuan Chen

Climate change has prompted global countries to implement carbon emissions reduction policies, including carbon tax policy, etc. However, no literature work has considered both carbon emissions reduction and fresh-keeping strategies under the broader effects of heterogeneous carbon tax policies. This work considers a fresh food supply chain consisting of one supplier and one retailer, which decide their freshness-keeping and carbon emissions reduction efforts, as well as pricing. Three different carbon tax policy configurations are examined, including upstream-only, downstream-only, and bilateral carbon tax. Decentralized decision-making is investigated based on Stackelberg game theory. In addition, the centralized decision-making is considered and a Nash bargaining based profit-sharing scheme is proposed for fair profit allocation. The effect of carbon tax rate on the optimal strategies is also investigated. The results reveal that upstream-only, as well as downstream-only, carbon tax directly impacts the tax payer's emissions reduction effort and indirectly affects the other one. Full-chain carbon tax induces significantly higher emissions reduction and fresh-keeping efforts, with elevated wholesale and retail prices, while the supplier's profit increases whereas the retailer's profit declines, compared with upstream-only tax, and vice versa for the downstream-only tax, showing trade-off between economic and environmental effects.

4 - Production Planning for a Closed-Loop Hybrid Manufacturing/Remanufacturing System with Emissions Control
Jean-Pierre Kenne

This paper explores the stochastic optimal control problem in a closed-loop hybrid manufacturing-remanufacturing system, which faces random failures while managing greenhouse gas (GHG) emissions. The system consists of two machines—one for manufacturing and one for remanufacturing—producing a single product type. The performance is evaluated by minimizing the total cost, which includes inventory holding, shortage, manufacturing and remanufacturing costs, as well as penalties for exceeding GHG emission limits set by regulations. The goal is to identify optimal production control policies that minimize total costs over an infinite time horizon while adhering to environmental constraints. The study highlights the significance and practicality of

incorporating environmental goals, such as GHG reduction and product reuse, into manufacturing system control to help preserve the environment. In this article, we develop optimal control policies for manufacturing systems within a dynamic stochastic context, considering the greenhouse gas (GHG) emissions produced during the decision-making process. Our goal is to propose optimization models that focus on minimizing the total incurred cost, which includes costs related to the storage of finished products, shortages, production, maintenance, and GHG emissions exceeding regulatory limits.

■ TC-43

Tuesday, 12:30-14:00 - Room: Newlyn GR.07

GenAI and Learning

Stream: Software for Optimization
Invited session
Chair: Jens Schulz

1 - GenAI and OR - a boost for productivity?
Jens Schulz

In Operations Research, we deal with complex business problems such as optimizing a logistics network incorporating uncertain demands, prices, and capacities along the supply chain, or identifying a pricing strategy that balances competing objectives such as expected return and risks. Deriving insights from data and running strategies what the best path forward is key to decision makers. With simple answers they are facing the challenge of trust; with complex answers and user interfaces, they feel overwhelmed. There are reoccurring themes of (i) missing data quality, (ii) the need for flexible software tools that adapt to the business situation rather than pre-canned screens, and (iii) efforts to level up via trainings in order to dare using decision support tools.

From the data scientist to the decision maker, there is a huge potential for where Generative AI can make users more productive and enables them to go beyond the current status quo. Onboarding experience for new software tools as well as having the right information at hand and presented in the right context is key. At the same time, a proper responsible AI policy is required by companies emphasizing transparency, ethical aspects and explainable outcomes before putting such models into production. Generative AI will not resolve all problems, yet, integrated properly into the tools with focus on the user needs and current obstacles it is having tangible impact.

2 - Generative AI for solving optimization problems: Is it helpful?
Mario Ruthmair

AI is reshaping many business fields, but can it reliably assist practitioners in solving optimization problems? This talk explores how Gurobi users can leverage Generative AI in their workflows. We discuss chat bots like the "Gurobot" and the "Gurobi AI Modeling Assistant" (both based on ChatGPT). Through examples, we will examine when AI enhances workflows and when human expertise remains essential.

3 - Embedding neural networks into optimization models with GAMSPy
André Schnabel, Hamdi Burak Usul

GAMSPy is a powerful mathematical optimization package which integrates Python's flexibility with GAMS's modeling performance. Python features many widely used packages to specify, train, and use machine learning (ML) models like neural networks. GAMSPy bridges the gap between ML and conventional mathematical modeling by providing helper classes for many commonly used neural network layer formulations and activation functions. These allow a compact description of the network architecture that gets automatically reformulated into model expressions for the GAMSPy model.

In this talk, we demonstrate how GAMSPy can seamlessly embed a pretrained neural network into an optimization model. We also explore the utility of GAMSPy's automated reformulations for neural networks in various applications, such as adversarial input generation, model verification, customized training, and leveraging predictive capabilities within optimization models.

4 - SupPy - a GPU-accelerated Python toolbox for superiorization of feasibility-seeking projection algorithms
Tobias Becher, Yair Censor, Niklas Wahl

Superiorization is an approach to constrained optimization problems that perturbs an underlying feasibility-seeking projection algorithm to steer it toward a solution with reduced objective function value. Contrary to constrained optimization, the superiorization method does not target the constrained optimum, but aims to find a satisfactory solution of improved objective function value compared to the solution of the bare feasibility-seeking algorithm. SupPy has three main modules: The first module implements flexible feasibility-seeking problems and projection algorithms. An object-oriented structure enables easy definition and solving of small geometric examples in various ways (sequentially, simultaneously, block-iterative and string-averaging), subgradient projections, split problems, as well as more complex implementations for various linear algorithms (Kaczmarz and Landweber methods, ARM, ART3+, etc). The second module enables the definition of perturbation strategies, which can be combined with a feasibility algorithm via a third module which manages their combination in order to perform superiorization. SupPy was tested on small geometric problems, as well as on real world applications like radiotherapy planning (RP) and image reconstruction (IR). All algorithms can be run both on the CPU and GPU, with the GPU allowing fast computation for problems heavily relying on large matrix multiplications (runtime of a few seconds for RP and IR with appropriate methods).

■ TC-44

Tuesday, 12:30-14:00 - Room: Newlyn 1.01

Approaches for handling computational complexity

Stream: Energy Economics & Management
Invited session
Chair: Boyung Jürgens

1 - Integrated Wind Farm Design: Optimizing Turbine Placement and Cable Routing with Wake Effects
Jaap Pedersen, Niels Lindner, Daniel Rehfeldt, Thorsten Koch

In this talk, we address the integrated wind farm layout and cable routing problem, a challenging nonlinear optimization problem. We present an exact solution framework for the novel Quota Steiner Tree problem with interference, optimizing turbine placement and network connectivity simultaneously while meeting expansion targets. Our proposed approach accounts for the wake effect - a region of reduced wind speed caused by each installed turbine - and enforces minimum spacing between turbines. By additionally introducing an interference-based splitting strategy, we show that the advanced solver is capable of tackling large-scale problem instances and outperforms generic state-of-the-art mixed integer programming solvers by up to two orders of magnitude.

2 - Decision-Based vs. Input-Driven Timeseries Clustering for Stochastic Energy System Design Optimization
Boyung Jürgens, Andrew Fulwider, Hendrik Schricker, Niklas von der Assen

Two-stage stochastic programming is widely used for energy system design optimization under uncertainty but can face an exponential increase of computational demand with the number of scenarios. Clustering reduces the number of scenarios: Input-driven clustering (IDC)

groups scenarios by similar inputs, e.g., demand projections. Decision-based clustering (DBC) groups scenarios by similar first-stage (i.e., design) decisions. In energy system design optimization, scenario variability often arises from timeseries data. Performance comparisons of IDC and DBC in energy system optimization frequently relied on timeseries generated by scaling reference patterns, which limits insights for varying timeseries shapes. In this study, we apply IDC and DBC to energy system design optimization with scenarios characterized by timeseries of varying shapes. The case study models a sector-coupled industrial energy system as a linear program. Uncertainty stems from up to seven timeseries, describing energy demands, energy carrier prices, and availabilities of renewables. We assess the performance of IDC and DBC across varying numbers of uncertain timeseries, scenarios, and clusters. Our findings imply that DBC can be more robust against uncertain energy demands than IDC. Our case study shows that DBC can remain more robust when varying the number of uncertain timeseries but is sensitive to the method used to group first-stage decisions, while IDC is computationally efficient but less robust.

3 - An upper bound on suboptimality for finite-horizon approximations of energy storage scheduling problems
Eléa Prat, Richard Lusby

Energy storage systems play a crucial role in the energy transition, making it essential to study their optimal operation. Energy storage scheduling problems are inherently infinite-horizon optimization problems and are therefore challenging to solve directly. In practice, rolling-horizon approaches are widely used, by repeatedly solving finite horizon problems, each time fixing the solution for the first periods and sliding the horizon forward. This raises a fundamental question: how does the horizon length affect solution quality?

We are the first to propose an upper bound on the suboptimality introduced by finite-horizon approximations of energy storage scheduling problems. This allows decision-makers to assess the trade-off between computational cost, data forecasting needs, and solution quality. We also derive a necessary and sufficient condition to detect when the solution of the finite-horizon approximation matches that of the infinite horizon.

Through various case studies, we illustrate how this upper bound decreases as the length of the horizon is incrementally increased until it ensures the optimal solution of the infinite-horizon problem is obtained. We demonstrate the limitations of approaches that increase the horizon length until the optimal solution does not change.

Beyond energy storage, our insights are also directly relevant to capacitated inventory management and warehouse scheduling problems, where similar finite-horizon approximations are common.

4 - Theoretical complexity and a graph-based feasibility algorithm for maximising power restoration in electricity distribution grids
Andrew Eliseev, Florian Steinke

Distribution grids (DGs) deliver electricity from high-voltage networks to end customers, such as households and factories, on a municipal level. A DG is called resilient if it can quickly restore service after a blackout. One way to improve the resilience of modern DGs that has received attention in the literature is through Distribution Service Restoration with Microgrids (DSRM).

DSRM divides a DG into smaller microgrids that can restart independently using generators installed in them. These microgrids can then gradually expand by launching additional generators and restoring power to more customers.

In this study, we assign weights to customers in the DG based on their importance for power restoration and aim to maximise the total weight of supplied customers, calling this problem MaxSupDSRM.

Finding a solution quickly is crucial in an emergency, however, we show that MaxSupDSRM is NPO-complete w.r.t. E-reductions, meaning that it is generally hard to find even a feasible solution for it in polynomial time. We also show that the problem remains difficult under various natural parameterisations relevant to real-world DGs. We then identify a practically relevant special case of MaxSupDSRM for which a polynomial-time algorithm for finding a feasible solution can be presented.

■ TC-46

Tuesday, 12:30-14:00 - Room: Newlyn 1.07

Decarbonizing the industry and heating sectors

Stream: Energy Economics & Management
Invited session
Chair: *Zara Hawezy*

1 - Many Roads to Rome: Near-Optimal Transition Pathways for Industrial Energy Systems Under Uncertainty
Hendrik Schricker, Boyung Jürgens, Maria Louise Schmitt, Niklas von der Assen

Optimization models support the transition of industrial energy systems to low-carbon systems but face uncertainties in input data (e.g., energy prices) and model structure (e.g., decision-maker preferences). Stochastic programming addresses input data uncertainty by considering multiple scenarios. Modeling to Generate Alternatives mitigates structural model uncertainty by identifying near-optimal solutions. Intersecting near-optimal spaces across scenarios reveals near-optimal solutions robust to input data uncertainty. However, high-dimensional multi-year pathway optimization makes established methods for computing these intersections intractable. We propose a scalable method that combines stochastic programming and Modeling to Generate Alternatives to directly explore intersections of high-dimensional near-optimal spaces without explicitly computing geometric representations. We apply our method to a sector-coupled industrial energy system and optimize multi-year pathways under natural gas phase-out by 2045, with uncertain natural gas, electricity, and CO2 prices. We observe that scenario-optimal pathways do not lie in the intersection of near-optimal spaces. We identify over 23,000 near-optimal pathways, with at most 15% higher costs than scenario-optimal pathways. Wind turbines and PV systems emerge as must-have early investments. Our approach enables decision-makers to identify flexible decarbonization strategies and avoid lock-ins in energy transition planning.

2 - Could companies gain a competitive advantage with daylight-oriented working time models?
Michael Schlicker

The expansion of solar energy leads to energy surpluses in the summer, with a drop in energy prices, while solar production collapses in the winter. Therefore, it is discussed under which conditions daylight-oriented worktime models with seasonal energy prices can improve the economic competitiveness of companies.

For this purpose, an extension of the general lot sizing and sequencing problem is formulated, considering time- and load-variable energy prices, seasonal worktime models and energy tied up in inventory. To test our hypothesis simulations of these models were run for both in plastic injection molding and aluminum die casting production. The model is designed for a complete annual cycle of manufacturing. To evaluate the effectiveness, preliminary costing, lot sizing and sequencing planning with multiple objective functions are compared against a discrete-time production simulation.

The results of the simulation of production (plastic or metal) show that seasonal working hours and energy price models, together with energy-oriented lot size and sequence planning, can reduce overall costs compared to the industry standard. Peak loads can be avoided, and energy can be shifted across inventories. Energy costs in the scenarios fall by up to 35% compared to the industry standard and unit costs by up to 22%. Inventory allows the loss-free intermediate storage and later use of 16.8% of the total annual energy consumption.

3 - Optimising Telecommunications Power Reduction: A Hybrid Depowering Strategy
Zara Hawezy, Alan McGuire

A current major challenge for telecommunications networks is power consumption across the network, representing a significant proportion of operational costs. This is exacerbated by the constant increase in demand for bandwidth, while also trying to achieve cost reductions and meet environmental goals. An ongoing approach to this is to move away from older less energy efficient networks, through long term programmes migrating consumers to new technologies and through depowering legacy platforms across sites. Optimising this approach needs to consider numerous background factors including field resource constraints, planning period duration, the power reduction obtained for a given time to depower different equipment types, and the number of site visits required. Given the population of devices available to depower within a planning period, a knapsack based approach can be employed to find the optimal selection. This can be implemented through considering individual devices or aggregating them by location. Each approach is seen to have distinct benefits: considering devices individually can give maximal power reductions, while considering the aggregates reduces number of visits on site required. Simulations suggest that a hybrid solution comparing both approaches within a planning period and selecting the best per planning period can deliver a better outcome than only adopting a single approach. We explore a heuristic for choosing the optimal strategy during planning.

4 - Optimising the role of hydrogen in heat and power systems decarbonisation
Margarita Efthymiadou, Vassilis Charitopoulos, Lazaros Papageorgiou

Burning fossil fuels is the primary driver of rising greenhouse gas concentrations, leading to global warming. To mitigate climate change, urgent action is needed to achieve Net-Zero and explore low-carbon alternatives. The UK was the first major economy to legislate for Net-Zero by 2050, publishing a strategy outlining policies for a decarbonised economy. Decarbonising residential heating is a critical step in meeting carbon targets. This requires phasing out natural gas boilers in favour of low-carbon alternatives, with electrification and hydrogen emerging as the primary solutions. Hydrogen plays a dual role as a direct substitute for natural gas and as an energy carrier for renewables. To explore its potential, a hydrogen-based heat transition was analysed using mathematical optimisation. However, a system-wide perspective is essential to ensure well-informed strategic energy decisions. This work presents a spatially explicit, multi-period spatially-explicit Mixed Integer Linear Programming (MILP) model for heat sector decarbonisation. The model jointly optimises hydrogen and electrification pathways for investment and operational decisions. Decomposition and clustering techniques are employed to preserve the quality of the solutions while reducing computational effort. A case study in Great Britain highlights gradual infrastructure investments and hydrogen's role in heat decarbonisation roadmap through 2050.

■ TC-47

Tuesday, 12:30-14:00 - Room: Parkinson B08

E-commerce

Stream: Retail Operations
Invited session
Chair: *Marjolein Buisman*

1 - Urban Network Design with Ship-from-Store Option
Imen Ben Mohamed, Walid Klibi, Florian Bertrand, Juan Carlos Pina Pardo

To meet the increase of tight responsiveness requirements, we introduce the urban delivery network design problem with ship-from store option under uncertainty. The problem builds on the two-echelon distribution structure by integrating stores as an intermediate layer to fulfill and deliver online orders. The problem involves decisions on store selection and carrier pickup time from selected stores while anticipating the revenues and costs induced by order fulfillment, delivery, store replenishment, and inventory holding. A two-stage stochastic program with mixed-integer recourse is developed to model this problem while considering the uncertain nature of multi-item online orders, in-store demand, and capacities. An exact solution approach combining scenario sampling with an integer L-shaped-based decomposition algorithm is proposed. Numerical results, inspired by a retailer's real case, are conducted to validate our model and to evaluate the efficiency of our solution approach.

2 - Pricing and Delivery Lead Time Policies for Online Retailers
Bartu Arslan

Consumers' purchasing decisions from online channels mainly depend on two critical factors; the selling price and the delivery lead time. The retailers face a major challenge of setting options which trigger enough demand and ensure high profitability. In this study, we tackle this challenge. We consider a retailer selling a product through its online channel. The demand is random and customers' purchasing behavior is characterized by their reservation prices. We characterize policies, which specify the options to be offered to customers. Each option has two specifications; a selling price and a delivery lead time. We propose two policies; the static M-option policy and the dynamic single-option policy. In the former, the retailer has M options to offer. The specifications of these options are set at the beginning of the planning horizon and the decisions on when to offer which options are made dynamically over the periods. In the latter policy, the retailer offers a single option but its specifications can differ in every period. We develop value iteration algorithms, analyze the structural properties of both policies. We propose exact and heuristic algorithms to optimize them. We evaluate the benefits of introducing additional options and the benefits of using the dynamic single-option policy over the static M-option policy. We conclude that both benefits are more prominent when the selling season is long and when the unit holding and loss of goodwill costs are high.

3 - From click to return: the hidden impacts of product returns in global fast e-commerce platforms
Danni Zhang, Harsha Halgamuwe Hewage

The rapid rise of global fast e-commerce platforms like Shein and Temu has transformed Western retail markets, generating significant revenues (e.g., Shein: '1.55 billion in 2023). Unlike traditional international retailers, these platforms act as intermediaries for numerous small and medium-sized businesses, adding complexity to the management of product returns. While existing research has explored aspects of their business models—particularly forward supply chains and sales strategies—significant gaps remain in understanding how product returns are managed. Importantly, consumer awareness of the financial, and environmental impacts of their global returns on these platforms, along with associated influencing factors, remains underexplored.

This research addresses these gaps through a two-phase approach. First, a desk review analysed the challenges and strategies employed by global fast e-commerce platforms to manage returns. Second, we conducted a UK consumer survey via Prolific applied Structural Equation Modelling to quantify how risk perceptions, financial and sustainability trade-offs, and ethical considerations influence return decision. The findings offer retailers and policymakers develop sustainable return practices and support circular economy initiatives beyond platform-specific measures, aligning with new EU regulations to reduce textile waste and ban the destruction of unsold clothing.

4 - Optimal Returned Policies for Multiple Products to Multiple Return Centers
Nizar Zaarour, Emanuel Melachrinoudis

Product returns are an essential part of conducting business today, due to the emergence of e-commerce and the proliferation of generous return policies. Such policies, however, can backfire due to their costly operations and unpredictability. To minimize the adverse impact, we develop and compare different collection policies to minimize

the combined inventory and transportation costs in a three-echelon network consisting of (a) customers returning products to initial collection points (ICPs), (b) the ICPs, and (c) the centralized return centers (CRCs), that receive the products shipped from the ICPs after they are aggregated into larger shipments to leverage economies of scale. Collection policies are developed for the case of multiple products with a single ICP and multiple CRCs, by using (1) individual shipment policy where ICPs ship out products to individual CRCs and (2) a combined shipment policy that allows shipping and routing from an ICP to multiple CRCs. Mathematical models are developed to determine the collection period at the ICPs to minimize the combined inventory and transportation costs for these policies. An efficient algorithm is developed, and results are presented with an experimental dataset.

■ TC-49

Tuesday, 12:30-14:00 - Room: Parkinson B10

Machine Learning and Information Systems

Stream: Analytics
Invited session
Chair: *Rosa Taghikhah*

1 - Enhancing Operational Performance in Textile Manufacturing: Impact Assessment of Computer Vision-based Defect Detection

Artur Carvalho, Vera Miguéis, Miguel Moura e Sá

The accelerated development of deep learning has provided powerful approaches to improve quality control in manufacturing, namely through automated defect detection. Despite significant advancements in model performance and efficiency, there is still a lack of research evaluating the operational impact of computer-vision-based solutions, which this study seeks to address.. A deep learning model that classifies fabric images as defective or non-defective at the production stage of a textile manufacturing process was firstly developed, with a non-invasive image acquisition approach paired with data augmentation. Subsequently, Markov Chain and sensitivity analysis were employed to estimate key performance indicators. The detection system identifies defects immediately, preventing their propagation to subsequently produced fabric and succeeding production stages. The results demonstrate a 1.4% reduction in costs, 1.4% increase in production rate, and over 90% reduction in waste generation, with an average of 1.4 false alarms per shift. The sensitivity analysis supports the robustness of these results and further guides the optimization of the image acquisition frame rate to balance detection accuracy and operational efficiency. This study highlights the potential of integrating computer vision and deep learning into textile manufacturing processes, providing actionable insights for industry managers to improve quality control, reduce waste, and optimize production performance.

2 - Information Systems Research Methodology for the 2030'es

Christer Carlsson

The prevailing ISR methodology has been built on decision analysis and design science for the creation, development and use of decision support systems, which have been major contributions to better decisions and enhanced productivity in (e.g.) transportation, finance, health care, education, cyber security, etc. The common denominator in most research inquiries is the accumulation of human cognitive power by using as support the analytic capabilities of computers. The rapid development of artificial and computational intelligence is challenging the assumption that only human cognitive power matters as these technologies can learn and build new cognitive skills. Decision makers still carry full responsibility for the decisions and the consequences they bring. Decision analytics is a partial response to the emergence of intelligent, analytic technologies. It is now clear that such pursuit is not enough: new principles and guidelines are needed for ISR methodologies in the 2030's as the cognitive capabilities of AI technologies grows. A new ISR methodology will probably take form as a synthesis of the successful elements of decision analysis, design science, decision support systems and decision analytics but with additional elements (both cognitive and digital) from digital coaching, which probably will use digital platforms to make artificial and computational intelligence methods operational for practical problem-solving and decision making.

3 - Presenting ONS Open Geography Portal

Irina Erchova

The UK Office for National Statistics (ONS) Open Geography portal is an official resource offering open access to geospatial data. This portal, averaging over 10,000 views per day, is the main source of statistical geography supporting operational research and beyond. Statistical geography combines geographic and statistical data, giving a spatial context to demographic, social, and economic patterns. It supports locational analysis, resource allocation, logistics optimization, and other types of analyses for government and business. The portal metadata comply with EU INSPIRE directive to facilitate synergy of data from different countries for cross-border studies and collaborations. Users can search, view, and download data and metadata for various products. The products, including detailed boundary datasets for the UK regions, postcode directories, geographies, and classifications, are regularly updated. The portal also offers datasets containing historical data for long-term comparison and research. The Hierarchical Representation of UK Geographies gives a structured overview of the different geographic levels within the UK. It helps integrate data from different sources for a wider view on complex problems. Classifications, like the rural/urban, help distinguish between different areas for developing targeted policies and programs. In addition, our open methodology provides a standard way to define, analyse and compare areas, for example, rural versus urban areas.

4 - A Pairwise-Frontier-Based Classification Method for Two-Group Classification

Qianying Jin, Kristiaan Kerstens, Ignace Van de Woestyne

Mathematical programming methods have been widely used to generate a separating boundary that can be used for two-group classification. A nonlinear separating boundary may have better performance than the linear ones, but requires a pre-specification of a nonlinear function form. This contribution proposes a novel pairwise-frontier-based classification (PFC) method to approximate nonlinear separating boundaries, without predetermining a nonlinear function form. It consists of two steps that explicitly handle overlap. The first step is to identify the overlap. Importantly, we propose to construct frontiers based on background knowledge of classification, thus ensuring that their intersection (i.e., overlap) is not increased by blindly applying commonly used axioms. Depending on the axioms applied, either convex frontiers are constructed using a Data Envelopment Analysis model, or nonconvex frontiers are constructed using a Free Disposal Hull model. The second step minimizes identified overlaps by allowing training observations to be misclassified, but all training observations that have been correctly classified remain correctly classified. The PFC method with hard frontiers is then extended to a one with soft frontiers. The applicability of the proposed PFC methods is illustrated by simulation studies and real-life data sets. The results show that the proposed method is competitive with some well-established classifiers and even performs better with unbalanced data sets.

■ TC-50

Tuesday, 12:30-14:00 - Room: Parkinson B11

Systems Thinking 1

Stream: Systems Thinking
Invited session
Chair: *Christian Heathcote-Elliott*

1 - Complex Systems in Supply Chains: Dynamics, Resilience, and Uncertainty Management
Felipe Olivera, Francisco J. Tapia-Ubeda, Jorge Tabilo Alvarez

Modern supply chains have evolved into highly interconnected and dynamic systems, characterized by increasing complexity due to globalization. From a complex systems perspective, the supply chain is not only a linear set of logistics processes, but also an adaptive network of multiple agents with nonlinear interactions. This study analyzes the key properties of complexity in supply chains, including adaptability, robustness, and perturbation propagation through models based on system dynamics and complex networks. In addition, strategies for effective complexity management are discussed. The results suggest that incorporating complex systems principles in decision making can improve the efficiency and responsiveness of the supply chain to disruptive events. Finally, future lines of research oriented towards the integration of advanced modeling tools for uncertainty management in these systems are proposed.

2 - Design Thinking and OR: a potential pathway for systems approaches?
Christina Phillips

There are many links between Design and OR, but although Design scholars often pay a nod to these links it is rarely recognised by OR researchers. In this talk we will look at the history of the two disciplines and how they intertwine and then focus on the links between OR and design thinking specifically. We will discuss what systems thinking is, and is not, and look at some of the tools that are similar to systems and soft OR approaches. We then go on to discuss how design thinking can help us to take a systems approach particularly when our standard tools are found wanting in a situation. This gives us alternative tools to both study and perform OR in systems.

3 - A Critical Systems Thinking Methodology to Explore Circularity of Food Waste in a University Campus
Toni Burrowes-Cromwell, Alberto Paucar-Caceres, Jose-Rodrigo Cordoba-Pachon

This paper reports on the learning process and main insights of applying a critical system thinking (CST) methodology to food waste prevention, at a UK university campus project. Across the globe, many universities are considering or adopting circular economy (CE) principles to meet the 17 United Nations Sustainable Development Goals (UNSDGs). Yet, there is still lack of understanding about the systemic issues and consequences of preventing food waste, towards improved management of campus food resources. Our case study approach combined Soft Operational Research (OR) and other methods to identify possibilities and challenges regarding adopting CE ideas and technologies. These processes featured high student participation and included student self-assessment of waste disposal, initial food waste scrap separation and sorting, and investigating on-site food composting or anaerobic digestion (AD) options. There were valuable project lessons from this tactile, practical approach. However, campus stakeholders following through with their own action agendas (while we maintained a critical, supporting role) came across as paramount. Among other insights from using Soft OR, our study presents this finding about the importance of flexibility, in seeking to progress the 12th UN sustainable development goal (UNSDG) to reduce food waste.

4 - Developing systems thinking capability in Welsh public services - early learnings from the Shaping Places in Well-being in Wales programme
Christian Heathcote-Elliott, Emily Woodward-Esseen

In Wales, the Well-being of Future Generations Act (2015) has established multi-agency Public Services Boards (PSB) to improve the economic, social, environmental and cultural well-being of their locality, contributing to seven well-being goals, including a healthier and fairer Wales.

Improving population health and well-being is a complex challenge involving multiple stakeholders, many interrelated elements, uncertainty and potential trade-offs between policy initiatives.

The Health Foundation funded Shaping Places for Well-being in Wales is a national three-year programme which aims to develop systems thinking capability in PSB to understand and act on strengthening the social, economic and environmental building blocks of health and well-being. The programme has established three learning groups with representation from 11 PSB. Each learning group is focusing on one area of interest: healthy inclusive transport, participation in fair work, or skills for a just green transition.

Participants in the learning groups are being guided through a flexible Applied Systems Thinking Approach comprising of a series of activities which focus on defining system boundaries, systems mapping and analysis, describing the desired change, and evaluating system changes.

This presentation will outline the design phase of the programme, implementation challenges, opportunities and how the programme is being adapted as part of an ongoing contribution analysis evaluation.

■ TC-51

Tuesday, 12:30-14:00 - Room: Parkinson B22

Multiobjective Decision Making

Stream: Multiobjective and vector optimization
Invited session
Chair: *Juho Roponen*

1 - A survey on the state-of-the-art of the multiobjective optimization methods for multiple decision makers
Juuso Pajasmaa, Kaisa Miettinen, Johanna Silvennoinen

Group decision making in multiobjective optimization (GDM-MOO) deals with problems involving multiple conflicting objective functions and several decision makers with conflicting preferences. The goal of GDM-MOO methods is to find an acceptable Pareto optimal solution for the group that can be also implemented in practice. When compared to methods for a single decision maker, developing GDM-MOO methods introduces new challenges. We present the highlights of a systematic review of the state-of-the-art in the GDM-MOO literature. We pay attention to, for example, how preferences of several decision makers are incorporated into the solution process, how to select the most preferred solution for the group and how the group is to operate during the solution process. Furthermore, we describe the main approaches in GDM-MOO methods used to solve various kinds of multiobjective optimization problems. We observe that the practical applicability has not been considered sufficiently in the literature. We identify several key issues that should be considered in further method development to increase the methods' practical applicability. Importantly, the group should be better supported in selecting the final solution. To support method developers, we recommend validating new methods using real-world problems or with realistic test settings that account for the identified key issues.

2 - "Enhancing Convergence and Diversity in Evolutionary Multiobjective Optimization via Dynamic Reference Point Adaptation"
Antonio Borrego Ortega, Rubén Saborido, Mariano Luque

Multiobjective optimization problems require algorithms that balance convergence and diversity in approximating the Pareto optimal front. The performance of these algorithms heavily depends on the front's shape. This paper presents a framework designed to enhance the later stages of Evolutionary Multiobjective Optimization (EMO) algorithms. We divide a Pareto front approximation into subregions using a distributed set of reference points in the objective space. For each subregion, weight vectors are computed and dynamically adapted based on the front's geometry. This adaptation improves both convergence and diversity. Additionally, we explore how to optimally determine the number of reference points to ensure a uniform distribution of solutions. A series of computational experiments were conducted using the

WFG benchmark suite, comparing the performance of our approach integrated into NSGA-III with the original NSGA-III. The comparison, based on the hypervolume indicator, shows the advantages of our method. This study emphasizes the potential of such mechanisms in EMO algorithms, particularly for bi-objective problems, and sets the stage for future extensions to many-objective optimization.

3 - Relatively Robust Multicriteria Optimization
Thomas Weber

For a general multicriteria decision problem with linear scalarization and unknown weights, we propose relatively robust decisions that are Pareto-efficient while maximizing a performance index. This index measures the worst-case ratio of the weighted objective to its maximum value across all possible weights. Key results include a simple boundary representation of the performance index as the minimum of criterion-specific performance ratios and an efficient method for determining a relatively robust decision within any given performance tolerance by maximizing an $\epsilon\epsilon$-augmented performance index. Our approach requires only the continuity of criterion functions and the compactness of the feasible decision set, accommodating nonconvex sets without restriction for finite action sets. A notable feature of our method is its endogenous derivation of trade-offs between criteria, providing a performance guarantee relative to any weighting. We illustrate its effectiveness through structural results, examples, and applications.

4 - Two-stage robust multiobjective optimization with an interactive method
Juho Roponen, Babooshka Shavazipour, Margaret Wiecek

Most areas of human activity involve trade-offs and uncertainty. Trade-offs make optimization difficult, because in the presence of multiple conflicting objectives, there is no individual optimal solution, but instead multiple - possibly infinitely many - Pareto optimal solutions. Uncertainty also makes optimization more difficult, because often no individual solution is going to be clearly the best for every possible use case or future scenario. When multiple objectives and uncertainty are considered simultaneously, the relative importance of different objectives may change based on the achievable ranges of the objectives in different scenarios. We present an interactive approach to solving two-stage robust multiobjective optimization problems. The advantage of solving the optimization problem interactively is that the decision maker has an opportunity to learn about trade-offs and uncertainties involved and redefine their preferences during the solution process. The updated preferences are expressed in a scalarized min-max-min problem which is reformulated into a minimization problem. By iteratively updating preferences and solving the scalarized problem, the decision maker can find a preferred solution. We apply this solution approach to a forestry problem with initial management decisions, after which, one of finitely many potential climate scenarios is realized, and a second round of management decisions follows.

■ TC-53

Tuesday, 12:30-14:00 - Room: Liberty Moot Court

New Trends in Game Theory VI

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Zhengping Wu*

1 - Generalized Nash Game under Uncertainty—a CVaR Based Approach
Kishan Suthar, Nagarajan Krishnamurthy

A generalized Nash game is an N-player game with interdependent strategy sets. Such games are used to model and solve the tragedy of the commons, traffic congestion, and so on. A generalized Nash equilibrium (GNE) is an equilibrium solution to a generalized Nash game. While the existence of a GNE is well-established in the deterministic setting, its existence in the stochastic setting is not known in general. Moreover, guaranteeing the uniqueness of such an equilibrium, even in the deterministic setting, is challenging. Uniqueness can be established under certain conditions such as the quasi-concavity of the utility function and the convexity of the interdependent strategy sets. Under uncertainty, previous studies have used various approaches including almost-sure formulations, expected value formulations, and risk measure considerations. In this study, we first demonstrate the existence of a GNE in stochastic generalized Nash games and use the Conditional Value-at-Risk (CVaR) to solve these games. The equilibrium solution is characterized by players' risk aversion, and we identify the conditions required for the existence of a unique GNE in such games.

2 - Does Smart Contract Add Value to a Retailer with Buyback Risk?
Zhengping Wu, Ao Zhuo, Wanshan Zhu

Retailers face buyback risk in supply chains when manufacturers fail to honor their buyback commitments. A smart contract can mitigate this risk by reserving a portion of the manufacturer's wholesale revenue in a dedicated account exclusively for buyback purposes. Intuitively, the smart contract benefits the retailer by reducing buyback risk. However, our analysis shows that the smart contract adds value to the retailer only if she is highly risk-averse and the smart contract must be carefully designed. In certain cases, the retailer suffers from the implementation of a smart contract because it allows the manufacturer to charge a higher wholesale price and to benefit consistently. Therefore, a "win-win" situation can be achieved for the supply chain only with a well-designed smart contract and a risk-averse retailer. In addition, a supply chain with a low-margin product is more likely to benefit from the deployment of a smart contract. Furthermore, an attractive investment opportunity can lead to a "lose-lose" situation when the buyback risk arises from investment constraints, as the smart contract prevents the manufacturer from pursuing a more lucrative opportunity. Although smart contracts are reliable technology for streamlining transactions, our research advises supply chain managers to carefully assess their implementation to avoid potential losses. When well designed, smart contracts significantly enhance overall supply chain efficiency.

3 - Non-deceptive counterfeiting with brand dilution and network externalities: Beyond conventional beliefs
Salma Karray, Simon Pierre Sigue

Non-deceptive counterfeiting involves producing and selling counterfeit products at lower prices without misleading consumers about their authenticity. This practice intensifies price competition for genuine brands while contributing to brand dilution and network externalities. Using a game-theoretic approach, we analyze how manufacturers of genuine products should adjust their advertising and pricing strategies over time in response to counterfeiting. Our findings reveal that in the presence of network externalities, manufacturers should increase both advertising investments and prices to maximize profits. However, when brand dilution occurs, the optimal response depends on market conditions. In some cases, a survival strategy- reducing advertising and/or prices- may be necessary to maintain profitability, even at lower levels than in a monopoly. In other cases, a differentiation strategy- raising advertising and prices- can lead to profit gains. Regardless of the approach, manufacturers must enhance advertising effectiveness to strengthen brand differentiation, maintain competitiveness, and mitigate the negative effects of brand dilution.

4 - Differential Game of Demand and Supply in Cobweb Dynamics
Prem Prakash Mishra

The demand and supply of agro-products at any time is a part of cobweb dynamics. We study about dynamic game of supply of inventory and its non-linear demand. The demand function constitutes with inventory-level as state variable and time dependent price as control variable. In contrary, the supply function constitutes with state variable as previous price and inventory level at current time as a control variable. Hence, we construct the system of Integral, differential equations and its corresponding Hamilton Bellman Jacobi Equations. The

Lagrange's method and Volterra' Integral equation solution techniques are employed to determine maximum value of demand and maximum value of supply of products at a particular time. In this consequence, we also get the optimum trajectory of price with its associated inventory level and optimum trajectory of inventory level with associated price of product.

■ TC-54

Tuesday, 12:30-14:00 - Room: Liberty 1.08

Methods & stochastic modelling

Stream: Stochastic modelling
Invited session
Chair: Fikri Karaesmen

1 - An MDP Design approach to redundancy allocation with dynamic maintenance
Luke Fairley, Rob Shone, Peter Jacko, Jefferson Huang

A system can be made to be more reliable by adding redundant copies of a component, where these copies serve as back-ups for cases where other components have failed. The inclusion of more copies decreases the probability of all copies failing at the same time, improving reliability. The problem of deciding how much redundancy to add is called the Redundancy Allocation Problem, which is a combinatorial optimisation problem. Previous work has shown that a repairable redundant system can be modelled as a Markov process by assuming that degradation and repair times are exponentially distributed, and assuming repairs are always started straight away. A natural question arises as to whether or not this second assumption can be relaxed. For example, with three levels of redundancy and only one failure, it need not be the case that this component is repaired straight away. The problem of deciding when to repair can be modelled as a Markov decision process (MDP). As it stands, these two problems are separate: we have one problem for designing a system, and another for determining repair policies. Our work focuses on the integration of these two problems into an MDP Design problem, where we wish to simultaneously design a system and determine the dynamic policy used for its operation. This talk showcases such a model, demonstrates the extent to which instances can be solved exactly using off-the-shelf solvers, and looks towards some more scalable solution methodologies.

2 - Dynamic Resource Allocation for a Multi-Class System with Returns
Fikri Karaesmen, Arash GandomkarGhalhar, Oktay Karabağ

Motivated by the case of a company that sterilizes used surgical instruments and medical devices to make them available for reuse in hospitals, we investigate a production-inventory model with multiple products and shared resources where the used products return to the facility with limited capacity for sterilization. We formulate a Markov Decision Process to explore the optimal dynamic resource allocation policy that minimizes the shortage and holding costs over the long run. Due to usage-dependent return rates, the optimal policy is complicated. To cope with this complication, we test a number of plausible and simpler policies. However, even the proposed class, there are many candidates to test and choose. To speed up the process of choosing the best among the class of proposed policies, we generate a training data by numerically solving instances of the Markov Decision Process model and labeling the performance of each proposed policy. Using machine learning, we then generate rules for determining the best proposed policy as a function of the problem parameters. The results are promising and suggest that the procedure can be automated.

3 - Stability of Polling Systems: A Linear Class of Two-Phase Switching Policies Near Fluid Limit
Kousik Das, Vartika Singh, Konstantin Avrachenkov, Veeraruna Kavitha

Among queueing systems, polling systems represent a special class where a single server cyclically visits multiple queues, potentially incurring non-zero switching times between queues. These switching times introduce vacation, making polling systems non-work-conserving. Polling systems are useful for traffic signals, manufacturing systems, logistics, railway crossings, etc. The analytical complexity of polling systems heavily depends on the service discipline adopted (e.g., exhaustive or gated). We anticipate that servers periodically switch between queues depending upon switching policies. This opens up an exciting new development in the analysis of polling systems under a fluid limit. We investigate a two-queue polling system embracing a fairly general and comprehensive class of two-phase switching policies near fluid regimes via the uniform acceleration technique. This class also contains one-phase switching policies. Here, the arrival and departure epochs form the potential switching epochs. Our switching policies include: (a) a class covering the Pareto frontier related to performance measures like stationary waiting times or mean number of waiting customers in each queue and (b) a class covering robust policies having performance measures like fraction of times the individual queue have reached specified danger levels. We formulate precise mathematical conditions under which the proposed two-phase switching policies ensure queue stability within fluid limit framework.

■ TC-55

Tuesday, 12:30-14:00 - Room: Liberty 1.09

Humanitarian Supply Chain and Network Design

Stream: Humanitarian Operations
Invited session
Chair: Sibel Salman

1 - Overcoming Barriers in Humanitarian Supply Chains in India: A Fuzzy Delphi and DEMATEL Approach
Pritha Dutta, Vernika Agarwal, Ritik Maheshwari

A resilient and adaptive humanitarian supply chain is crucial for delivering timely and effective relief in disaster-prone regions like India, which frequently faces natural calamities such as floods, droughts, earthquakes, and cyclones. However, humanitarian supply chains often face numerous challenges that lead to delays in aid delivery and prolonged hardships for vulnerable communities. This study examines the primary challenges and barriers to effective and efficient humanitarian supply chains in India, focusing specifically on disaster relief operations. A two-phase methodology integrating the Fuzzy Delphi Method (FDM) and the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) is utilized. The findings of this research highlight significant barriers to the efficiency of humanitarian supply chains in India, including inadequate infrastructure, poor coordination among stakeholders, limited funding, bureaucratic obstacles, and minimal adoption of advanced technologies. By classifying and visualizing the barriers into causal and effect categories, this analysis provides insights into their hierarchical structure and relative importance. This comprehensive understanding can help policymakers, humanitarian organizations, and other stakeholders in developing targeted strategies for addressing these challenges.

2 - Cost Effective Tactical Pre-Disaster Relief Supply Planning under Time-Phased Networks
Halit Uster, Vala Rahmati

We consider emergency preparedness for foreseen disaster such as hurricanes and flooding. Proper preparation and planning for timely relief supply in a cost-effective manner can be a crucial determinant of how quickly the recoveries take place and with least suffering of the affected populations. Assuming a host of shelter locations aggregated locally, we are interested in determining supply locations (DCs) and routing of supply through the transfer nodes on a time-phased network from the DCs to the shelters for timely delivery under cost considerations. We present a mixed integer optimization model to address this problem under the assumption of covering worst-case demand at the shelters. To

solve our model, we develop an efficient Benders Decomposition (BD) based algorithm that handles the challenges associated with obtaining optimality cuts via master problem solution modifications and various surrogate constraints among other enhancement techniques. We test the performance of the enhancement techniques on an extensive randomly generated test data set to identify the most effective approach. We finally use our model and the solution algorithm on a real case study in southern Texas data incorporated and managed by Geographical Information System (GIS) to examine the impact various input parameters on the design and tactical operation of the relief networks as well as for further model verification and validation.

3 - A Simulation-Optimization Approach for Resilient Humanitarian Supply Chain Focusing on Elderly Populations During Pandemics
Behzad Mosalla Nezhad, Mostafa Hajiaghaeikeshteli, Fatemeh Gholiyanjouybari, Neale Smith

Pandemics are disruptive events that put severe pressure on people, especially the elderly, while also making it very difficult for supply chains to respond and meet demands. This study develops a sustainable humanitarian supply chain network that prioritizes timely and equitable resource distribution for elderly communities. Moreover, an age-structured Susceptible-Infected-Recovered system dynamics model is employed to estimate the demand of different age-specific for critical medical supplies. The proposed multi-objective stochastic optimization model aims to minimize costs, reduce unmet demand, and mitigate environmental impacts. A case study based on the COVID-19 pandemic in Mexico is presented, focusing on the distribution of personal protective equipment, medical supplies, and test kits to hospitals, pharmacies, and other demand points. It can be concluded that the proposed model effectively prioritizes the demand of the elderly population, resulting in the resilience of the supply chain for pandemics.

4 - A Quantum-Inspired Bilevel Optimization Algorithm for the First Responder Network Design Problem
Sibel Salman, Anthony Karahalios, Sridhar Tayur, Amirreza Pashapour, Barış Yıldız

In the aftermath of a sudden catastrophe, first responders (FRs) strive to reach and rescue immobile victims. Simultaneously, civilians use the same roads to evacuate and access medical facilities and shelters via private vehicles. The escalated traffic congestion can significantly hinder critical FR operations. A preventive strategy is to allocate a lane on specific road segments exclusively for FR use and precommunicate them publicly. For a successful implementation, an FR path should exist from designated entry points to each FR demand point in the network. The reserved FR lanes along these paths will be inaccessible to evacuees, potentially increasing evacuation times. We aim to determine a subset of links along which an FR lane should be reserved and analyze the resulting evacuation flow under evacuees' selfish routing behavior. We introduce this problem as the first responder network design problem (FRNDP) and formulate it as a mixed-integer nonlinear program. To efficiently solve FRNDP, we introduce a novel bilevel nested heuristic, the Graver augmented multiseed algorithm (GAMA) within GAMA, called GAGA. We test GAGA on synthetic graph instances of various sizes as well as scenarios related to a potential Istanbul earthquake. Our comparisons with a state-of-the-art exact algorithm for network design problems demonstrate that GAGA is a promising alternative approach.

■ TC-56

Tuesday, 12:30-14:00 - Room: Liberty 1.11

Last-Mile Delivery

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Christopher Bayliss*

1 - Parcel placement optimization in multimodal last-mile crowdsourced delivery: A behavioral framework
Mina Akbarpour, Stefan Ropke, Otto Anker Nielsen, Yu Jiang, Soora Rasouli, Feixiong Liao

With the rise of e-commerce, crowdshipping has emerged as an efficient and sustainable last-mile delivery solution. However, its effectiveness depends on strategic parcel placement and crowdshippers' willingness to accept tasks, introducing uncertainties that impact system performance. This study presents an optimization framework for a multi-modal crowdshipping system, where parcel placement is optimized using a heuristic approach to enhance delivery performance and adaptability. The framework integrates multiple transport modes for crowdshippers, alongside professional delivery fleets. Data has been collected regarding the decision of travelers to act as crowd-shippers on which basis a multinomial logit (MNL) model is employed. The simulated crowdshippers' probabilistic task acceptance behavior allows for a behavior-driven allocation strategy. The objective is to reduce total system costs, including parcel placement, compensation incentives, and fleet operations. Tasks that remain unassigned are reassigned to a professional fleet, optimized using a vehicle routing problem (VRP) model. We report results from numerical experiments based on urban delivery data from Copenhagen and report the situation under which the crowd-sourced parcel delivery can be optimally operated.

2 - Optimizing Last-Mile Delivery with Mixed Fleets and Uncertain Travel Time
Mahdi Noorizadegan, Mohammad Fattahi

We study a last-mile delivery problem with uncertain travel times, focusing on the selection of hubs, deciding the fleet size at each hub, and the routing of a mixed fleet comprising conventional vehicles and drones. Unlike most of existing models where drones operate in single-trip delivery, we allow them to visit multiple delivery points, enhancing efficiency and operational flexibility. To address uncertainty in travel times, we incorporate chance constraints and distributionally robust chance constraints to ensure route feasibility under worst-case probability distributions. To solve this complex problem, we develop an exact branch-and-price method capable of handling both vehicle and drone routing decisions and the uncertain travel time.

3 - Simulation and evaluation of sustainability impacts of last mile delivery consolidation
Christopher Bayliss, Djamila Ouelhadj, Andrew Bullock, Graham Wall, Mohanad AL-Behadili, Graham Fletcher

Consolidation in parcel delivery operations refers to the process of assigning delivery routes to many parcels such that delivery costs are minimised, as well as pollution and congestion. Consolidation can be achieved by grouping parcels with common destinations together at some location. Consolidation can be performed at: parcel lockers (reducing number of final delivery locations); delivery vehicles (shared usage for reduced empty vehicles miles); kerbside (where groups of parcels are transferred to smaller more sustainable vehicles); and urban consolidation centres (a third party who take on the responsibility of last mile delivery for any number of carriers). This work proposes heuristic routing algorithms for simulating these consolidation strategies. A multi-modal two-echelon location routing heuristic is introduced for simulating the urban consolidation centre and shared vehicle usage strategies. A local search based algorithm is introduced for simulating the kerbside consolidation strategy. The performance of the location-routing algorithm is validated relative to an exact MIP formulation. Experiment results, based on city sized instances, are presented to illustrate the relative merits of each consolidation strategy and different last-mile mode choices. Additionally, in collaboration with the DfT funded Solent Future Transport Zone project, we analyse cost, pollution and social impacts of placing consolidation centres at a range of candidate locations.

4 - Vehicle Routing Problem with Public Transit, Parcel Lockers and Delivery Options
Soumen Kumar Das, Vincent F. Yu

This research studies the integration of vehicle routing with public transportation systems, various delivery options, and parcel locker facilities. The main objective is to develop a routing plan that reduces overall costs, factoring in both travel expenses and compensation for customers using self-pickup services. A mixed-integer linear programming is developed and solved using the CPLEX optimization solver. To efficiently handle larger problem instances, an adaptive large neighborhood search algorithm is proposed. The performance of this algorithm is assessed through numerical experiments. In addition, the study offers managerial insights into the use of public transportation for improved logistics decision-making. It concludes by summarizing key outcomes and suggesting areas for future exploration.

■ TC-57

Tuesday, 12:30-14:00 - Room: Liberty 1.12

Air transportation I

Stream: Transportation
Invited session
Chair: *Philip de Bruin*

1 - An Exact Method for Storage Space Assignment at Airport Cargo Terminal: A Temporal-spatial Packing Problem

Mengxue Yuan, Chenhao Zhou, Nuno Ribeiro

With the spiking volume of non-stackable cargos, such as cargo pallets or unit loading devices, to be transported by airplanes, the ground space at airport cargo terminals becomes tight and requires precise management regarding storage space assignment, making it a temporal-spatial packing problem. The problem is first formulated as a mixed-integer linear programming model, adhering to the Last-In-First-Out principle, to minimize wasted space and maximize the dispersion effectiveness of the assignment decisions, and subsequently, the logic-based Benders decomposition (LBBD) approach is proposed. Two enhancement methods are developed, where effective constraints and corresponding cuts are applied to the master problem, and the Lagrangian relaxation method is adopted in the subproblem, converting the original LBBD into a bi-level decomposition structure. An extensive analysis highlights the superiority of the bi-level LBBD approach, augmented with corresponding enhancement methods, over other decomposition-based approaches. Specifically, it demonstrates that our approach can successfully solve 90% of instances involving 200 cargos. Compared to an empirical approach, our approach is shown particularly effective in handling instances with 150 cargos, successfully placing all items within the storage space while also delivering superior dispersion performance.

2 - Optimizing Airport Selection for Electric Aircraft Operations

Imke Joormann, Frederic Kroner, Andreas M. Tillmann

With ambitious emission reduction targets set by the international community and individual states, the development of electric aircraft will be further pursued in the upcoming years. However, the operation of electric aircraft requires substantial airport infrastructure investments, making a strategic selection crucial. Given the high costs of airport expansions and range limitations of electric aircraft, an optimized global approach ensures that selected airports minimize overall emissions within a fixed investment budget. The passenger demand between airport pairs are modeled as a multi-commodity flow. Additionally, to account for airlines' motivation to minimize operating costs, we extend our approach to a two-stage optimization problem. At the first level, the leader determines the selection of airports for electrification, focusing on minimizing total emissions. At the second level, airlines route passengers based on the chosen electrification to reduce their operational costs. To solve this model efficiently, we can reformulate the bilevel formulation as a Mixed-Integer Program (MIP). We then apply a path-based formulation within a column generation framework to identify the most beneficial flight routes based on electrification status. We have gathered real-world data, which are utilized to analyze the model with regards to solvability in relation to the instance size and the established emission limits.

3 - Integrated Airline Fleet and Crew Recovery through Local Search

Philip de Bruin, Marjan van den Akker, Kunal Kumar, Lisanne Heuseveldt, Marc Paelinck

Airline operations are prone to delays and disruptions, since the schedules are generally tight and depend on a lot of resources. When disruptions occur, the flight schedule needs to be adjusted for the operation to continue. This needs to be done as close to real-time as possible, posing a challenge with respect to computation time. Moreover, to limit the impact of disruptions, we need a solution with minimal cost and passenger impact. Airline operations include many interlinked decisions, making the use of sequential methods suboptimal. For this reason, we study an integrated approach, specifically looking at the aircraft and crew schedules. Resolving these disruptions in an integrated way is a complex problem.

To solve this, we developed a fast simulated annealing approach. Our approach is compared with traditional approaches, and an experimental study is done to evaluate different neighbour generation methods, and to investigate different recovery scenarios and strategies. We use real world data from KLM Royal Dutch Airlines. We show that our approach resolves disruptions quickly and in a cost-efficient manner, and that it outperforms traditional approaches. Compared to naive delay propagation, our method saves 40% in non-performance costs. Moreover, while most airlines use tools that consider resources separately, our approach shows that integrated disruption management is possible within 30 seconds.

4 - Managing the flow of unit load device in air cargo network

Kritika Karwasra, Narayan Rangaraj

Air cargo networks use Unit Load Devices (ULDs) for moving cargo, much like container movement in the maritime supply chain. ULD requirements vary across the network depending on cargo demand, and ULD handling capacity. A key challenge in ULD management is the imbalanced flow of ULDs as cargo movement is often asymmetrical, causing excess ULD at some locations and ULD deficiency at others. To maintain operational efficiency, it is essential to redistribute ULD by repositioning them empty. Effective management of ULD flows starts with determining inventory levels incorporating safety stocks for different types of ULD (solid and pallet). Once these inventory levels are established, the decision can be made on how many empty ULDs to be moved between airports. Another critical factor in ULD repositioning is the type of service used to transfer. Air cargo network operates on a hub and spoke network where spoke-level airports (and long-distance hubs) are connected via central hub airports. Repositioning ULD with such an intermediate hub facility is only possible if the hub has enough capacity to handle additional demand from incoming airports. This requires a careful assessment of flight schedules and the synchronization of empty ULD movements with existing service schedules to ensure an efficient ULD flow across the network. So in this research, we address the empty ULD repositioning problem considering the capacity level constraint of intermediate hub in different service routes.

■ TC-58

Tuesday, 12:30-14:00 - Room: Liberty 1.13

AGVs

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Giusy Macrina*

1 - Collision-Free Path Planning for Heterogeneous AGVs with Different Maximum Speeds
Hyun Shin Lee, Byung Do Chung, Gyusung Cho

With the increasing complexity of tasks handled by Automated Guided Vehicles (AGVs) in logistics and manufacturing, deploying heterogeneous AGVs with different capabilities and capacities in the same operational area is becoming more common. This study addresses the problem of scheduling heterogeneous AGVs with different maximum speeds working together without collisions, which introduces chase collisions in addition to traditional AGV conflicts. To tackle this problem, we formulate a mathematical model for AGV scheduling and propose an efficient algorithm to obtain high-quality solutions within a reasonable time. We verify the effectiveness of the proposed algorithm through simulation experiments and demonstrate that allowing each AGV to adjust its speed within its maximum speed range improves the algorithm's overall performance in heterogeneous AGV operations. These findings provide new insights into optimizing AGV deployment strategies, especially in warehouses and smart factories, where different types of AGVs need to work together efficiently to meet different task demands.

2 - Optimizing Smart Manufacturing: Scheduling of Smart Robots in Intralogistics
Bilgenur Erdogan, Quang-Vinh Dang, Mehrdad Mohammadi, Ivo Adan

With Industry 4.0 advancements, manufacturing environments are becoming increasingly automated and intelligent, enhancing operational flexibility. However, integrating smart robots into these systems introduces scheduling challenges that require efficient coordination. Unlike previous studies, we address the joint scheduling of heterogeneous smart robots in a flow shop setting, where different types of robots are responsible for distinct transport and handling tasks. Our model involves assigning tasks to appropriate robots and sequencing them alongside workstation operations. The objective is to minimize makespan while managing complex task interdependencies. We propose a mixed-integer linear programming model and, to address scalability, develop a matheuristic that combines iterated local search with linear programming. Using real-world data, we demonstrate the effectiveness of our approach across varying fleet sizes, job volumes, and time constraints. The proposed method improves MILP results and significantly enhances computational efficiency, outperforming current practices.

3 - Last-mile delivery using AGVs and Public Lines
Giusy Macrina, Giovanna Miglionico, Luigi Di Puglia Pugliese, Francesca Guerriero

This study explores the potential for integrating passenger and freight transportation into last-mile delivery networks, using electrical autonomous ground vehicles (AGVs). Specifically, it investigates the possibility of using the spare capacity of existing public transport lines, such as subways, trams, and buses, to distribute goods. Given the different objectives and constraints characterising goods and passenger transportation, integrating the two domains is a complex and promising challenge. One of the major concerns is the definition of distribution plans ensuring the coordination of all network resources while meeting customer expectations, both in terms of passenger and goods shipment. The proposed framework is modelled as a variant of the Vehicle Routing Problem (VRP), in which a fleet of AGVs must serve customers in an urban area by carrying out part of the service via public lines. A preliminary computational study is carried out to attest to the behaviour of the proposed framework. Keywords: VRP, Public Lines, Autonomous Vehicles

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■ TC-59

Tuesday, 12:30-14:00 - Room: Liberty 1.14

Innovations for a Greener City and Sustainable Urban Logistics I

Stream: Transportation
Invited session
Chair: Eloisa Macedo
Chair: *Jorge Bandeira*

1 - Evaluating Sustainable Last-Mile Logistics: Barriers, Solutions, and Readiness Metrics
Jorge Bandeira, Eloisa Macedo

As part of the SPOTLOG Interreg Europe Project, a survey was conducted to understand stakeholders perspectives concerning barriers, challenges and potential solutions for sustainable last-mile deliveries (SLMDs). With 95 valid responses from different professional sectors, results show cycle logistics, e-vehicles, micro-hubs and shared delivery systems enhance efficiency and reduce last-mile logistics impact. Moreover, results suggest community cooperation and infrastructure development are key to enabling sustainable delivery practices. We then propose a novel framework for assessing regional readiness for SLMDs through the development of a Regional Readiness Level for SLMDs (RRSLMD) indicator. Recognising the growing importance of efficient and SLMDs, particularly in the face of increasing e-commerce and urbanisation, the need for a standardized metric to evaluate a region's preparedness for SLMD practices seems relevant. The proposed RRSLMD indicator consolidates a set of measures, encompassing key dimensions such as infrastructure (e.g., charging stations, micro-consolidation centers), policy frameworks (e.g., regulations, incentives), technology adoption (e.g., electric vehicles, smart logistics platforms), and consumer awareness (e.g., acceptance of alternative delivery methods). A practical tool was designed to empower regions to understand and evaluate their current status, identify improvement areas, and benchmark progress towards achieving SLMDs.

2 - Towards Sustainable Festival Mobility: A Stated Choice Experiment on Visitor Transportation Modes in Germany
Valerija Gottselig, Christoph Herrmann, Katharina Friederike Sträter

Over the years, the number of music festivals in German-speaking countries has increased. These attract tens of thousands of visitors and have a significant economic impact. However, they also pose major transportation challenges since visitors typically camp on-site for several days, bringing tents and supplies. This, in turn, is likely to influence their choice of transport mode, making it different from well-researched transportation choices in everyday life. Travel to and from festivals makes up for 40-80% of their scope 3 emissions. This study analyses transport mode choice behavior of festival-goers using the Theory of Planned Behavior. To elicit the preference structure, a discrete choice experiment (DCE) was designed that confronts "festival affine" participants with hypothetical decision situations in which they must choose between different means of transportation with varying levels of price and CO2 emission, among other attributes. In addition to the DCE, psychological and socio-demographic variables were surveyed from 778 festival-goers from four German music festivals. The data was analyzed using a hybrid choice model. The results demonstrate, among others, a willingness to pay for shorter travel times and reduced CO2 emissions when choosing hypothetically between transportation modes while a preference for car travel persists. Options for reducing CO2 emissions could, therefore, include improved concepts of carpooling or renting of festival equipment.

3 - Assessing the Potential Economic and Environmental Benefits of Peer-to-Peer Crowdshipping
Emma Innocente, Jean-Sébastien Tancrez

In recent years, crowdshipping has garnered attention as a potentially cost-effective and sustainable alternative to traditional delivery. Crowdshipping is a collaborative delivery system that outsources delivery tasks to ordinary citizens that act as non-professional couriers. In particular, peer-to-peer crowdshipping concerns intercity, and longer-distance deliveries carried out by car. By exploiting excess capacity in existing personal transport for the delivery of freight, crowdshipping is inclined to reduce the number of dedicated freight delivery trucks, reducing delivery costs and supporting sustainability. The impact of crowdshipping remains unclear due to the novelty and broad nature of the concept and the fact that existing crowdshipping platforms are continuously changing. Moreover, most studies on the impact of crowdshipping consider the matching between crowdshippers and parcels as an input in the experiments. However, it may affect the potential benefits of crowdshipping as it impacts the length of crowdshippers' detours, and the number of parcels delivered through crowdshipping. We assess the potential economic and environmental benefits of peer-to-peer crowdshipping and highlight the parameters influencing those benefits. We address the matching of crowdshippers and parcels using a dynamic and stochastic assignment method based on Approximate Dynamic Programming with Value Function Approximation.

4 - Optimising the Biorefinery Supply Chain: A GIS-Based Multi-Objective Approach for Sustainable Bioenergy Production
Maryam Roudneshin, Amanda Sosa

The strategic utilisation of biomass, particularly seaweed and agri-waste, presents a significant opportunity for advancing renewable energy production and fostering a circular bioeconomy. This study develops a data-driven framework for optimising biomass supply chain networks by integrating Geographic Information Systems (GIS) and the Analytical Hierarchy Process (AHP). The model evaluates multiple economic, environmental, and logistical factors to determine the most suitable locations for biorefineries, ensuring efficiency in feedstock collection, transportation, and processing. By incorporating spatial and multi-criteria decision analysis, the proposed approach enhances supply chain resilience and supports informed decision-making for sustainable bioenergy development. The findings offer valuable insights for policymakers and industry stakeholders, promoting the effective deployment of marine biomass resources in the transition towards a low-carbon economy.

■ TC-60

Tuesday, 12:30-14:00 - Room: Western LT

DEA applications in Education

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: Michael Carrillo

1 - Evaluating Teaching Efficiency Through Contingent Faculty Utilization: A DEA Study of a Flagship Public University
Michael Carrillo

This study examines instructional efficiency across 16 academic colleges at a flagship public university using Data Envelopment Analysis (DEA) from 2018 to 2024. With rising reliance on non-tenure-track (NTT) faculty, the study investigates how varying faculty compositions and revenue inputs (state appropriations and tuition) translate into key outputs—student credit hours and degrees awarded. DEA, combined with Slack and Malmquist Productivity Index (MPI) analyses, reveals consistently high-performing units (e.g., Business, Journalism, LAS), as well as units with persistent inefficiencies (e.g., Medicine, Dentistry, Vet Med). Findings show that high NTT utilization does not guarantee efficiency; rather, balanced portfolios and output alignment drive performance. The study also surfaces underleveraged instructional capacity and offers strategic implications for hiring, resource allocation, and faculty development. As higher education evolves, this work underscores the need for data-informed decisions to optimize instructional impact while sustaining academic quality and institutional mission alignment.

2 - Measuring Performance and Productivity of the Indian School Education Sector: using the Global Malmquist-Luenberger DEA Approaches
Vishal Chaubey

The educational system of schools plays a crucial role in enhancing the quality of human resources and promoting sustainable growth within nations. By utilizing a general Directional Data Envelopment Analysis (DDEA) model, both constant and variable return scales are taken into account to evaluate educational efficiency, with a focus on minimizing input and undesirable outputs while maximizing desirable ones. Findings from the analysis demonstrate notable inefficiencies in a considerable number of states and union territories (UTs) during this timeframe, 2016 to 2021, with 87.1% identified as inefficient under the Constant Return Scale (CRS) model and 38.7% under the Variable Return Scale (VRS) model. The use of the Malmquist-Luenberger Productivity Index (MLPI) and Global MLPI (GMLPI) allows for the assessment of productivity changes over the specified period. The results from MLPI and GMLPI reveal a decrease in relative efficiency for various states and UTs, underscoring the ongoing challenges in educational productivity. This pattern persists across both constant and variable return scale frameworks, indicating the presence of systemic challenges that hindering educational advancement.

3 - Analysis of the International Mobility of Researchers through a Markov Chiain model
Vincenzo Scardigno, Valerio Ficcadenti

Researchers, during all their careers, face significant barriers (e.g., Glass ceiling and gender pay gap) that limit their career development. This paper focuses on the idea that there exists a barrier given by academic affiliations. So, we analyze how the reputation of the university to which an academic is initially affiliated influences his/her carrier development. The data used to track professional carriers year by year come from the ORCiD database, which cover more than 3.8 million individuals. Whilst, university's global ranking is used to qualify the university standing. In this sense, per each year, the best university in the world is ranked 1 and the last N , with N equal to the number of university or classes used. A sample of the ORCiD data is used to obtain the transition probability of moving from one university to another, revealing how aca- demic reputation influences researchers carrier trajectories. We perform a set of evaluations using Markov chains based on ranking and years. This study present the carrier realizations of thousands of colleagues, proving difficulties in moving from high and low ranked universes and presenting some ideas on how to tackle such an issue.

■ TC-61

Tuesday, 12:30-14:00 - Room: Maurice Keyworth G.31

Behaviour in information systems

Stream: Behavioural OR
Invited session
Chair: Michael Leyer

1 - The impact of AI video summaries on video platform learning and teaching mode
Yan Peng, Dan Ke

This study investigates the impact of the AI-generated summaries of video content on users' cognitive load and learning productivity, and therefore, how to improve the teaching design of online video platforms. Grounded in Cognitive Load Theory (CLT), this study hypothesizes that AI video summaries increase learning productivity, and cognitive load (intrinsic, extraneous, germane cognitive load) mediates this relationship. The video complexity moderates the effectiveness of AI summaries on learning productivity. We conduct three between-subject experiments to validate the main hypothesis and the mediating and moderating effects, using several online videos with varying complexity levels. Participants are randomly assigned to groups with or without AI-generated summaries and complete post-video learning assessments by measure cognitive load using established self-report scales.Preliminary findings suggest that AI-generated summaries reduce extraneous cognitive load, allowing users to focus on intrinsic knowledge acquisition, thereby increasing learning efficiency. This research provides empirical evidence on how AI tools optimize cognitive resources, improve content comprehension, and shape digital knowledge acquisition. AI content summaries grasp the core content of online videos, thus improve users' learning process and productivity. Online knowledge sharing platforms can adopt such AI tools to enhance the teaching design and performance.

2 - Using AI in the presence of congestion

Benjamin Legros, *Francis de Véricourt*

This study examines the application of artificial intelligence (AI) in service systems where a decision maker (DM) must diagnose a patient. Drawing on a rational inattention framework, we model the DM's diagnostic accuracy and associated cognitive cost. While incorporating AI always enhances diagnostic accuracy, it can simultaneously increase cognitive burden. This elevated cognitive cost is particularly concerning in congested service settings, where decision-making delays translate into extended waiting times for patients.

Moreover, prolonged waiting creates added pressure on the DM, raising the marginal cognitive cost of allocating attention. In turn, the DM may opt for less cognitively demanding (and therefore less accurate) decisions. Despite this potential drawback, we prove that AI usage consistently improves diagnostic accuracy, even under conditions of heightened marginal cognitive cost. We further show that the service value—defined as the difference between accuracy and cognitive cost—also benefits from AI adoption.

However, when the arrival rate of patients surpasses a certain threshold, leveraging AI leads to longer waiting times. We define the payoff as the difference between accuracy and a cost that is proportional to waiting time. Adopting AI proves beneficial primarily in settings with very low or very high congestion levels. By contrast, scenarios with moderate patient arrival rates may be better served without AI.

3 - How to foster structural empowerment with AI Governance to improve work practices

Michael Leyer, *Oliver Behn*, *Marc Jungtaeubl*, *Mascha Will-Zocholl*

Today, professionals using AI systems in business operations face high public and legal expectations, requiring them to develop a strong understanding of their functionality and implications. For instance, the EU AI Act demands that deployers of AI systems are needed to ensure their personnel have sufficient AI knowledge. However, a recent survey of AI practitioners revealed that many lack confidence in managing AI solutions, with only one in four believing their skills and knowledge are sufficient. This points to a significant lack of AI literacy and raises the question, how a solid level of understanding can be effectively attained and maintained, particularly as AI continues to evolve. This challenge becomes even more pressing as AI systems become more sophisticated, transitioning from mere tools to autonomous agents. As a result, the relationship between humans and AI is shifting from simply using a tool to engaging in a collaborative partnership. To navigate this transformation, new competencies are required—both for employees and organizations—to assess AI trustworthiness effectively. We address this challenge from the perspective of how work practices can be improved by fostering structural empowerment of employees with AI Governance. Our work aims to develop normative design principles for responsible algorithmic decision-making from a human-centric perspective and to provide tailored recommendations for organisations.

4 - The impact of explainability and relationships on trust in AI for supplier compliance

Daniel Sanchez-Loor

AI technologies offer significant potential to enhance decision-making by augmenting human capacity and automating processes, such as evaluating supplier contract compliance. While these technologies promise efficiency, concerns about the opacity of AI reasoning and its impact on established human relationships remain unresolved. This study investigates how pre-existing supplier relationships and AI explainability influence user trust in AI decisions and empowerment. Using actor-network theory and agency theory, hypotheses are tested through a factorial survey experiment manipulating supplier relationship tenure and explainability. A pilot study of 105 professionals familiar with generative AI reveals that both relationship tenure and explainability positively affect trust and empowerment. Empowerment partially mediates the relationship between trust and intention to use AI, highlighting the need to translate trust into user confidence. However, longer supplier relationships negatively moderate the link between trust and empowerment, suggesting resistance in well-established supplier relationships. Practitioners could address these reservations by tailoring explanations to foster trust and promote the effective adoption of AI technologies in supplier compliance.

Tuesday, 14:30-16:00

■ TD-01

Tuesday, 14:30-16:00 - Room: Great Hall

Sanja Petrovic

Stream: Keynotes
Keynote session
Chair: Ender Özcan

1 - Operational Research challenges in healthcare
Sanja Petrovic

Various Operational Research methods have been developed for all levels of decision-making in healthcare including strategic level, for example, for capacity planning, location of facilities, services to be offered, facility layout, etc; tactical level, for example, for supply chain management, equipment selection, financial resource allocation, staffing levels, etc; and operational level, for example, for appointments booking, personal scheduling, inventory replenishment, etc.

This talk will discuss the role of Operational Research, Data Science and Artificial Intelligence as related disciplines in a number of healthcare problems. First, this talk will introduce the problem of radiotherapy planning of patients and a Case-based Reasoning system developed to support this decision-making process. Then scheduling problems in healthcare including appointments booking, and future work on junior doctor rotas will be discussed. The role of data mining, especially some innovative ways of patients clustering we are developing, will be presented. The focus will be on the real-world problems present in the healthcare institutions we have collaborated with. The developed methods will be presented, formula free.

The talk will complete with insights into challenges that research with healthcare institutions may pose, and some directions for future research work.

■ TD-03

Tuesday, 14:30-16:00 - Room: Esther Simpson 1.01

Panel debate: Communicating Operations Research: Strategies for Engaging Stakeholders, Academics, and the Public

Stream: Tutorials (and Workshops)
Panel session
Chair: EUROYoung Forum

1 - Communicating Operations Research: Strategies for Engaging Stakeholders, Academics, and the Public
EUROYoung Forum

Effective communication is essential for maximizing the impact of Operations Research (OR), whether in academia, industry, or public discourse. This panel session, organized by the EUROYoung Forum and the Early Career Researchers (ECR) network of the UK Operational Research Society, brings together distinguished experts to discuss best practices for conveying OR insights to different audiences.

The session will feature Vanesa Guerrero (Universidad Carlos III de Madrid, Spain), Francisco Saldanha-da-Gama (Sheffield University, UK), M. Grazia Speranza (Università degli Studi di Brescia, Italy), and Anand Subramanian (Universidade Federal da Paraíba, Brazil), who will share their perspectives on effectively presenting OR research in journal articles, engaging with industry stakeholders, and raising awareness among the general public.

Following the panel discussion, an interactive Q&A session will provide attendees with the opportunity to engage with the speakers, exchange ideas, and explore challenges in OR communication. This session aims to foster a productive discussion on improving the visibility and accessibility of OR, equipping researchers with valuable strategies to enhance their communication skills.

Host: the EUROYoung Forum and the ECR network.

■ TD-07

Tuesday, 14:30-16:00 - Room: Clarendon GR.01

Quantitative methods for systemic and climate risk

Stream: Risk Management in Commodities and Financial Markets
Invited session
Chair: Gabriele Torri

1 - From reputational risk to contagion risk in ESG-ranked equity mutual funds
Francesco Morelli, Rocco Ciciretti, Marco Nicolosi

We analyze a network of equity mutual funds, characterized by different levels of compliance with Environmental, Social, and Governance (ESG) criteria, as well as different degrees of reputational risk. Our study investigates the impact of portfolio liquidations during stress scenarios, where funds within the network are shocked based on the reputational risk of the assets they have in portfolios. The subsequent spillover effects from fire-sales spread throughout the entire network because of indirect contagion, driven by shared asset holdings among funds. Focusing on the US market from June 2016 to June 2022, we assess, on a monthly basis, whether High ESG-ranked funds demonstrate greater resilience to contagion compared to Low ESG-ranked funds under varying stress scenarios. Furthermore, by applying principal component analysis to the network's adjacency matrix, we empirically demonstrate that the coordinates of the first principal component serve as a measure of each fund's vulnerability to contagion.

2 - Using Causal Inference to Assess the Value of Dual Sourcing
Thomas De Backker

Recent disruptions from events like COVID-19, climate change and trade embargoes have driven firms to adopt strategies to implement supply chain resilience. One such measure is the adoption of multi-sourcing strategies, where components and products are procured from multiple suppliers to mitigate risks associated with failures from the primary supplier. We aim to investigate the effectiveness of dual sourcing in mitigating disruption risk and provide insight into which components benefit most. We differentiate between using a second supplier as a regular supplier (supplier diversification) or an emergency (backup) supplier, activated only if a disruption occurs. We employ causal inference methodologies to examine the causal effect of dual sourcing on stockout risk. This allows us to isolate the independent causal relationship between the presence of a second supplier and a component's stockout vulnerability. A case study is conducted with an OEM, analyzing 597 components (22 dual-sourced), using historical stockout data(01/2022 - 01/2025). By controlling for other component characteristics and considering the potential mediating effect of inventory policies, we investigate the causal impact on the predicted number of stockout days over a predefined period. To inform recommendations for or against dual sourcing, we analyze conditional treatment effects with component characteristics to determine which types of components are more susceptible to the effects of dual sourcing.

3 - Pricing of synthetic CDOs with infectious defaults and market based measures of systemic risk

Gabriele Torri, Rosella Giacometti, Gianluca Farina

A vast literature that studied the pricing of synthetic CDOs flourished in the first decade of the 00s due to the expansion of the market of CDOs and other complex credit derivatives. The relevance of CDO-type contracts and the correct estimation of the probability of joint defaults is still relevant today. Indeed, the market perception of joint default correlations implied by such contracts is valuable to regulators and practitioners interested in assessing systemic risk and financial contagion. We introduce a model for the loss distribution of a credit portfolio considering a contagion mechanism for the default of names which is the result of two independent components: an infection attempt generated by defaulting entities and a failed defence from healthy ones. We then propose an efficient recursive algorithm for the loss distribution. Then we extend the framework with a more flexible mixture distribution to better fit real-world data. In the empirical analysis, we calibrate the model on the CDO tranches of the iTraxx index, and we use the information embedded in the market prices of CDOs as market based measures of systemic risk.

4 - Improving portfolio optimization with ESG disagreement information.

Marco Bonomelli

ESG scores are becoming central for integrating sustainability into portfolio selection and investment strategies. Companies with stronger sustainability efforts are believed to be more resilient to ESG-related risks. For this reason, from a theoretical point of view, portfolios with higher sustainability scores should offer greater stability during periods of market volatility and uncertainty. However, ESG scores for publicly traded companies are issued by multiple providers, and each of them adopts different methodologies and data sources. This results in discrepancies among scores. However, as companies improve reporting practices and adopt best sustainability standards, such as reducing emissions and adopting specific 'green' policy, their scores should move and converge at higher levels over time. This study examines the link between ESG scores alignment and portfolio performance, focusing on two aspects: score disagreements and the effect of new ESG updates. In our study we aim to assess whether assets with high average score and low disagreement from ESG data contribute to better portfolio performance. These assets, considered "mature" in terms of sustainability, may lead to more stable investment strategies and high long-term returns.

■ TD-08

Tuesday, 14:30-16:00 - Room: Clarendon SR 2.08

Session in honour of Theo Stewart

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: *K.Nadia Papamichail*
Chair: *Ian Durbach*
Chair: *Salvatore Greco*

1 - Contributions to Research of Theo Stewart

Murat Koksalan, Jyrki Wallenius

We review the contributions to research of Theo Stewart. We distinguish two important streams of research: 1) His theoretical work in multi-criteria decision analysis and multi-objective optimization often seeking to integrate several related fields and different schools, such as MCDM & Data Envelopment Analysis; 2) His applied work based on the use of multi-criteria decision analysis and multi-objective optimization, notably dealing with environment, energy, sustainability, land use, and fisheries.

2 - Scenario-Focused Decision Analysis: A Discussion

Simon French

Scenarios have been used in risk management for many years, first in scenario planning to identify risks and their possible impacts, which may then be explored using quantitative risk analysis. Qualitative scenario planning has also been used in problem formulation for MCDA studies and more generally to support decision-making and strategic deliberations. Until relatively recently, however, scenario thinking has not been more fully combined with quantitative MCDA studies. There are issues to overcome in forming meaningful quantitative comparisons between scenarios and in presenting the results to decision-makers in ways that help them reach a conclusion which they judge to be requisite. This paper discusses these issues and suggests possible ways forward.

3 - Balance and baselines: an impossibility theorem and a new axiomatisation of an additive scoring rule

Alec Morton, Lars Østerdal

A feature in many multicriteria problems is a preference for "balance" - an equal distribution of resources across stakeholders or conceptual categories. An excellent example of this phenomenon is Theo's case-study paper "A multi-criteria decision support system for R&D project selection" published in JORS in 1991. In this paper we present a normative exploration of the implications of this preference when baselines are uncertain or contested. We prove an impossibility theorem showing that if a decision maker is strictly outcome-based yet expresses a strict preference for balance over gains whatever the baseline, then a normative inconsistency arises. We then show that if the balance preference is weakened and combined with standard conditions (such as a weak Pareto principle and continuity), the only consistent aggregation rule is an additive one. Our results highlight a key theme of Theo's work: that deliberative decision making necessarily involves reconciling preferences intuitions "in the small" - over a fragment of the decision space - and "in the large" - over the whole of that space.

4 - Integrated Multi-Objective Optimisation for Walking School Bus Route Planning and Supervisor Rostering

Leena Ahmed, Matthias Ehrgott, Judith Y. T. Wang, Ahmed Kheiri

Walking School Buses (WSBs) are a form of supervised Active School Travel (AST) that provide a safe and sustainable transport option for children under adult supervision. They help to reverse the global trend of parents chauffeuring children to school and reduce the negative effects of the use of motorised vehicles. However, the success of WSB programmes has been impeded by key challenges, particularly in safe route planning and personnel availability. There has been a limited number of studies on routing optimisation but no specific studies on rostering of WSB supervisors. This presents a specific research gap for us to address both challenges with optimisation. We propose an integrated optimisation framework combining two sequential multi-objective integer linear programming models for route planning and supervisors rostering. The route planning model aims to find efficient walking routes considering three conflicting objectives: travel time, walkability as a measure of safety and comfort, and pollution dose. Additionally, it determines the demand on each route for the rostering model. The supervisor rostering model then assigns supervisors on the planned routes based on their availability and preferences, ensuring enough supervisors to cover the demand on each route. The rostering model, formulated as a set-partitioning problem aims to minimise scheduling costs while ensuring adequate coverage. The proposed framework is tested on real-world instances from two schools in Bradford, UK, Shipley C.E. Primary and Wycliffe C.E. Primary. Our results demonstrate the effectiveness of the approach in generating safe and efficient walking routes and balanced supervisors' rosters, ensuring a scalable and sustainable WSB service.

■ TD-09

Tuesday, 14:30-16:00 - Room: Clarendon SR 2.01

Insurance and financial innovation for sustainable growth

Stream: OR in Finance and Insurance
Invited session
Chair: Susanna Levantesi

1 - The role of households in financing the move towards a sustainable economy: results from a lab-in-the-field experiment in Italy
Beatrice Bertelli, Marianna Brunetti, Costanza Torricelli, Mariangela Zoli

Based on survey data from a lab-in-the-field experiment ran in October-November 2024 in different branches of a large Italian bank, this paper investigates the household Willingness to Pay (WTP) for sustainable assets with the final aim of exploring the effect of a visual treatment and possible differences across the three sustainability dimensions, i.e. E, S and G. Three are the main results based on a linear regression model. First, once observations of incoherent or ESG-averse individuals are dropped from the sample, the estimate for the negative visual treatment reaches marginal significance, whereby the positive one is not significant, implying that only the exposure to a negative visual treatment is associated to an increase in the WTP for ESG. Second, both treatments are not significant once control variables are added, with the WTP lower for graduates, but higher for those with a medium investment horizon, aware of climate change, worried about pollution and engaged in volunteering. Third, when dissecting results by the factor of interest, the negative visual treatment significantly increases the WTP for the E dimension only. This result hints to household investors not considering sustainability as multidimensional, but it is encouraging since the treatment used leveraged on the environmental dimension only. Hence, the correct leverage might stimulate the demand for ESG assets and a potentially positive WTP for them, with obvious industry and policy implications.

2 - A Prospective Analysis of LTC Insurance: model risk and subjective utility assessment
Gabriella Piscopo, Emilia Di Lorenzo, Alba Roviello, Marilena Sibillo

The emergence of aging and health deterioration, coupled with increasing pressure on global healthcare systems, calls for greater effort from long-term care (LTC) systems. These systems can provide solutions that address social needs while promoting collective well-being, aligned with the principles of sustainable finance. In this work, we examine how insurers can dynamically evaluate profits from a LTC portfolio under a forward-looking perspective. In particular, these types of coverage are based on health-related tables and transition probabilities, whose determination is complex and subject to a high degree of uncertainty. In order to exhibit the consequences of making an incorrect choice in terms of technical bases, we built our methodology on a 'risk-adjusted' procedure and investigate expected profit/loss patterns over time, as well as perceived risk in different valuation scenarios. Additionally, to enables profitability measurement to reflect risk exposure, we incorporate model risk into a subjective evaluation, considering CRRA utility functions adjusted for risk.

3 - The greenium in the European banking sector: an application to the fixed income market
Chiara Pederzoli, Edit Rroji, Anna Maria Fiori

Consistently with the Sustainable Development Goals of the 2030 Agenda, the green bond market has been growing rapidly in the last few years. Since green bonds should finance projects embedding environmental benefits, environmentally responsible investors should be willing to accept lower financial returns from investing in these bonds. However, in the literature there is no consensus on the premium for greenness, the so called greenium. In particular, there is no clear evidence on the dynamic behaviour of the greenium. To analyse this topic, we consider a set of green and brown bonds issued by financial institutions in the Euro area. We classify bonds according to the ICMA Green Bond Principles. We paired these bonds by minimizing a distance based on rating, currency, bond type (callability), coupon, nominal amount issued, duration and distance from issue date. The resulting dataset of green and brown bonds allows shedding light on the possible existence of a green factor. Based on data from April 2022 to January 2024, we perform a Principal Component Analysis in order to highlight the difference in factors explaining the variability of both returns and variations in OAS of green as opposed to brown bonds. Although common factors explain most of the variability, room is left for a greenness component. This issue deserves further analysis, since the possible existence of a green factor would be relevant in guiding investments.

4 - Risk sharing assessment in health insurance: a loss function approach
Alberto Piscitelli, Emilia Di Lorenzo, Massimiliano Menzietti, Marilena Sibillo

The study deals with an innovative securitization framework, fully aligned with the social goal of health protection. Among the key players influencing the entire economic-social cycle, the insurer plays a central role. In line with the insurer's perspective, the paper provides an in-depth analysis of the loss function, deriving strategic insights tailored to the specific characteristics of the context. Within this framework, the loss function is examined in light of the risk-sharing mechanisms, highlighting the implications for managing and optimizing insurance policies.

■ TD-10

Tuesday, 14:30-16:00 - Room: Clarendon SR 1.06

MCDA and urban planning 1

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Francesca Abastante
Chair: Marta Bottero
Chair: Isabella Lami

1 - Evaluating urban quality through a participatory spatial multicriteria analysis
Marta Bottero, Sebastiano Barbieri, Caterina Caprioli, Federico Dell'Anna, Federica Volpatto

Urban quality is a multifaceted concept that has been explored by different disciplines in both theoretical and practical ways. The definition given by the urban design priorities the physical setting of the built environment, its morphological layout and the consideration of intangible and social values (Oppio et al. 2020). This definition highlights the hierarchical and multi-attribute nature of urban quality, which requires an assessment capable of considering these multiple aspects in a multi-stakeholder context. The present research proposes the use of Spatial Multicriteria Analysis (S-MCA) (Malczewski, 2006) to evaluate the urban quality of the northern part of the city of Turin (Italy). After a literature review, the evaluation problem is hierarchically structured in 4 criteria and 16 sub-criteria. The set of weights is assigned during a workshop involving a group of stakeholders, including the Turin City Councillor for Urban Planning, a representative of the citizens, the local public transport and the Environmental Agency. The analysis supports the definition of the city's public administration policies, particularly in the context of the implementation of the new municipal plan.

2 - A spatial A'WOT for the sustainable management of World Heritage Sites
Sebastiano Barbieri, Caterina Caprioli, Marta Bottero

Cultural heritage plays a fundamental role in preserving the history and identity of the world's communities. In this context, UNESCO promotes the intercultural understanding of this priceless heritage by including eligible sites on the World Heritage List. This prestigious award requires that cultural heritage sites have an Outstanding Universal Value (OUV) meeting one of the ten criteria established by the institution. Sustainable management of UNESCO sites is essential for their long-term value conservation. This process requires identifying and evaluating site-related challenges and defining effective strategies and intervention priorities. Usually, qualitative methods are used for this purpose, such as surveys, SWOT and Stakeholder analysis. However, to support and inform the process through quantitative measures, other methods are required. Within this context, this work applies an A'WOT to a World Heritage Site to assess challenges and define priorities for sustainable management. The integrated approach exploits the potential of both analyses. SWOT identifies the challenges and potentials of the area under investigation to develop appropriate strategies. The multicriteria evaluation allows to structure and evaluate complex scenarios, considering qualitative and quantitative variables to identify the most suitable solution. Furthermore, GIS is integrated to generate maps that visually represent key priorities, enhancing decision-making and stakeholders' engagement.

3 - Stakeholder-driven decision support for public building reuse: A multi-criteria approach to urban regeneration
Danny Casprini, Marta Bottero, Giulio Cavana, Federico Dell'Anna, José Rui Figueira, Alessandra Oppio

Repurposing public buildings is a complex challenge that requires structured decision-making to balance social, economic, and environmental priorities. This study presents a Multi-Attribute Value Theory-based model that integrates stakeholders' input to support strategic urban regeneration initiatives and improve project evaluation. The model is designed to incorporate stakeholder preferences at multiple stages of the decision-making process, ensuring that value assessments align with real needs and priorities. To define value functions for each criterion, the study employs an extended version of the Simos-Roy-Figueira (SRF) method (Bottero et al., 2018), allowing decision-makers to structure performance scales based on expert preferences. Additionally, the Swing method is integrated into the model to derive criteria weights, ensuring that the importance of each factor is rigorously assessed and systematically incorporated into the evaluation framework. A case study in Turin, Italy, demonstrates how this stakeholder-driven approach enhances legitimacy and robustness in urban decision-making. By embedding diverse perspectives into the evaluation process, this model strengthens consensus-building, improves ability to prioritize impact objectives, and supports more effective urban regeneration strategies, capable of generating societal outcomes at the neighbourhood and city level.

4 - From Academia to Practice: Experiences and observations from four years of MCDA practice in Canada
Francis Marleau Donais

Multi-criteria decision-aiding methods (MCDA) are increasingly used in practice as they enable several, often conflicting, objectives to be considered in decision-making processes. However, developing an MCDA process is not an easy task. A decision analyst needs to be familiar with the characteristics of various MCDA methods, and to have facilitation skills. However, in the province of Quebec, Canada, there is a gap between best practices, coherent with the scientific literature, and the application of MCDA methods in the industry. Professionals using MCDA methods often lack comprehensive knowledge about these methods, and apply the them without knowing their limitations. Consequently, numerous missteps are made throughout the decision process, proposing solutions to ill-defined problems and leading, in some cases, to results that are challenged or rejected by decision-makers. These issues arise at all stages of a MCDA process, from problem structuring to model building. This talk will present briefly different case studies, based on four years of industry experience in different transportation projects. It will highlight the observed challenges in the application of MCDA methods.

■ TD-11

Tuesday, 14:30-16:00 - Room: Clarendon SR 1.03

Pharmaceuticals and manufacturers

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Marie Baratto

1 - Innovation in vaccine supply chains: Profit-sharing contract
Milad Asadpour, Guven Demirel, Brigitte Granville

Glass vials are widely preferred in pharmaceutical packaging due to their unique attributes, particularly their ability to maintain the liquid inside from contamination by factors such as moisture, oxygen, and chemicals. Despite their advantages, glass vials pose significant drawbacks that may hinder the efficient delivery of vaccines. The most critical drawback is breakage, which can occur at various stages — from pre-filling to post-filling processes. Official reports indicate that vaccine vial breakage rates can average around 10% of total vials. Given the large-scale production of vaccines, even this seemingly modest percentage translates into a substantial number of damaged vials, potentially disrupting supply chains. To address this challenge, vial suppliers must prioritise enhancing vial quality. Using a game-theoretical framework, we investigate the effectiveness of profit-sharing contracts in promoting innovation to reduce vial breakage. Our analysis considers a market structure where the manufacturer determines the final price of the vaccine, and demand is price sensitive. We model the interactions between one vial supplier and one vaccine manufacturer, exploring a profit-sharing contract in which the vaccine manufacturer shares a percentage of its profit with the supplier to support R&D projects. We evaluate the contract's effectiveness in fostering innovation and lowering the vial breakage rate.

2 - The Role of Information Asymmetry Between Brand-Name and Generic Firms in Pharmaceutical Markets: Limit Pricing and the Generic Competition Paradox
Qinquan Cui, Kenan Arifoglu, Dongyuan Zhan

Brand-name firms, leveraging their extensive resources and patent protection, possess more information about consumers compared to generic firms. This information asymmetry plays a crucial role in shaping pharmaceutical markets. Moreover, following the entry of their generic alternatives, some brand-name drug prices experience a paradoxical increase (i.e., the Generic Competition Paradox (GCP)). However, existing research overlooks the information asymmetry between brand-name and generic firms, failing to provide a comprehensive understanding of pharmaceutical markets. To address this, we develop a game-theoretic model with signaling to analyze interactions between a brand-name firm and a generic firm over two periods (signaling and full-information). We find that the brand-name firm can use limit pricing during the signaling period to deter generic entry by charging below its monopoly price, then increase its price and allow entry in the full-information period, leading to the GCP. Consequently, under information asymmetry, limit pricing may arise from the brand-name firm's anticompetitive practices, offering an alternative explanation for the GCP. While typically resulting in higher drug prices and reduced consumer choice, limit pricing and the GCP can sometimes benefit consumers and society. This challenges the prevailing belief that information asymmetry and the GCP are always detrimental, highlighting their nuanced impacts

3 - Optimizing product allocation for automated drug dispensers at central fill pharmacies
Marieke Brederveld, Renzo Akkerman, Sander De Leeuw

Part of the daily operations of central fill pharmacies consist of collating and shipping of medication to local pharmacies based on client orders. There exist various designs of automated order collation systems to facilitate the order fulfilment. The system considered in our study consists of multiple parallel working automated drug dispensers and one basket loading machine; which requires more manual labor. Therefore we aim to achieve a higher percentage of client orders for which the automated drug dispenser can be used. The allocation of products in a parallel operating system design is however challenging. It resembles a densest k-clustering hypergraph problem, but also has additional characteristics. Therefore, we developed an effective solution method to find a product allocation that leads to a higher rate of orders filled by the automated drug dispensers, and runs in a reasonable amount of time, given the characteristics of the set of orders and assortment, and given the slot design of the machines.

4 - Optimizing the tailoring of the Dutch medicines stockpiling policy
Marie Baratto, Harwin de Vries, Thomas Breugem, Stef Lemmens

Medicine shortages are a worldwide global challenge, prompting countries to develop mitigation strategies, including stockpiling. In the Netherlands, stockpile quantities are uniform across all medicines. This "one-size-fits-all" approach is ineffective, whereas tailored policies —specifying different minimum stock levels for different categories of medicines— can enhance supply resilience and reduce costs. However, tailoring increases policy complexity, which must be balanced with simplicity for ease of implementation and governance. Decision trees offer an elegant way to navigate this trade-off.

We develop a general approach for optimal stockpiling decision trees, ensuring simplicity and practicality, and apply it to the Dutch case.

Our research is in line with recent work on optimal descriptive, classification and prescriptive trees which apply machine learning and optimization techniques to solve mixed integer optimization formulations of decision tree problems. Unlike traditional greedy heuristics, we aim to construct the tree in a single step by solving an MILP formulation. To balance tailoring and simplicity, we explore various tree structures, such as symmetrical complete trees and incomplete trees. In collaboration with the Dutch government and pharmaceutical stakeholders, we apply our model to optimize stockpile levels, developing a cost-effective policy that is practical for implementation and strengthens pharmaceutical supply resilience.

■ TD-12

Tuesday, 14:30-16:00 - Room: Clarendon SR 1.02

Job shop scheduling

Stream: Scheduling and Project Management
Invited session
Chair: *Joost Berkhout*

1 - Integrated Flexible Job Shop and Operator Scheduling
Reza Ghorbani Saber, Pieter Leyman, El-Houssaine Aghezzaf

This study addresses the Flexible Job Shop Scheduling and Operator Timetabling Problem (FJSPOT), which integrates operation scheduling with operator timetabling under shift regulation constraints. A key distinction between this study and prior works is that operations may span multiple shifts and operators are assigned to machines and shifts to cover the scheduled operations on machine. Furthermore, the feasibility of the operation schedule may be restricted by operators' availability and their timetable. To address the problem, we present a strengthened mixed integer programming (MIP) to enhance the existing models for this problem. Furthermore, we develop a decomposition approach that deploys a cut generation process. Additionally, we develop two heuristic-based solution approaches to tackle the problem in large scale. Our findings indicate that for small instances, the hybrid decomposition approach outperforms the MIP formulation. In medium and large instances the proposed heuristics can efficiently generate solutions within a reasonable computational time.

2 - Well-being-aware Dual-resource-constrained flexible job shop scheduling problem
Peyman Yasari, Dieter Claeys, El-Houssaine Aghezzaf

Nowadays, the importance of well-being in the work environment is undeniable. A lack of physical well-being leads to musculoskeletal disorders, while a lack of mental well-being contributes to worker burnout. Both issues result in significant losses of time, cost, and energy for industries. Although the primary phase for addressing these aspects is during task and workstation design, it is also possible to manage resources to balance and adjust workloads during the exploitation phase. Well-being-aware task allocation and scheduling aims to address this gap.

To achieve this, a mixed-integer linear programming (MILP) model has been developed. This model limits the experienced aggregated task loads to an operator-specific threshold. However, aggregating task loads poses a significant challenge: for physical loads, only a few validated methods exist, which makes the model non-linear for most risk factors, while for cognitive loads, no established method is available. Nevertheless, the proposed model is flexible and can accommodate different measures that provide this feature. An exact solution method is introduced to address the complexity added by the threshold constraints. Additionally, the presentation will discuss a simplified version of the problem that forms the basis for developing a more efficient solution method.

3 - (Sim)PyJobShop: Integrating Optimization and Simulation for Uncertainty-Aware Scheduling
Joost Berkhout, Leon Lan

This talk introduces PyJobShop, an open-source Python library for modeling and solving scheduling problems, and SimPyJobShop, an extension integrating discrete-event simulation to account for uncertainty.

PyJobShop offers a flexible interface for various scheduling problems, including job shop and resource-constrained project scheduling. It integrates two constraint programming solvers: the open-source OR-Tools CP-SAT and the commercial IBM ILOG CP Optimizer. Large-scale experiments on 9,000+ benchmark instances show that PyJobShop identifies new best-known solutions. Additionally, CP-SAT performs competitively with CP Optimizer on most scheduling problems, though CP Optimizer scales better for large and permutation-based instances.

SimPyJobShop extends PyJobShop by enabling uncertainty modeling through a simheuristics framework. We evaluate multiple simheuristic strategies across diverse scheduling scenarios, demonstrating how SimPyJobShop facilitates uncertainty-aware decision-making with minimal additional modeling effort. By unifying optimization and simulation, we provide researchers and practitioners with a powerful tool for improving scheduling solutions under uncertainty.

■ TD-13

Tuesday, 14:30-16:00 - Room: Clarendon SR 1.01

Machine learning in healthcare

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Antonio Sergio da Silva*

1 - Clinical Pathway Modelling of a Trauma & Orthopaedics Department
Matthew Howells, Paul Harper, Daniel Gartner, Geraint Palmer, Antonio Riccioli

Trauma and Orthopaedic (T&O) departments face dual pressures from backlogs caused by the COVID-19 pandemic and ageing populations, leading to increased frailty and greater demand for services. Growing waitlists already negatively impact patients and will continue to do so without intervention. Clinical pathways (CPs) provide structured processes for standardising essential steps in managing a health condition or medical procedure. This research implements the ALERGIA algorithm in Python to generalise CPs from a T&O patient dataset in the UK's National Health Service. This allows us to infer potential future CPs not present in the dataset while filtering out statistically insignificant pathways. We further demonstrate how these CPs inform a novel approach to parameterising a discrete-event simulation (DES) of a holistic T&O surgical pathway. This ensures the model remains adaptable rather than strictly tied to historical data while refining routing probabilities by reducing noise. The DES model is then integrated with a system dynamics model that assesses the burden of orthopaedic conditions in the population and how patients deteriorate over time while awaiting a referral from their General Practitioner. This approach enables us to assess how changes in demand and capacity, both inside and outside the hospital, impact patient flow and health outcomes. It provides hospital staff with better decision-making tools to alleviate treatment backlogs and improve patient care.

2 - Optimizing Post-Discharge Follow-Up Using Operational Research and AI-Driven Risk Stratification
Matilde Santos, Mariana Peyroteo, Luís Lapão

Hospital readmissions pose significant operational challenge, demanding efficient resource allocation and smarter decision-making in healthcare organization. This study applies Operational Research (OR) methodologies to optimize post-discharge follow-up through iFollow@Care digital platform - a decision-support system integrating machine learning-based risk stratification with workflow optimization. The digital platform was implemented with streamlit and python libraries. Using three years of patients' follow-up data, we developed a classification model (Logistic Regression, AUROC: 0.9531) to dynamically prioritize patient follow-up needs, reducing unnecessary interventions while ensuring timely care for high-risk cases. The application of predictive analytics, and resource optimization enabled the reduction of nurse workload by at least 79%, reallocating time toward more value-added patient care. Additionally, evidence-based validation demonstrated its potential to enhance patient outcomes and hospital efficiency. This work highlights the role of AI and OR in data-driven healthcare decision-making, offering a scalable framework for real-time risk management and proper resource allocation in hospital settings.

3 - Quantifying the association between the doctor patient ratio and patient life expectancy in England
Colin Stewart

Data collated by the World Health Organization shows that countries with longer life expectancies have higher doctor to patient ratios on average. It seems reasonable to suppose that this relationship between resourcing and life expectancy should also hold true within countries. To test this, More Metrics have analysed publicly available data for 6000 general practice surgeries in England. The objective of this study is to quantify the incremental impact on life expectancy of the primary care doctor patient ratio taking full account of confounding factors (such as community deprivation levels). Our study uses disaggregation to show the same directional relationship between life expectancy and resourcing in England as seen in the international data. In the talk we will first illustrate the disaggregation method applied to smoker status exposures before applying the same method to quantify the impact of different doctor patient ratio exposures on life expectancy. The results show that while the doctor patient ratio is important, other factors relating to the work of primary care professionals also affect patient life expectancy. An extension of our study that combines resourcing levels with GP diagnosis patterns illustrates the benefits of taking a more rounded view. This extended study has led to the development of a GP performance grid aimed at supporting local resourcing decisions. This will be briefly described together with our plans for further work.

4 - Applications of Machine Learning to Optimal Facility Design for Healthcare Worker and Patient Safety
Hengameh Hosseini

Designing healthcare facilities to accommodate individuals with disabilities, particularly for workers in physically demanding roles, presents significant challenges. Many healthcare facilities fail to meet the needs of workers with disabilities, especially those with physical disabilities and low vision, who are at increased risk of injury due to poorly designed environments. This study investigates the impact of facility design on healthcare workers with low vision, focusing on the potential safety risks posed by insufficient accommodations.

We conducted surveys, interviews, and in-facility observations across seven healthcare facilities in the U.S., representing various sizes and ownership models. Our analysis identified five major design shortcomings common across all facilities that could endanger physically and visually impaired employees, ranging from minor to severe hazards. A key finding was the lack of design empathy among facility managers and administrators.

To address these issues, we propose three solutions to guide design: (1) leveraging an open-source Augmented Reality (AR) application to simulate the low-vision experience for designers; (2) employing a machine learning model to analyze patient and employee feedback to detect facility shortcomings; and (3) using computer vision to predict hazardous facility features for visually impaired employees. Through comparative experiments, we demonstrate which methods can be effective under specific conditions.

■ TD-15

Tuesday, 14:30-16:00 - Room: Esther Simpson 1.08

Methodological developments in public transportation and medical tourism

Stream: Combinatorial Optimization
Invited session
Chair: Erwin Pesch
Chair: *Alena Otto*
Chair: *Sven Mallach*
Chair: *Marie Schmidt*

1 - A column generation approach for line planning with frequency-dependent travel times and integrated rapid transit route selection
Rowan Hoogervorst, Evelien van der Hurk

The line planning problem focuses on picking the lines to be operated in a public transport network together with their frequency. The lines' frequency impacts the passenger service level through the expected waiting time for passengers when alighting and transferring and the operational costs through the number of buses required for maintaining the frequency. In this talk, we look at this line planning problem with frequency-dependent weighted passenger travel time in the context of the construction of a new rapid transit line, where one also has to decide on the route of the rapid transit line. We use a branch-price-and-cut approach to solve this problem, where frequency-dependent passenger paths are dynamically generated using column generation and where we add valid inequalities connecting the passenger flow and opening of lines. Moreover, we use a problem-specific primal heuristic to find integer solutions quickly within the branch-and-bound tree. We test the proposed method on instances available through the LinTim package and a case study for a planned Bus Rapid Transit (BRT) line around Copenhagen.

2 - Line planning with route- and frequency-dependent demand
Siv Marie Cartland Hansen, Evelien van der Hurk, Rowan Hoogervorst

The line planning problem addresses the selection of transit lines and their operating frequencies within a public transport network. While traditional approaches often assume that demand is fixed, real-world travel demand is endogenous and depends on the service. In this study, we consider the minimization of passenger and operator costs subject to budget and capacity restrictions. Passenger costs are evaluated using weighted travel time considering frequency-dependent waiting and transfer times. We include demand elasticity in the sense that the demand between any two stations depends on the weighted travel time that is available given the established lines and frequencies. Passengers are only assigned to paths if the weighted travel time is competitive compared to an alternative. The resulting mixed-integer linear program is solved using an exact iterative relaxation-based algorithm. This approach effectively handles a large set of frequency options, which allows for a detailed representation of travel time and demand. Our computational experiments on multiple networks show that incorporating demand elasticity during optimization leads to more efficient use of resources, reduces travel times and captures more travel demand compared to a fixed-demand approach.

3 - Short-term timetable re-scheduling for maintenance possessions
Gabor Maroti

The smooth operation of passenger and freight networks requires regular preventive maintenance where infrastructure segments are fully or partially closed for a few days. These possession necessitate large changes in the annual timetable. The re-scheduling takes place up to two months before the operations.

In this research we present an iterative optimisation approach for the adjustment problem of a periodic timetable. The algorithm consists of a macroscopic network-level timetable optimisation model and mesoscopic (station-level) platform track optimisation model. The models are connected by a feed-back loop.

We illustrate the power of the optimisation approach by applying it to realistic large-scale problem instances of Netherlands Railways. The instances concern the entire Dutch railways network, and feature various combinations of simultaneous maintenance possessions. Our methods are able to provide practically relevant solutions within a few minutes of computation time.

4 - A Learning-Enhanced Matheuristic Approach for Optimizing Recreational Activity Planning in Medical Tourism
Burak Pac

In medical tourism, the integration of medical treatments with recreational activities requires careful planning to ensure tourist satisfaction and operational efficiency. The Recreational Activity Planning Problem involves assigning recreational activities to medical tourists while respecting their medical schedules, budget constraints, and activity preferences. Activity durations and capacities must be adhered to, with the aim of maximizing a weighted sum of profit from touristic activities and tourist satisfaction. The problem is formulated as an Integer Programming model, and its NP-hardness is established through a reduction to the Multiple Knapsack Problem with Assignment Restrictions. A matheuristic approach based on Variable Neighborhood Search is proposed, leveraging diverse neighborhood structures to efficiently explore alternative solutions with a broad scope. A key aspect in the methodology devised is the use of neural networks to predict at incumbent solutions the improvement potential of different neighborhood structures. These predictions enhance the prioritization of neighborhood structures to be searched, significantly improving the efficiency of the algorithm. Experimental results highlight the added value of neural network predictions in guiding the search process, enabling the solution of large-scale instances that are unsolvable within reasonable time by commercial solvers.

■ TD-16

Tuesday, 14:30-16:00 - Room: Esther Simpson 2.07

Sustainable Forestry

Stream: Sustainable Food & Agroforestry
Invited session
Chair: *Lidija Zadnik Stirn*

1 - Forest Road Network for Firefighter Access
Miguel Constantino, Marta Mesquita, Mariana Sempiterno

Wildfires pose a growing threat to the environment, economy, and human life, demanding effective prevention and firefighting strategies. Despite the crucial role of forest roads in granting firefighters access, their planning often overlooks firefighting requirements. In this talk, we present models designed to determine the most cost-effective road network for ensuring firefighter access to the forest. We formulate the problem as a Steiner Tree Problem in a graph and discuss results from a case study conducted in a Portuguese forest.

2 - Planning harvesting and timber transportation with a fix-and-improve heuristic
Marta Mesquita, Miguel Constantino, Susete Marques, Jose Borges

The primary challenges in forest management planning involve spatio-temporal decisions, particularly in harvest scheduling where stands are chosen for harvesting within specific time periods. This process must align with the design of a forest road network, facilitating machinery access to stands and timber transportation to sawmills. To address this problem, we propose a MILP model integrating harvest scheduling, road planning, and timber routing, aiming to maximize income calculated as the difference between the revenue of selling the harvested timber against the associated extraction, road build or maintenance, and transportation costs. However, this problem incorporates a NP-hard fixed charge network flow, making it challenging to solve real-life instances as their size and complexity increase. We have developed a fix-and-improve heuristic that iterates between solving the integrated problem within a restricted road network and solving a subproblem on road planning and timber routing across the full road network. In each iteration, the solution of the subproblem gives information on how to improve the restricted forest road network. The proposed solution approach was applied to a real-life case study of a forest landscape in Portugal, showing its effectiveness and practical applicability

3 - Recent experience in applying tabu search and threshold accepting to contemporary forest harvest scheduling problems
Pete Bettinger

The contemporary tactical forest harvest scheduling problem (20-30 year time horizon) involves the use of integer decision variables and spatial constraints that limit the placement and timing of harvest activities based on other similar activities that have already been scheduled. Enhancements to both tabu search and threshold accepting metaheuristics were recently assessed to determine the extent to which the values of tactical forest plans might vary. These enhancements included 2-opt moves and search reversion (both tabu search and threshold accepting) and second-best selection from the neighbourhood (tabu search). Results indicate that significantly different (improved) values of tactical forest harvest schedules can be developed with certain combinations of enhancements to each metaheuristic. However, the trade-offs between solution quality and relative time to generate solutions may require consideration by the planner.

4 - Modeling the provision of ecosystem services by combining different multi-criteria concepts
Lidija Zadnik Stirn, Vasja Leban, Špela Pezdevšek Malovrh

Multi-criteria paradigms are developed to optimize resource/landscape management that contributes to the efficient allocation of ecosystem

services (ES) while balancing economic, social, political and environmental objectives. They aim to account for the inherent complexity of ecosystems, especially regarding multiple objectives, multiple stakeholders, lack of information and - due to rapidly changing global conditions - stochasticity. In this context, the combination of qualitative (multi-criteria group decision methods) and quantitative (open-ended questionnaires) approaches to modeling ES supply in conjunction with ES demand appears to be a powerful framework. The study area (agroforestry and urban area) is divided into analytical units. Data on the existing supply and demand of ES in the study area were collected through surveys and from official statistics. They were qualitatively analyzed and resulted in a list of potential ES for further analysis. The amount of ES that can be provided by a particular landscape unit depends on the financial, human, political and technical resources used as inputs in output-oriented DEA (ES are outputs). The efficiency of the units is then used in a comprehensive stochastic and group multi-criteria decision analysis to evaluate sustainability-oriented management strategies and criteria to improve resilience and environmental challenges. Some strengths, opportunities and limitations of the presented approach are also highlighted.

■ TD-17

Tuesday, 14:30-16:00 - Room: Esther Simpson 2.08

Optimizing Complex Systems: Advances in Combinatorial and Stochastic Techniques

Stream: Combinatorial Optimization
Invited session
Chair: Bo Chen

1 - Multiproduct Price Competition on a Retail Platform
Lusheng Shao, Ying-Ju Chen

Many online retail platforms operate as both a reseller and a marketplace. This paper studies price competition between a multiproduct manufacturer and a retail platform in which the manufacturer sells its products directly to consumers by paying a commission fee to the platform (i.e., agency selling) while wholesaling the products to the platform for reselling. We develop a Nash game model under multinomial logit demand to characterize the firms' equilibrium pricing behaviors and investigate the impact of agency selling on the equilibrium outcomes.

2 - Scheduling multiple flexible maintenance activities
Eun-Seok Kim, Ik Sun Lee, Sunghoon Lim

Maintenance scheduling is a major challenge that many industries, such as manufacturing, aviation, railway, and service industries, face today. Poorly planned maintenance can lead to shortened equipment life and decreased productivity. This article considers a single machine scheduling problem with multiple flexible maintenance activities and health index requirements of jobs. The single machine features a health index that decreases as it processes jobs, each with its own health index requirements. The objective is to minimise the total completion time of the jobs.

The considered problem is NP-hard in the strong sense. We study several special cases which are polynomially solvable and present a Mixed Integer Programming (MIP) formulation for the general case. Some valid inequalities are also developed to narrow down the search space for finding an optimal solution of the MIP. Furthermore, we examine optimal properties of the problem and develop a simple heuristic algorithm with its approximability. In extensive computational experiments, it is demonstrated that the proposed heuristic algorithm produces solutions that are highly effective and efficient.

3 - Mixed-Integer Linear Programming Approximations for the Stochastic Knapsack
Roberto Rossi, Steven Prestwich, Armagan Tarim

We develop a general approximation framework based on mathematical programming to tackle the stochastic knapsack problem. In this problem, the decision maker considers items for which either weights or values, or both, are random. The aim is to select a subset of these items to be included into their knapsack. We consider both static (predetermined) and dynamic (sequential) decision settings. The knapsack has a given capacity, and if the total realised weight exceeds this capacity then a penalty cost is incurred for each unit of excess capacity utilised. The goal is to maximise the expected net profit. We develop mathematical programming heuristics that can tackle probability distributions of item weights belonging to the exponential family of distributions, as well as a dynamic cut generation heuristic to tackle the case in which item weights follow generic probability distributions. In contrast to other competing approaches in the literature, our heuristics extend seamlessly to the case in which item weights are correlated and follow a multivariate normal distribution. In an extensive computational study we demonstrate that our models are efficient, scalable, and near-optimal.

■ TD-20

Tuesday, 14:30-16:00 - Room: Esther Simpson 2.11

Applications of combinatorial optimisation in industry and services 3

Stream: Combinatorial Optimization
Invited session
Chair: Adriana Cherri
Chair: José Fernando Oliveira
Chair: Célia Paquay

1 - Real-time disruption management in a three-dimensional loading vehicle routing problem with split pickup and time windows
Emeline Leloup, José Fernando Oliveira, Célia Paquay, Thierry Pironet

In recent years, the growth of e-commerce has led to an increase in the number of product returns, leaving logistics service providers (LSPs) with an ever-increasing number of boxes to collect from different locations in an urban area. This gives rise to a three-dimensional loading vehicle routing problem with split pickup and time windows.

Throughout the day, real-time changes, called disruptions, occur. Disruptions that we consider here are the arrival of a new customer, the cancellation of a planned customer, the removal or addition of boxes from a planned customer request, the referenced box type being larger (by volume) than expected and a planned customer who is not ready on time.

The LSP must respond to these disruptions by adjusting his ongoing routes, schedules, and the box loading arrangements in the vehicles. His goals are to collect all the boxes from as many customers as possible and to minimize the total travel distance. We present specific recourse actions that the LSP can take to deal with these disruptions. These actions differ from those for delivery operations since the vehicle is initially empty and is progressively loaded in pickup operations.

2 - Optimizing Facade Manufacturing and Packing: A Pull System Approach
José Fernando Oliveira, Maria Antónia Carravilla, Elsa Silva, Tiago Silveira, Fernando Sousa, Rui Guerreiro

Efficiency in production and logistics is critical for timely project completion in the construction industry. This study presents a pull system approach, demonstrating the seamless progression from facade design to factory production planning.

The workflow begins with the reception of 2D CAD files, which are converted into 3D models and validated to ensure geometric accuracy before manufacturing. Once approved, components are grouped by installation sequence, facilitating an optimized container loading

and pallet packing process. The packing strategy maximizes transport efficiency, considering volume utilization, weight distribution, and fragility constraints, while factory scheduling ensures smooth production flow.

This case study highlights how digital automation and structured logistics planning enhance efficiency, minimize material waste, and reduce errors throughout the supply chain. By integrating design, cutting, packing, and transport planning, this pull-based system aligns production and logistics with project execution needs, ensuring a streamlined and cost-effective installation process.

Acknowledgement This work is a result of Agenda "PRODUTECH R3 - Agenda Mobilizadora da Fileira das Tecnologias de Produção para a Reindustrialização", nr. C645808870-00000067, investment project nr. 60, financed by the Recovery and Resilience Plan (PRR) and by European Union - NextGeneration EU.

■ TD-23

Tuesday, 14:30-16:00 - Room: Esther Simpson 3.01

Data Analytics for Business Resilience and Sustainability - Leveraging ML Models

Stream: OR for Societal Development
Invited session
Chair: *Helper Zhou*
Chair: *Sadia Samar Ali*

1 - A Willingness To Purchase (WTP) based Dynamic Pricing of Tatkal Tickets in Indian Railways
Sundaravalli Narayanaswami

Indian Railways (IR) has always been central to the travel journeys of the million Indians for commuting across the country. However, with the rising urbanization and increase in disposable income, the preference for travel mode has been shifting towards the airways especially in the tier 1 and tier 2 cities. Despite being a monopoly in railway traffic, alternate modes such as airways and roadways are huge business threats for IR (state owned and operated National Railway carrier), as people now often choose airways over railways even it means to pay a higher price for the relatively very short travel time in case of air travel. Tatkal (Just-in-time or Current booking) services is a booking service in IR, where passengers are allowed to book at a premium pricing on the travel day. As of now, the structure adopted in tatkal pricing is somewhat loosely defined; in this paper, we present a scientific model to deduce the tatkal pricing of a service, by using the Willing-to purchase (WTP) factor of a passenger, in presence of a competitive alternate mode of travel, which is airways.

2 - Building a Digital Twin Framework Using Practice-Based View for Smart Warehousing
Sadia Samar Ali

Although a number of technology-oriented approaches exist to formulate digital twins of warehouses, they often fall short by neglecting applicability and vertical linking of mission-driven practices along the value chain. It is essential for analysing and optimising warehouse-level digital twins through interconnected systems to support real-time industrial operations. To fulfil a research gap, this paper propose a practice-oriented digital twin framework integrated with the Practice-Based View (PBV) theory for smart warehousing. This work compare existing technology-oriented development practices, digital twin integration, enterprise models and non-institutional innovation efforts against the PBV prescriptive to develop a digital twin of warehouses as a practice. This results in identifying critical success factors related to digital twin of warehousing practice. However, much of the current research ignores this important relationship between new technological capabilities and the established practices of the organization. By including both technical and organizational perspectives, this framework serves as a comprehensive approach to implementing digital twins in different types of warehouses. It systematically reviews the literature on PBV, critically examines its context, explores future directions in design development while proposing the framework along with a suggested evaluation methodology.

3 - A multi-target radial basis function (RBF) network with variable shape parameters for return predictions from generative South African ESG indexes
Nina Kajiji, Gordon Dash, Helper Zhou, Bruno Kamdem

A company's commitment to environmental, social, and governance (ESG) principles has sparked interest in developing firm-level ESG scores, particularly in a VUCA world—characterized by Volatility, Uncertainty, Complexity, and Ambiguity. These challenges create rapid changes, unpredictable scenarios, and intricate interdependencies, influencing stock prices and complicating decision-making. This study aims to establish an innovative algorithmic framework to identify dynamic ESG factors that assess sustainability risk in securities traded on the Johannesburg Stock Exchange (JSE). The proposed methodology employs an alternative data approach, using asset returns in exploratory factor analysis to derive high-validity factor scores, forming JSE-specific sustainability factors. The performance of these factors is evaluated using a multi-target multi-objective radial basis function neural network (RBFN). A Bayesian-enhanced regularized RBFN, with a variable shape parameter strategy, is applied to analyze complex valuation signals. Utilizing explainable AI (XAI), findings highlight the newly developed S-factor as the key predictor of next-period returns, followed by the E-factor, the SA volatility index, and a precious metals factor. XAI demonstrates that these factors effectively capture the unique ESG priorities of South African firms, offering meaningful insights into the impact of sustainability metrics on stock performance.

4 - Option pricing in uncertain financial markets: a bibliometric analysis
Frank Ranganai Matenda, Helper Zhou

Uncertain financial markets are characterised by financial asset price processes driven by uncertain processes, which are an integral part of uncertainty theory. This study aims to analyse research trends in option pricing in uncertain financial markets, with particular attention to the growing role of artificial intelligence (AI) and machine learning (ML) techniques. Extant literature on option pricing in uncertain financial markets is examined and future research avenues are identified. A bibliometric analysis approach is employed, incorporating network and descriptive analysis to assess publication trends. The study identifies research trends, leading researchers, influential journals, notable articles, contributions from countries and institutions, significant themes and avenues for future research. Interestingly, the implementation of AI and ML techniques in option pricing in uncertain financial markets is at its developmental stage. Researchers can can implement AI and ML techniques to enhance predictive accuracy and decision-making under uncertainty. This study offers valuable insights for researchers and practitioners seeking to enhance predictive accuracy and decision-making in uncertain financial markets.

■ TD-25

Tuesday, 14:30-16:00 - Room: Maurice Keyworth 1.32

Making an Impact with Systems Thinking

Stream: Making an Impact: The Practitioners' Stream 2
Making an impact session
Chair: *John Medhurst*

1 - Making an impact with systems thinking
Ben Follows

The interactions between colleague experience, customer service, customer experience, complexity and compliance are numerous and complex; and mean that simple solutions are rarely appropriate. In this workshop, we will introduce the concepts of systems thinking and the application of Causal Loop Mapping.

Drawing on the systems thinking guide for civil servants, we will explore a generic government 'customer service system' archetype and we invite participants to collaborate, develop their own system thinking skills, identify feedback loops, leverage points and systems behaviours. We will reflect on the findings from the session and wider learning from experiences in His Majesty's Revenue and Customs (HMRC) from the UK.

Link to the systems thinking guide for civil servants: https://www.gov.uk/government/publications/systems-thinking-for-civil-servants

■ TD-26

Tuesday, 14:30-16:00 - Room: Maurice Keyworth 1.33

Digital Twins : Sharing techniques, real cases and advice

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: *Anne Liret*

1 - Digital Twin Technology and the Promise for Security: Myths, Opportunities, and Challenges
Rasheed Hussain

Is Digital Twin just a buzzword or is it going to revolutionise the way we approach X, for instance, security testing, evaluation, prediction, forecasting, scale-up, down, and more. Will it make it easier or more challenging to meet the ever-increasing demands in different domains? Consider cyber security, which is omnipresent, will Digital Twin Technology revamp the way we approach it? Simultaneously, the design and testing of future networks, including 6G, that are invisible infrastructures enabling services including business practices, are advancing at an unprecedented pace. Amid this rapid evolution, the need for robust security measures has never been greater, especially as attackers grow more sophisticated. This talk will focus on the technical and non-technical side of the Digital Twin Technology and will cover the myths around Digital Twin Technology, its uses, and explore how this technology can enhance security in systems. The talk will offer a balanced exploration of both technical and conceptual insights.

2 - AI Driven Digital Twins for Systems of Systems from Smart Cities to Industrial Automation
Faiyaz Doctor

The term "System of Systems" (SoS) describes systems that are composed of independent or integrated constituent systems, which collaborate to contribute towards achieving operational goals. Digital Twins (DTs) are virtually created digital counterparts of a physical object, process, or service facilitating the seamless interplay between the virtual and physical systems. SoS engineering and DTs are closely related in the development of modelling and monitoring solutions for complex real-world applications acting as enablers for managing the complexity of SoS offering features such as virtual representations of physical systems, simulation, predictive analytics, and optimization through the integration of AI. This is particularly useful where multiple interacting systems need to be managed effectively in terms of their lifecycle, data sharing, modelling and integration. This talk will introduce recent research on the interplay between both concepts looking at challenges and current trends. Case studies of DT and SoS inspired applications pertaining to weather aware traffic monitoring for smart cities, advanced integration of augmented reality and AI for manufacturing quality control, and appliance load monitoring in facilities management will be presented, opening up the possibility of new research directions.

3 - Panel Discussion : Can Digital Twins approach bring a better decision support tools adoption?
Anne Liret, Faiyaz Doctor, Rasheed Hussain, Luciana Blaha, Dennis Dokter

The aim of this session is to provide attendees with some clues on what Digital Twins approach can bring to practitioners, how it could help getting stakeholders buy-in by visual modelling of their needs before running live optimisation, what aspects they should pay attention to, and sharing some use cases of Digital Twins combined with optimisation models. In this session, attendees will hear from expert practitioners in Digital Twins and their applications in real world. Time will be reserved for discussing with subject matter experts so that attendees can take away knowledge useful to their work. The first part aims at discovering how DT can help practitioners, mixing technical and application talks. We will hear from 2 experts in Digital Twins : - Dr Fayiaz Doctor (university of Essex) who will share his long-running experience in using Digital Twins in real world decision-support domains. Fayiaz Doctor will talk about AI driven systems of systems from smart cities to industrial automation, and how it was applied to collaborative case studies on weather aware traffic monitoring systems in Singapore, VR/AR driven manufacturing automation. - Dr. Rasheed Hussain from Bristol university who will share myths around Digital Twin technology, its uses and share how this technology can help enhancing security in networks decision-making systems.

In the second part, following the invited talks, subject matter experts and practitioners will join a panel discussion and will be able to discuss how DT may help in building decision support tools in real world and moving forward in their operational research problem.

Dr. Luciana Blaha will talk about the Human side of Digital Twinning, how we can conceptualise the relationship between humans and systems in the context of DTs, and what persuasion and configuration mean in this sense. Luciana Blaha is currently an Assistant Professor in Edinburgh Business School. She is an Associate Fellow of the Higher Education Academy, member of the Chartered Management Institute, and part of the Editorial Board for Scottish University Press, and the Scottish AI Playbook and has over 10 years of industry work experience. Luciana's research investigates Intelligent Automation systems (including AI, RPA and chatbots) and their impact on organisational behaviour, reuniting findings from science and technology studies, business management and computing science. Her work explores emerging behaviours and understandings of technology from the perspective of stakeholders within and outside the organisation.

Dr. Rasheed Hussain is a Senior Lecturer at the Smart Internet Lab, and Bristol Digital Futures Institute (BDFI), UK. With a strong research focus on cyber and network security, he specialises in Digital Twins for future networks and systems, artificial intelligence (AI) applications in cybersecurity, and responsible AI practices. He is actively advancing Digital Twin Technology to enhance the security of future networks and Cyber-Physical Systems and co-leading project focusing on socio-digital futures of the high-performance networks. He also serves as an ACM Distinguished Speaker.

Dr. Faiyaz Doctor is Senior Lecturer (Associate Professor) with the School of Computer Science and Electronic Engineering at the University of Essex, U. K, head of the Intelligent Connected Societies Group and Chief Technology Officer at Interactive Coventry Ltd. Over the course of his career Dr Doctor has worked in both industrial and academia developing and applying AI driven or nature inspired Computational Intelligence approaches for human centred systems related to various real-world domains, such as predictive maintenance, digital content intelligence, intelligent transportation systems and smart healthcare. He also serves as an associate editor of the IEEE Transactions on Fuzzy Systems.

Dr. Dennis Dokter, postdoctoral researcher at the University of Leeds, will discuss the importance of Digital Twins from a governance perspective. Dennis will share highlights about making sure the ecosystem for DT application is correctly mapped to technologies used.

■ TD-28

Tuesday, 14:30-16:00 - Room: Maurice Keyworth 1.03

Risk and Financial Decision Making

Stream: Decision Support Systems
Invited session
Chair: Antonia Gieschen

1 - Data-Driven Decision-Making in Credit Risk Assessment: A Novel Deep Neural Network Model
Reza Ghasemy Yaghin, Nima Mahmoodian

This paper presents a novel six-layer deep neural network (DNN) framework designed to enhance credit risk assessment within a decision support system. Leveraging the Lending Club dataset, the proposed method integrates an extensive preprocessing pipeline—including feature elimination, categorical encoding, scaling, and random under-sampling—to effectively manage missing data and class imbalance. Four distinct DNN architectures were developed, each employing ReLU activation functions in the hidden layers and a sigmoid function in the output layer, along with elastic net regularization and a 20% dropout rate to mitigate overfitting. Comparative experiments reveal that one of the models, achieves superior performance, particularly in recall and F1-score, when benchmarked against both other DNN configurations and a contemporary stacking approach. Embedding the proposed framework into a decision support system enables financial institutions to harness data-driven insights for informed credit decisions and improved risk management. These results not only highlight significant improvements in prediction accuracy but also underscore the system's potential to streamline credit scoring processes, ultimately providing a robust tool for strategic decision-making in financial operations.

2 - Towards Digitally Trusted Blockchain-enabled-Supply Chain- A Causal Analysis of Challenges
Rajeev Agrawal, Vaibhav Sharma

The ongoing digital transformation, where organizations collaborate through digital technologies like blockchain, requires sharing critical information in their supply chain. Digital trust (DT) in blockchain (BC)-enabled supply chain (SC) is crucial and remains unexplored. With the involvement of the stakeholders' information on the BC platform, the protection of the participant data has a significant role to play. The study underscores the need to assess DT for cybersecurity enhancements, regulatory alignment, and governance frameworks to foster DT. Therefore, this study investigates the challenges to DT in BC-enabled SCs. To address the challenges, this study identifies and establishes a causal relationship among the challenges by a Decision-Making Trial and Evaluation Laboratory-Machine Learning (DEMATEL-ML) integrated approach. The DEMALTEL identifies the causal relationship, while the ML is used to validate the expert inputs. Experts from the Indian manufacturing sector were consulted, whose inputs categorize 13 key challenges into six causal and seven effect factors. The primary causal barriers include organizational culture, data privacy and security concerns, high costs, system complexity, regulatory diversity, and limited data sharing. Effect factors, such as credential loss risks, immutability issues, a lack of robust on-chain analytics, and scalability limitations, further hinder trust and adoption. The study also provides the limitations and future directions.

3 - Data-Driven Approaches to Financial Inclusion: The use of Cluster Analysis for Enhancing Newcomer Families' Financial Well-Being in Canada
Antonia Gieschen, Avneet Bhabra, Khushi Toprani, Catherine Paquet, Laurette Dubé

Financial inclusion describes the act of widening access to financial products and services for diverse people and businesses. In order to support vulnerable populations in achieving this goal, understanding their unique characteristics and financial situation is crucial. In this study, we present a data-driven approach to improving the financial inclusion of immigrant families in Canada through three studies. Leveraging unsupervised machine learning, specifically hierarchical clustering and Partitioning Around Medoids (PAM) clustering, we analysed financial wellbeing survey data from the Financial Consumer Agency of Canada (FCAC) between 2019 and 2022 to identify distinct financial behaviour and spatial location patterns among immigrants. The presented analysis will build on our previous work in defining cluster-driven personas to allow policy makers to personalise financial inclusion support and interventions. We utilised these personas and their geospatial pattern to demonstrate their use in localised policy making. In subsequent research, we statistically analyse the differences in subjective (perceived) financial wellbeing between immigrant women and men, as well as between individuals at different stages in their life. Through discussion of our findings, we demonstrate that tailored, data-driven interventions can significantly enhance the financial literacy and wellbeing of immigrant families, contributing to broader financial inclusion goals in Canada.

■ TD-31

Tuesday, 14:30-16:00 - Room: Maurice Keyworth 1.06

Stochastic Programming in Energy and Waste Management

Stream: Stochastic and Robust optimization
Invited session
Chair: Frantisek Zapletal

1 - Multi-stage multi-horizon optimization of virtual power plants under stochastic non-dominance constraints
Jana Junova, Miguel Carrión, Milos Kopa

We model a virtual power plant (VPP) that integrates renewable and conventional power plants, battery storage, fixed electricity demand, and flexible electricity demand from an electrolyzer. Our objective is to determine the optimal investment strategy for new generation and storage units and electrolyzers that minimizes the total investment and operational costs of the VPP. Operational costs depend on electricity prices, renewable energy availability, hydrogen prices, and demand fluctuations, while investment costs include the installation of power plants and the procurement of a battery, electrolyzer capacity, and hydrogen storage. Future operational and investment costs are unknown and, therefore, modeled using different scenarios. To capture the complexity of long-term decision-making, we use a multi-stage multi-horizon optimization model featuring two stages of investment decisions, each followed by a stage of operational decisions. In addition, we investigate the impact of constraining the costs by stochastic dominance and non-dominance.

2 - Smart System of Waste Collection and its Potential for the Czech Republic
František Zapletal

Waste collection affects all citizens, with studies aiming to improve efficiency by enhancing convenience or reducing costs and environmental impact. Many recent approaches rely on IoT-based systems, which may not always be affordable. This research proposes a smart waste management system based on citizen reports as an alternative to fixed schedules. The model is validated using real-world data about households in the Czechia and the artificial network. It considers household sizes, distributions, and stochastic waste production, including external shocks. Key parameters analyzed include travel distance, citizen comfort (waiting time), and household costs.

The results show that the smart system will lead to increased comfort (lower waiting times) for most households, but also to longer distances and thus higher costs. A thorough sensitivity analysis was carried out to investigate what changes in parameters (in particular household behaviour) would lead to distance and therefore costs being the same or

lower than the current fixed system. In conclusion, a hybrid approach combining citizen reports with waste reduction strategies may offer suitable and sustainable solution.

3 - Enhanced Benders' Decomposition for Stochastic Unit Commitment Using Interval Variables
Mathis Azema, Vincent Leclere, Wim van Ackooij

The Unit Commitment (UC) problem is a fundamental challenge for energy producers and network operators aiming to determine an optimal generation schedule for electricity production units, such as thermal and hydro units, while adhering to technical and economic constraints. A major source of complexity in UC arises from uncertainty, particularly in forecasting energy demand and wind power generation. To address this, decomposition strategies such as Lagrangian relaxation and Benders' decomposition have been studied to efficiently handle many scenarios.

Recently, a new formulation of the deterministic UC problem based on interval variables has been proposed to better model unit production decisions. Building on this approach, we introduce a novel Benders' decomposition that leverages interval variables to generate stronger cuts enabling convergence in a few number of iterations. Through computational experiments, we demonstrate that our method significantly improves solution efficiency, enabling the resolution of large-scale instances. In particular, we show that our approach scales effectively for two-stage stochastic UC with many scenarios and performs efficiently under both a risk-neutral framework and an average value-at-risk measure.

4 - Fuzzy Multi-Choice Goal Programming for Effective Scenario Selection in Stochastic Optimization of the Newsvendor Problem
Yu-Rong Chen, Wen-Yi Lee

The newsvendor problem is a fundamental challenge in stochastic optimization, where demand uncertainty complicates inventory decisions. While recent studies have identified effective scenarios in distributionally robust stochastic programs to avoid overly conservative solutions, they often overlook variations in vendors' attitudes toward the costs of overstocking and understocking. In this study, we examine how vendors respond differently to these costs and propose a fuzzy multi-choice goal programming (MCGP) approach to model these behaviors. By incorporating membership functions, our model accounts for uncertainty in decision-making and improves scenario selection in the newsvendor problem. Our results highlight the crucial role of vendors' attitudes in optimizing inventory decisions under uncertainty.

■ TD-32

Tuesday, 14:30-16:00 - Room: Maurice Keyworth 1.09

Container Stacking and Yard Planning-2

Stream: Maritime and Port Logistics
Invited session
Chair: *Christopher Expósito Izquierdo*
Chair: *Israel López-Plata*

1 - Discovering Import Container Dwell Time Determinants in Multipurpose Maritime Terminals: A Multi-port Analysis
Sebastian Muñoz-Herrera, Rosa G. González-Ramírez, Karol Suchan

This study examines Container Dwell Time (CDT) determinants across three Chilean multipurpose maritime terminals. While CDT research in container-specialized terminals is established, knowledge gaps exist regarding multipurpose terminal dynamics, hindering effective policy development and accurate estimation models. Based on three-year import container data, this research incorporates temporal, geographical, operational-logistical, and specialized cargo attributes. The methodology combines Cramer's V association analysis, Multidimensional Scaling, and Classification/Regression methods to identify key CDT determinants and generate good predictions. Results reveal significant differences in CDT determinants across terminals, showing that similar operational characteristics yield different CDT outcomes based on terminal-specific cargo profiles, operational rules, and regional economic markets. Findings indicate that accurate CDT estimation requires terminal-specific modeling rather than relying on generic prediction methods. Each terminal exhibits unique operational patterns influenced by local constraints, cargo composition, and market demands. The research contributes to terminal efficiency optimization literature by providing evidence-based insights for tailored CDT management strategies, thereby enhancing resource allocation, improving planning capabilities, and supporting more effective policy development for multipurpose maritime terminals.

2 - Yard capacity and external truck quotas planning: a case study in Chile
Rosa G. González-Ramírez, Karol Suchan, Sebastian Muñoz-Herrera

In this study, we examine a real-case scenario of a multipurpose terminal in Chile for landside operations to coordinate truck arrivals. The terminal currently operates with an appointment system for import containers, where port managers assign strict appointments to external trucks based on the unloading sequence (direct dispatch) or offer an alternative schedule with additional container handling fees (indirect dispatch). On the other hand, trucks for export operations can arrive randomly within a stacking window of 3 to 5 days before the vessel's arrival.

Terminal managers aim to introduce a truck appointment system for export operations to reduce congestion and truck turnaround times of external trucks. This requires balancing truck arrivals across different time zones each day and the yard's workload and vehicle traffic. Therefore, we propose a workload assignment model to allocate tasks to the available yard cranes over a one-shift planning horizon (eight periods of one hour each). The aim is to determine the yard's slack capacity to receive external trucks for incoming vessels while performing loading and unloading tasks for vessels already moored and dispatching import containers unloaded in prior shifts. Using historical data provided by the terminal, we conducted numerical analyses to compare the workload assignment solutions implemented by the terminal with our proposed model and recommend truck quotas considering container groups.

3 - A Systematic Literature Review on Machine Learning-Enabled Optimization for Container Yard Management
Nazin Shokravi, Dongping Song, Yuanjun Feng

Abstract: Effective Container Yard Management (CYM) is a critical component of global maritime logistics, directly influencing port efficiency, supply chain resilience, and operational costs. In the recent years, machine learning (ML) has emerged as a transformative tool to optimize CYM processes. This paper presents a systematic literature review on Machine Learning-enabled optimization techniques applied to container yard management, synthesizing advancements, challenges, and future research directions. Following the PRISMA framework, we reviewed 461 peer-reviewed articles based on the Scopus database. The thematical analysis is conducted from multiple perspectives, including application areas, types of ML models, types of optimization methods, and the performance measures. This study provides researchers and practitioners with a comprehensive view of ML applications in CYM, equips researchers with insights to advance data-driven yard management systems, and provides further research opportunities that are needed in the era of smart ports.

■ TD-34

Tuesday, 14:30-16:00 - Room: Michael Sadler LG10

Advancements of OR-analytics in statistics, machine learning and data science 5

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: Jinal Parikh
Chair: *R. M. Kazakov*
Chair: *Gerhard-Wilhelm Weber*
Chair: *Emilio Carrizosa*

1 - How LLM Reshaped Complex OR Problem Solving?
Yuan Wang

Operations Research (OR) seeks to develop mathematical models for addressing complex decision-making problems encountered across various industry sectors. To streamline the process and minimize reliance on domain-specific modeling experts, NL4Opt (Natural Language for Optimization) (Ramamonjison et al., 2022a) has recently been introduced as a promising yet challenging task within the field of Natural Language Processing (NLP). The goal of NL4Opt is to convert textual descriptions of OR problems into mathematical formulations suitable for optimization solvers. In this paper, we investigate the automatic modeling and programming of complex OR problems derived from real-world industrial demands. We propose the first solution based on large language models (LLMs), termed Chain-of-Experts (CoE), a novel multi-agent cooperative framework designed to improve reasoning capabilities. In this framework, each agent is designated a specific role and equipped with domain-specific knowledge related to Operations Research (OR). Additionally, we introduce a "conductor" that coordinates the agents using a mechanism of forward thought construction and backward reflection. To further advance OR research and foster community engagement, we develop a benchmark dataset, ComplexOR, which comprises intricate OR problems. Experimental results demonstrate that CoE significantly outperforms the current state-of-the-art LLM-based approaches.

2 - A Mathematical Programming Approach to Hierarchical Clustering
Lavinia Amorosi, Justo Puerto, Carlos Valverde

Hierarchical clustering is a statistical technique to study the occurring groups (clusters) within a dataset creating a hierarchy of clusters. This is represented by a rooted tree (dendrogram) whose leaves correspond to the data points, and each internal node represents the cluster containing its descendant leaves. Among methods to perform hierarchical clustering, the agglomerative ones are based on greedy procedures that return a sequence of nested partitions, where each level up joins two clusters of the lower partition relying on a local criterion. In this work, motivated by the lack of exact approaches that guarantee global optimality, we focus on a unified mathematical programming formalisation that embeds single and complete linkage procedures. Through preliminary experiments, we evaluate, according to different measures commonly used in this context, the dendrograms obtained from the exact resolution of the formulations and those produced by the greedy approach. Furthermore, by exploiting the mathematical formulation, we also present a scalable matheuristic algorithm capable of generating better quality dendrograms than those produced by the greedy approach, even for large-sized datasets.

3 - Optimizing ICU Operations with Digital Twins and Machine Learning: Enhancing Decision-Making and Resource Management
Margarida Parrado, Luís Lapão

Backgroud: Digital Twins (DTs), virtual representations that replicate real-world entities, are emerging as transformative tools in healthcare operations, particularly in Intensive Care Units (ICUs). ICUs are high-stakes environments requiring continuous patient monitoring and advanced medical interventions. However, operational inefficiencies and data overload often delay decision-making, affecting patient outcomes and resource utilization. Methods: This study developed a DT platform, in collaboration with ICU director from Francisco Xavier Hospital in Lisbon, integrating Machine Learning (ML) to enable decision-making. The model incorporates real-time patient and operational data to predict sepsis. Results: The DT model demonstrated 78.8% accuracy in predicting Sepsis onset, supporting early detection and timely intervention. Furthermore, the system successfully forecasted systolic arterial blood pressure (ABP) and heart rate (HR) responses to vasopressor administration, achieving a mean absolute error (MAE) of 4.9 mmHg for ABP and 4.1 bpm for HR. These insights enable proactive treatment adjustments, improving patient outcomes and care efficiency. Conclusion: Merging DTs with ML enables a data-driven approach to optimizing ICU workflows and reducing medical errors. Beyond ICUs, this technology holds promise for operational research, providing intelligent, real-time decision support for optimizing critical care processes, resource management and patient care.

4 - On Recommender Methods in E-Learning
Alejandro Fuster-Lopez, Jesús Martínez Cruz, Pablo Guerrero-García, Eligius M.T. Hendrix

The use of e-learning systems has a long tradition. Students can study online helped by a system. In this context, the use of recommender systems is relatively new. In a research project, we investigated various ways to create a recommender system based on several methodologies. They all aim at facilitating the learning and understanding of a student. Methods may aim to predict, which next question or which new material (video, description) may help the student further in obtaining insight measured as getting the next question well answered. Given past information of users in a database, machine learning methods like Random Forest have been suggested and implemented. However, these are data and energy hungry types of methods. Instead, we implemented methods on collaborative filtering which is based on matrix factorization methodologies. Our investigation goes in the direction of comparing the machine learning ideas with matrix factorization ones measuring effectiveness and efficiency.

■ TD-36

Tuesday, 14:30-16:00 - Room: Michael Sadler LG16

Approximations in global optimization

Stream: Global and nonconvex optimization
Invited session
Chair: Dmitri Kvasov

1 - new algorithm for maximizing the difference of convex functions
Aharon Ben-Tal

Maximizing the difference of 2 convex functions over a convex feasible set (the so called DCA problem) is a hard problem. There is very large number of publications for solving this problem. Most of them are variations of the widely used DCA algorithm. The success of these algorithms for reaching a good approximation of a global solution depends crucially on the choice of its a starting point. We introduce a new algorithm (MDCF) which is notoriously different from DCA. A major effort in MDCF is the generation of a good starting point. This is based on the COMAX algorithm for maximizing constrained convex problems. The success of MDCF is demonstrated numerically in a variety of applications.

2 - The improvement function in branch-and-bound methods
Oliver Stein, Peter Kirst, Marc Rodestock, Stefan Schwarze

We present a new branch-and-bound approach for treating optimization problems with nonconvex inequality constraints. It is able to approximate the set of all global minimal points in case of solvability, and else to detect unsolvability. The new technique covers the nonconvex constraints by means of an improvement function which, although nonsmooth, can be treated by standard bounding operations.

The method is shown to be successful under a weak regularity condition, and we also give a transparent interpretation of the output in case that this condition is violated. Numerical tests illustrate the performance of the algorithm.

3 - Nonconvex Regularization Methods for Low Rank Matrix Recovery
Yaohua Hu, Jing Qin

Low rank matrix recovery, aiming to find a low rank solution from the linear measurements, has a wide range of applications. In this talk, we will present the nonconvex regularization methods for the low rank matrix recovery problem in three aspects: theory, algorithm and application. In the theoretical aspect, by introducing a notion of spectral regularity condition, we will establish the global recovery bound for the nonconvex regularization problem. In the algorithmic aspect, we will apply the well-known proximal gradient method to solve the nonconvex regularization problem, and establish its linear convergence rate to the ground true low rank solution under a simple assumption. In the aspect of application, we will apply the nonconvex regularization method to solve genotype imputation problem for single-cell RNA-sequencing data.

4 - Engineering Applications of Black-Box Global Optimization Algorithms
Dmitri Kvasov

In this contribution, we consider practical black-box multiextremal optimization problems from various applied fields. As in many engineering design problems, the objective function and constraints can be multidimensional functions with unknown analytical representations and evaluated by running computationally expensive simulations. Due to the significant computational costs involved, we are typically willing to perform only a small number of function evaluations when optimizing such expensive functions. Therefore, the main goal for us is to develop fast global optimization algorithms that would obtain good solutions to the considered practical problems with a limited number of function (and constraint) evaluations. We will discuss various deterministic approaches to develop efficient and reliable numerical methods to tackle the related problems, in particular, in the field of chemical and food engineering. These approaches are based on the Lipschitz continuity assumption on functions and also make use of recent advanced high-performance techniques adopted for global optimization.

The experimental study of decision-making processes in the agri-food sector, as part of this work, was conducted within the project B29J24001440005 "smart pacKagIng and LOgistics for food WAsTe reducTion (KILOWATT)".

■ TD-38

Tuesday, 14:30-16:00 - Room: Michael Sadler LG19

Foundation Models and Optimization

Stream: Data Science meets Optimization
Invited session

Chair: *Peer-Olaf Siebers*
Chair: *Yoon Sua*

1 - Scenario Space Search for Two-Stage Stochastic Optimization Using Deep Generative Models
Atefeh Hemmati Golsefidi, David Pisinger

Many important decisions are taken under uncertainty since we do not know the development of various parameters. In particular the ongoing green transition requires large and urgent societal investments in new energy modes, infrastructure and technology. The decisions are spanning over a very long time-horizon, and there are large uncertainty towards energy prices, demand of energy, and production from renewable sources. Such problems can be described as two-stage stochastic optimization problems. If the decision variables are discrete, such problems are extremely difficult to solve. Instead of solving a complex stochastic optimization problem defined on a fixed set of forecasted scenarios, we propose to use an iterative process: We repeatedly generate new scenarios, solve them and find the corresponding investment solutions. Our novel way of optimization makes use of Deep Generative Models to generate small sets of scenarios matching the real distribution, and use a guided local search process to select scenarios that properly reflect properties of the full set of scenarios. The process can be seen as a local search in the scenario space. The framework is tested on three real-life problems: Facility location of charging stations, the capacity expansion problem, and vehicle routing problem using real-life historic scenarios.Computational results show that the framework is able to generate a small set of artificial scenarios that result in high-quality first-stage decisions.

2 - Improving Decommissioning of Offshore Platforms using Generative AI: An application of Large Language Models in the Oil and Gas industry
Leonardo S. L. Bastos, Pedro Hamacher, Pedro Lobato, Gabriela Ribas Klein, Luidgi de Jesus da Silva Colimerio, Adriano Simões, Alexander Fernandes, Marcos Vinicius Marques da Silva, Vitor Sabbagh

When offshore oil extraction platforms are no longer economically viable, they enter the decommissioning phase (DP), during which the structures are removed from the sea, a process that involves several activities and whose proper execution is crucial to reduce impacts on the marine environment. During DP planning, it is required to describe the platform's operational history, requiring labor-intensive activities to search and summarize decades of reports, which may delay the whole process and is prone to inconsistencies. Recently, the use of language-based Generative Artificial Intelligence (GAI) such as the Large Language Models (LLMs) has shown high potential in improving processes, especially regarding the processing of text-based data. Hence, this work proposes an LLM-based system to process and generate summarized information for the DP in a large Oil and Gas company. A Retrieval Augmented Generation (RAG) framework was developed, consisting of two stages: searching the report database with semantic search and filters to identify the documents relevant to that oil well and using them to draft the final document with an LLM. Computational experiments were conducted to optimize the framework's efficiency, using metrics designed for RAG evaluation to calculate its ideal hyperparameters. This work connects the domains of Oil & Gas and Generative Artificial Intelligence with a practical use case, automating processes for productivity optimization and cost reduction.

3 - Generative AI Meets the Service Sector: A Study Using Topic Modeling
Arkomita Mukherjee, M. P. Sebastian

Artificial Intelligence (AI) is being increasingly integrated in organizational operations owing to enhanced efficiency, productivity and innovation. Service sectors such as healthcare, banking and education are steadily utilizing AI. Further, AI-powered business processes also enable superior customer services. Generative AI (GenAI) facilitates users to create new content such as text, images or animation based on user inputs in human languages. Following the breakthrough acceptance of GenAI, this study aims to steer forward the emerging discussion surrounding GenAI in services. To address the dearth of studies exploring dominant themes in this particular landscape, we perform natural language processing (NLP) based topic modeling via Latent Dirichlet Allocation (LDA) model. We collect relevant literature comprising of articles and conference proceedings indexed in the Scopus database. We also include suitable publicly available industry reports published by consultancy firms. Our final corpus consists of more than

200 documents. Diverse and meaningful underlying topics are identified which we categorize into overarching themes such as GenAI application in service operations, opportunities, ethical concerns and need for regulations which help provide a holistic view to managers and stakeholders.

4 - Contrastive Learning-based Semantic Embedding of Technology Groups
Yoon Sua, Dohyun (Norman) Kim

Accurate embedding vectors that effectively capture the semantics of technology groups are essential in technology analytics. Traditional approaches commonly derive these embeddings by averaging individual paper embeddings within a technology group. However, this simple averaging often fails to preserve distinctive semantic features, diluting critical contextual information unique to each technology domain. To overcome this limitation, we propose a novel embedding approach using contrastive learning between technology groups and their associated paper embeddings. Our method explicitly models semantic relationships, resulting in embeddings that accurately reflect the inherent meaning and contextual differences among technology groups. Experimental evaluations demonstrate that our contrastive learning-based embeddings significantly outperform conventional averaging methods. Our results suggest that the proposed embedding methodology is expected to be effective and practically useful in diverse technology analysis tasks.

■ TD-39

Tuesday, 14:30-16:00 - Room: Newlyn LG.01

Sustainable & Resilient Digital Twins

Stream: Sustainable & Resilient Systems and Infrastructures
Invited session
Chair: Dennis Dokter
Chair: *Tristan Becker*

1 - A European-Wide Multi-Objective Hydrogen Supply Chain Model Considering Sector-Specific Decarbonization Potentials
Julia Erdmann, Tristan Becker

Meeting the European Union's climate targets demands timely and substantial carbon emission reductions. Hydrogen has emerged as a key solution for decarbonizing hard-to-abate industries. However, large-scale deployment requires a systematic approach to identify the optimal hydrogen distribution across sectors. Addressing this challenge, we propose a multi-period, multi-objective optimization framework that focuses on carbon emission mitigation and cost optimization in the European Union. Our model determines the optimal locations for production, transport, and storage infrastructure, while allocating hydrogen to various sectors based on their respective country- and sector-specific emission mitigation potentials. In addition, we incorporate carbon emissions from multiple production, transport, and storage pathways by accounting for each country's unique electricity grid, reflecting the diverse carbon intensities of hydrogen supply. Furthermore, we consider spatially and temporally resolved renewable energy potentials to capture seasonal variability that influences production and storage decisions. By quantifying the trade-offs between cost and emissions, our results identify the optimal timing and locations for hydrogen infrastructure deployment, as well as the regions and sectors that should be prioritized to maximize decarbonization impact.

2 - Optimizing Emergency Grocery Store Selection for Crisis Food Supply
Sandra Rudeloff, Alex Duan, Hanno Friedrich

Ensuring food supply during crises, such as prolonged power outages or pandemics, is a critical aspect of emergency management. Grocery stores serve as natural distribution points because people already rely on them for food in daily life, and they have the necessary logistical infrastructure. However, with limited resources - such as emergency power generators - authorities must strategically select a subset of stores to remain operational. This research formulates a mathematical optimization problem to minimize the population-weighted distance between open stores and the population, ensuring access to essential food supplies. The problem includes key constraints: the maximum number of operational stores due to resource limitations, store capacity to meet demand, and retail chain diversity to enhance supply chain resilience. These constraints are informed by qualitative insights from workshops and interviews with municipal authorities, ministries, and retail stakeholders. The model is applied to Lower Saxony, Germany, providing a case study on how these constraints shape emergency food supply planning at the regional level. This research offers a tool for policymakers to enhance food crisis preparedness and response strategies.

3 - Distributioanlly Robust Supplier Selection and Order Allocation under Disruption Risk over a Wasserstein Ambiguity
Xin Li, Xuan Vinh Doan, Juergen Branke

Supply chain resilience has become indispensable for safeguarding operations against disruption risk, presenting decision-makers with the challenge of balancing cost efficiency and effective risk mitigation. We study the problem of resilient supplier selection and order allocation under uncertain disruption impact. Probability distributions of the actual disruption impact are unknown, and only a possibly small set of historical realizations may be available. To handle the distributional uncertainty, we first construct an ambiguity set that encompasses all possible distributions of disruption impact within a 1-Wasserstein distance from the empirical distribution. We then define a two-stage distributionally robust supplier selection and order allocation problem to determine optimal sourcing and contingency decisions among available suppliers under capacity constraints. The objective is to minimize the total cost consisting of the fixed cost related to contracting suppliers plus the worst-case mean-CVaR associated with disruption over all distributions defined in the ambiguity set. We derive an equivalent mixed-integer linear programming (MILP) reformulation that can be implemented and solved using off-the-shelf optimization software. We conduct numerical experiments with real-world procurement data and the experimental results demonstrate that our proposed model yields robust solutions and achieves superior out-of-sample performance over the stochastic approach.

4 - Transformation of primary steelmaking networks to mitigate industrial greenhouse gas emissions
Yannik Graupner, Thomas Spengler

To mitigate greenhouse gas emissions, energy-intensive industries must transition toward less CO2-intensive technologies within their production networks. Globally, the steel industry is one of the largest greenhouse gas emitters. In primary steelmaking, several technologies are available to reduce these emissions, such as modifying conventional processes or replacing them with low-carbon alternatives. However, companies need to decide how to transform production networks favorably economically and environmentally. As a result, planning models are required to support decision-makers in designing transformation pathways for their production networks. Against this background, we developed a mathematical optimization model that enables corporate decision-makers to identify optimal strategies to modify and replace conventional production facilities to mitigate greenhouse gas emissions from industrial production processes. Among other factors, the impacts of European Emissions Trading are considered in this decision-making process. The model is formulated as a mixed-integer linear programming model that aims to maximize steelmaking's net present value. Using the production network of a major European steel manufacturer as a case study, the network redesign is analyzed within different scenarios. The results indicate that mitigation of greenhouse gas emissions in conventional production processes is rarely pursued.

■ TD-41

Tuesday, 14:30-16:00 - Room: Newlyn GR.01

General contributions to Soft OR/PSM practice

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: Chris Smith
Chair: Adrian Small

1 - Integrating Soft Systems Methodology and the Theory of Planned Behaviour for Privacy Preservation in Health IoT Devices
Abdulaziz Alshammari, Masoud Fakhimi, Christopher Turner

The growing adoption of Health Internet of Things (H-IoT) devices in healthcare enhances real-time monitoring and decision-making but introduces critical privacy risks, including data breaches, unauthorised access, and ethical concerns over patient data protection. While conventional security measures, such as encryption and access controls, provide technical safeguards, they often neglect human behaviour, organisational structures, and cultural influences in privacy management. This study addresses these gaps by integrating Soft Systems Methodology (SSM) and the Theory of Planned Behaviour (TPB) to develop a socio-technical framework for privacy preservation in H-IoT environments. SSM provides a systemic approach to analysing multi-stakeholder complexities in H-IoT ecosystems, while TPB models behavioural factors influencing privacy compliance and cybersecurity practices. A qualitative research approach was employed, drawing on semi-structured interviews with experts in systems thinking, behavioural science, cybersecurity, and H-IoT technology. The study utilised CATWOE analysis to develop Root Definitions and Conceptual Models, integrating insights from healthcare professionals, patients, regulators, and IT specialists. Findings reveal key privacy challenges, including low privacy awareness, ethical ambiguities in data sharing, and cultural barriers, which directly influence user engagement with privacy-enhancing technologies, adherence to cybersecurity protocols, and parti

2 - Balancing improvements in health outcomes while reducing inequalities by targeting housing quality in the Greater Manchester Combined Authority
Shraddha Ghatkar, Abi Fin, Lisa Garnham, Emma Comrie, Rob Clay, Nic Lomax, Joao Duro, Robin Purshouse

The link between poor-quality housing and health is well-established in public health literature. In Greater Manchester, recent data estimates the NHS spends approximately '62 million annually due to poor-quality housing. In this talk, we detail applied research undertaken as part of the Systems Science in Public Health and Health Economics Research Consortium (SIPHER) with Greater Manchester Combined Authority (GMCA), one of SIPHER's four policy partners.

Working with GMCA, we began with a broad remit of how its housing policy levers can be more effectively used to improve health and reduce health inequalities in its population. In this presentation, we focus first on the problem formulation stage, during which we engage with experts on housing, policy, and modelling to identify and refine a problem, integrating real-world problem constraints and options from a policy setting. Second, we present our novel integration of a multi-objective optimisation framework and dynamic microsimulation model. This integration enables the outcomes of interest, as well as the decision variables to align with GMCA aims, and solutions are explored and evaluated through the dynamic microsimulation model to understand dynamic impacts over a chosen time horizon.

We showcase the interactive trade-off visualisation wherein the objectives and outcomes can be explored by decision-makers to understand and compare policy options across sub-populations to help identify effective interventions.

3 - Making problem structuring practices (more) visible
Mike Yearworth

Online group support systems have the potential to extend their application beyond the implementation of 'standard' workshop-based problem structuring methods. The generic constitutive definition for PSMs opened up the study of non-codified problem structuring in organisations and then to the notion of everyday problem structuring. The ubiquity of the latter, arising from an imperative to act, should be of interest to us - but also some concern; how can we make such practice visible and open to evaluation? GSS have a role to play, but only by becoming as widespread in use as the common online collaboration tools that already enable teams to work together. The question of how to widen their use is explored through modelling a transformation in group working practice towards the use of notional problem structuring platforms (PSP).

■ TD-42

Tuesday, 14:30-16:00 - Room: Newlyn GR.02

Sustainable supply chain design

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: Ozlem Mahmutogullari

1 - A strategic logistics design for multi-period organic waste collection and compost distribution
Germán Paredes-Belmar, Carola Blazquez, Gabriel Gutiérrez-Jarpa

This article aims to design a strategic logistics design for household organic waste collection, processing, and compost distribution under a horizon plan. This involves the location of composting plants and their expansion over a long-term horizon, collecting organic waste for compost processing from clustered households (neighborhood associations), and distributing it back to households or communities. Within transportation decisions, we decide the number of trucks to purchase and trips for organic waste collection and compost distribution. Decisions about compost production include the plant location, their expansions over time, and the accumulation of organic waste within compost piles.

A mixed integer linear programming model is designed to minimize the total costs, including transportation, truck purchasing, plant location and expansions, and production costs. The results include a detailed logistics network design for the Quilpué commune, Chile. This design considers a 15-year horizon plan, a constantly increasing rate of household organic waste accumulation and collection, 84 clusters, and four sites for plant location. A sensitivity analysis is presented to evaluate the performance of the mathematical model. The results reveal the importance of having a structured plan for organic waste treatment and compost production.

2 - A Co-Location and Allocation Model for Supply Chain Facility and Microgrid with Net-Zero Operations
Tongdan Jin

Manufacturing supply chain design usually focuses on the uncertainties in materials, capacity, yield, and demand, while energy variability is inadequately investigated. We propose a location-allocation model for siting and sizing plants, distribution centers and renewable microgrids to achieve net-zero carbon operations under power demand and supply uncertainty. The model further schedules production, inventory, transportation, energy storage, and demand response to lower the operational cost. The study represents a first-of-its-kind in jointly sitting and sizing industrial facilities and distributed energy resources to attain the net-zero goal in a multi-layer supply chain infrastructure. Numerical experiments show that transactive energy, time-of-use rate, and weather conditions play a critical role in locating and allocating plants,

warehouses, wind turbines, solar panels, and energy storage. Contrary to intuition, energy storage, which balances the intermittent power and uncertain load, has limited benefit to the cost saving. It is concluded that the transactive energy market adds new value to the manufacturing supply chain by generating new revenue streams, in addition to increasing energy resilience and mitigating climate change.

3 - Sustainable CO2-Based Synthesis Gas Supply Chain Design under Demand Uncertainty
Ozlem Mahmutogullari, Nevin Mutlu, Tarkan Tan

The electrolysis of CO2 offers a sustainable alternative for producing synthesis gas, reducing dependence on fossil-based feedstocks. However, its widespread adoption faces economic, environmental, and regulatory challenges. This study addresses these challenges by evaluating CO2 electrolysis for synthesis gas production and proposes a supply chain design for the product. We identify key uncertainties and incorporate expert insights obtained from iterative surveys and workshops into the decision-making process. A multi-period planning approach is applied to consider strategic and tactical decisions. To mitigate environmental impact, we explore an electricity consumption strategy that integrates renewable electricity and battery storage alongside grid electricity. Demand uncertainty is addressed using a robust optimization approach, where demand realization intervals are endogenously dependent on the pricing decision. We develop a mixed-integer programming model to design a robust supply chain for CO2-based syngas, ensuring the economic and environmental sustainability. A case study on the BENELUX region analyzes different grid and electricity transmission scenarios. Our results demonstrate the value of robust supply chain design in minimizing risks of unmet demand and high costs. Additionally, we highlight the critical role of renewable energy integration, battery storage, and government financial support in the development of the CO2 electrolysis technology.

4 - Pay or Abate - or Circumvent? - Supply Chain Level Analysis of Adaptation Strategies Under the EU CBAM Regulation
Tobias Breitenbach, Moritz Fleischmann

The EU's environmental ambition to achieve carbon neutrality by 2050 has prompted concerns about a loss of competitiveness and carbon leakage, due to companies shifting production abroad. To address these challenges, the EU aims to implement a Carbon Border Adjustment Mechanism (CBAM) that imposes a levy on embedded emissions of selected imported goods. In theory, CBAM should level the playing field for carbon pricing between imported and domestic products in scope. While it is clear that this measure will affect supply chains both directly and indirectly, its specific impact on strategic supply chain decisions—as well as the influence of particular supply chain and policy design characteristics, including potential circumvention options—remains insufficiently understood to date. In response, this research develops a scenario-based analytical model of a two-stage supply chain, incorporating the varying incentives induced by the CBAM across different supply chain stages and locations. The model assesses the effects on multi-stage location decisions, green technology investments, and profits while accounting for circumvention options and identifying the conditions under which they are expected to be adopted. These insights enable an evaluation of the CBAM's effectiveness in achieving its sustainability and competitiveness objectives and provide a basis for assessing potential CBAM extensions and design modifications by specifically accounting for supply chain responses.

■ TD-43

Tuesday, 14:30-16:00 - Room: Newlyn GR.07

Toolboxes & APIs

Stream: Software for Optimization
Invited session
Chair: Léa Blaise

1 - Recent Developments in Optimization with MATLAB
Paul Kerr-Delworth

MATLAB has solvers for engineering and scientific applications where problems range from linear to nonlinear, mixed-integer, and non-smooth. We will present an overview of the latest developments in MATLAB optimization, focusing on two major areas. First, new capabilities in code generation from linear and conic solvers will be shown. This will include running the same code in MATLAB as that run on target hardware. Next, new graphical interfaces for monitoring and investigating the progress of optimization solvers will be presented. Finally, usage of the MATLAB optimization tools will be illustrated with an example.

2 - Writing and solving models with the new FICO Xpress C++ API
Daniel Junglas

Starting with version 9.4 FICO Xpress introduced new APIs for object oriented programming languages (Java, .NET). This was finished with the C++ API in the latest release The new APIs are designed as an object-based layer ensuring a memory-efficient and reliable experience to the user. With the new API, the use of features such as callbacks becomes easier, and it gives access to the full set of problem types available with Xpress.

Among the key features of the new Xpress API are the ability to use modern programming concepts such as lambdas, templates, STL containers etc.

We will present the new C++ API, show different ways of building models with it, benchmark the model building performance compared to the plain C API and also present a showcase that used the API to solve a real world problem.

3 - Large-scale modeling with AMPL in Python: Fast Integration, Cloud Deployment, and Generative AI
Marcos Dominguez Velad

Python and its vast ecosystem are great for data pre-processing, solution analysis, and visualization, but Python's design as a general-purpose programming language makes it less than ideal for expressing the complex optimization problems typical of prescriptive analytics. AMPL is a declarative language that is designed for describing complex optimization problems and that integrates naturally with Python. In this presentation, we'll explore how the combination of AMPL modeling with Python environments and tools has made optimization software more natural to use, faster to run, and easier to integrate with enterprise systems. We will show how AMPL and Python work together in a range of contexts: - Installing AMPL and solvers as Python packages anywhere - Fast data transfer from/to Python data structures such as Pandas and Polars dataframes - Deploying models to the cloud quickly and easily You'll also see how Generative AI technology can be used in order to enable a rapid development process for both AMPL and Python, reducing the time and effort to produce a working application that's ready for end-users.

4 - Compact set-based modeling for scheduling problems with Hexaly
Léa Blaise

Hexaly is a model & run global optimization solver based on exact and heuristic techniques. In this talk, we will focus on its performance on scheduling problems in general (problems with precedence constraints and disjunctive or cumulative resources, minimizing makespan, weighted sum of tardiness, etc.). Hexaly's nonlinear and set-based modeling formalism makes it very straightforward to express many academic and industrial scheduling problems, using only generic operators. These models combine two kinds of decision variables: intervals and lists. On the one hand, we use interval decisions to model the time span of the tasks. Besides, we use list decisions (decisions whose values are permutations) to represent the order in which the tasks are scheduled on each disjunctive resource. These interval and list-based models have the advantage of being compact, enabling the solver to handle large-scale problems. Indeed, the algorithms implemented within Hexaly exploit this modeling and enable it to achieve very good performance on various scheduling problems: less than 2%

optimality gap in one minute with up to 2,000 tasks on classical problems such as the Job Shop, the Flexible Job Shop, the Open Shop, or the Resource-Constrained Project Scheduling Problems. We will also show that models written in Hexaly's set-based formalism are more compact than their equivalents in the linear or constraint programming formalisms used by other classical solvers, such as Gurobi or CP Optimizer.

■ TD-44

Tuesday, 14:30-16:00 - Room: Newlyn 1.01

Interactions between electricity, hydrogen and carbon markets

Stream: Energy Economics & Management
Invited session
Chair: Julia Grübel

1 - Long-term contracts in incomplete electricity and carbon markets.
Matthieu Delacommune, Sébastien Lepaul, Simon Quemin, Yannick Perez

Decarbonization requires massive, rapid investment in low carbon technologies, notably in the electricity sector. Yet markets for risk sharing are missing or incomplete, which impairs investment incentives and warrants the use of long-term contracts. These contracts will increasingly interact with the carbon price in the EU emissions trading system, the main decarbonization policy in the EU. We anlayze the impacts of long-term contracts in the electricity sector and various carbon pricing policies, focusing on the interactions between them and their effects on low-carbon investment. . A hybrid modeling framework combining optimization and simulation approaches is developed in which electricity and carbon prices are endogenous and co-determined. The co-determination is enabled by an analysis of the dual variables of the optimization module inside the hybrid model. We propose a new use of the dual variables of the carbon constraints inside a Generation Expansion Planning allowing carbon permits banking. This use -representing a perfect market- allow us to compare with a market with frictions (limited foresight) thanks to the simulation model. Even in the absence of market frictions and uncertainty, an ex-ante equivalent tax and cap and trade do not lead to identical market outcomes due to electricity supply inertia, path dependency and degeneracy issues. In the presence of market frictions, long-term contracts can restore optimal investment incentives.

2 - Investment decisions and market pricing in coupled energy markets under demand uncertainties
Julia Grübel, Jonas Egerer, Veronika Grimm, Johannes Wirth

The transition to a climate-neutral energy system will depend primarily on low-carbon electricity and hydrogen-based fuels. Achieving this transition will require significant infrastructure investment in both sectors, particularly in renewable energy sources, storage technologies, and flexibility measures, including electricity-to-hydrogen conversion and reconversion. However, the future distribution of energy demand between the two sectors remains highly uncertain, influenced by R&D investments and the development of market designs and regulatory frameworks. This uncertainty poses a key challenge, as it increases investment risks and may delay the deployment of essential infrastructure. In this work, we model investment decisions in both sectors under this uncertainty. We account for market participants' expectations of future demand scenarios and the resulting expected profits from trading in the coupled electricity and hydrogen spot markets. We then apply our model to the German energy system, using different 2045 demand scenarios from the literature. Our results indicate that, regardless of the realized demand scenario, mixed expectations lead to only modest welfare losses. Furthermore, sector coupling technologies in particular can effectively hedge against demand uncertainties through portfolios that cover both directions of coupling.

3 - Green Hydrogen Subsidies and Certification: Interactions with Electricity and Emissions Trading
Alexander Hoogsteyn, Jelle Meus, Kenneth Bruninx, Erik Delarue

Our research delves into various policies that support renewable hydrogen production, examining their interactions with energy markets and cap-and-trade systems like the EU emission trading scheme. We explore different certification rules applied globally that determine if hydrogen is considered renewable. We develop and deploy a state-of-the-art equilibrium model to analyze the impact of hydrogen support policies on the dynamics between hydrogen, electricity, and emission markets. Our model optimizes the profits of hydrogen and electricity production operations, which are interconnected through an electricity, hydrogen, and emission market. We utilize ADMM to determine the equilibrium prices. Our analysis reveals that mechanisms compensating hydrogen production can distort spot prices of electricity and hydrogen more profoundly than mechanisms that reward hydrogen production capacity. Moreover, hydrogen support mechanisms encourage renewable electricity generation and discourage investment in conventional generation facilities. A case study conducted in an emission-constrained region, inspired by the European Union, demonstrates that the operational distortions associated with production-based mechanisms tend to lead to higher costs compared to the investment distortions associated with capacity-based mechanisms.

4 - Electrolyzers in optimized energy systems while dealing with uncertainties in investment and deployment planning using different case studies
Laura Thiel, Simon Gloeser-Chahoud, Tino Schütte

Green hydrogen plays a pivotal role in transforming the energy and heating sectors, however, the operation of electrolyzers is not yet economically. Especially as the investment and deployment planning of electrolyzers is influenced by the availability of more cost-effective alternative technologies. However, the selection of a suitable operating strategy, the utilization of electrolysis by-products and the interplay of electricity prices and the share of renewable energies offer the promising possibility of increasing the usability of electrolyzers in various energy systems. This leads to the question: Which operational strategies for electrolyzers contribute to a cost- and CO_2-emission-optimized energy system when uncertainties are adequately considered? To address this, energy system simulations are conducted for various case studies, including a hospital and a gasification plant site. Numerous technologies and grid supply options are available to cover the respective energy demand, from which the optimum investment planning is determined. Particular attention is given to scenarios where electrolyzers form part of the optimal energy system solution, highlighting the potential to enhance their own profitability. Uncertainties in the model are addressed using a Monte Carlo simulation. The goal is to support decision-making for hydrogen system deployment and investment planning under uncertainty, while developing an economically viable strategy for electrolyzers.

■ TD-46

Tuesday, 14:30-16:00 - Room: Newlyn 1.07

Multi-dimensional impact assessment of energy systems and projects

Stream: Energy Economics & Management
Invited session
Chair: Janeth Carolina Godoy

1 - AD-MERGE-2.0: An Integrated Assessment Approach to Assess World Energy and Climate Policy Options
Olivier Bahn, Kamyar Amirmoeini, Kelly de Bruin, Hamed Kouchaki-Penchah, Pierre-Olivier Pineau

We present version 2.0 of AD-MERGE, an integrated assessment model that incorporates reactive and proactive adaptation strategies as well as mitigation options. AD-MERGE-2.0 builds on its predecessor by incorporating improved geographic disaggregation, enhanced technology representation, and updated assessments of climate damages and adaptation. In particular, this new version introduces six additional regions and includes new energy technologies, with a focus on variable renewable energy mechanisms. We examine three main scenarios with AD-MERGE 2.0: Baseline, Reference and Announced Pledges. The first is our calibration scenario (based on SSP2-7.0) and provides a counterfactual baseline for comparison purposes, as it excludes climate damages from decision making. The second scenario represents the evolution of world energy systems under existing policies and measures and is based on the IEA's Stated Policy Scenario (STEPS). The third scenario corresponds to net-zero GHG emissions by 2100, based on the IEA's Announced Pledges Scenario (APS). The improved regional disaggregation and energy technology representation in AD-MERGE-2.0 allows for a more detailed and accurate assessment of climate policy impacts, particularly in the context of a global transition to low-carbon energy systems.

2 - Implementation of health costs due to air pollution in the TIMES model: the case of the Italian National Energy and Climate Plan (NECP) Scenario
Silvia Laera

This work presents a methodology to include health costs due to exposure to the air pollutants nitrogen oxides (NOx) and particulate matter (PM) in the energy system optimisation model TIMES-RSE and assess their impact on the Italian National Energy and Climate Plan (NECP) Scenario. The health costs, evaluated by RSE with the air quality model SIMBAD, are expressed per unit of fuel consumed and applied to road transport and building sectors in the Italian model TIMES-RSE. TIMES is a bottom-up technology model that optimises the cost of the entire energy system over the time horizon in which the assigned demand for energy services is to be met, under environmental, technological and/or policy constraints. Health costs are then applied to the Italian NECP Scenario - developed by RSE and submitted by Italy to the European Commission in 2024 - to assess how they can influence energy planning. Comparing a scenario with and without health costs highlights changes in energy consumption, electrification and CO2 emissions. The results pave the way for including CO2-related health costs too as the model opts for solutions with lower health costs related to NOx and PM but produce more CO2, as observed with the replacement of biomass boilers by gas or diesel cars with gasoline ones. More broadly, this analysis falls under the RSE activity to create a soft link between TIMES and the air quality model SIMBAD to explore the interdependence between energy emissions and health costs.

3 - Selection of the method of transportation of oil and oil products through a pipeline network: an approach using the crown method
Anderson Goncalves Portella, Marcos Santos, Daniel Pereira

Pipeline logistics is a strategic component in the energy sector, directly affecting costs, efficiency, and environmental impacts. This study applies the CROWM (Communalities on Ranking and Objective Weights Method), a robust multicriteria decision-making approach, to evaluate 40 pipeline alternatives based on eight criteria, including cost, environmental impact, and operational safety. Expert input was collected through an anonymous questionnaire, and the results identified the AF pipeline, featuring advanced automation and real-time monitoring, as the most advantageous option. The AN pipeline, designed for high-pressure transport in densely populated areas, ranked second. Conversely, pipelines with vulnerabilities, such as frequent interruptions or susceptibility to vandalism, were the lowest-ranked. The study demonstrates the method's effectiveness in prioritizing complex logistical alternatives and its potential for broader applications in the energy sector, contributing to sustainability and competitiveness. Future work includes exploring its use in other transport modes and regional infrastructure solutions.

4 - Integrating Multicriteria Analysis and Participatory Governance in Energy Optimization Models: A Pathway for Ecuador's Power Sector
Janeth Carolina Godoy

Effective energy planning requires integrating quantitative and qualitative methods, combining data-driven modeling with stakeholder participation. This study presents a framework that integrates optimization models with multicriteria analysis and participatory governance to develop an energy model for Ecuador's power sector. Using the Analytic Hierarchy Process and PROMETHEE methods, the research captures the perspectives of government, academia, the private sector, and civil society, evaluating nine criteria across social, environmental, and technical categories. These inputs feed into the energy cost optimization model using the urbs tool. Results highlight differences in stakeholder priorities: civil society values biodiversity protection, while others focus on minimizing displacement to avoid conflicts. Technical criteria like accessibility and proximity to transmission lines are prioritized by the public and private sectors due to economic impacts. Three scenarios are explored: the Policies scenario based on government plans, the Governance scenario with multi-actor preferences, and the Ambitious scenario targeting a 100% renewable energy matrix by 2040. Findings show that the Governance scenario balances social and environmental criteria but still depends on non-renewable sources, while the Ambitious scenario eliminates fossil fuels at higher costs. This approach suggests a shift in energy modeling, balancing environmental, social, technical, and economic aspects.

■ TD-47

Tuesday, 14:30-16:00 - Room: Parkinson B08

Consumer Demand and Marketing I

Stream: Retail Operations
Invited session
Chair: Winfried Steiner

1 - Using Sensor Technology to Evaluate the Effects of a Price Promotion on Store Arrival Times
Ignacio Inostroza-Quezada, Leonardo Epstein, Ronald Goodstein

Store managers conduct frequently marketing actions (MAs) to boost store traffic. Thus, measuring this traffic is crucial for assessing the effectiveness of such initiatives. Recently, store managers have gained access to sensors that record data continuously, enabling a more in-depth analysis of how their actions affect consumer behavior. In this talk, we present a novel approach that uses shopper-specific arrival times outside a MA to build a counterfactual baseline for store traffic during this MA. This baseline (i) assumes that the MA has not taken place, and (ii) is essential because a store cannot operate simultaneously with and without the MA. Next, we compare observed traffic data with the counterfactual baseline during the MA to evaluate its effect on store traffic. Finally, we assess the uncertainty of this effect during the MA. We illustrate our approach with data from an actual two-week price promotion, which showed an increase of 2880 store arrivals attributed to the promotion. Additionally, we complement our results with visual plots that help managers (i) examine the evolving effects of the promotion and (ii) understand the influence of time-varying covariates on consumer behavior.

2 - Computing Nash equilibria for product design based on hierarchical Bayesian mixed logit models
Jan Dressler, Peter Kurz, Winfried Steiner

Over the past few decades, choice-based conjoint analysis has become an indispensable technique for the elicitation of consumer preferences, serving as the foundation for product design and assortment optimization in marketing and retailing. Despite a substantial body of theoretical and empirical research, there has actually been little effort in this field devoted to exploring subsequent reactions of competitors based on non-cooperative game theory, although manufacturers and retailers are increasingly interested in market equilibria to support managerial decisions. Only a fraction of the existing frameworks considered

competition on both price and design, none of which accounted for Bayesian hyperparameter uncertainty, let alone under different choice rules.

In order to close this research gap, we developed a comprehensive system for conjoint-based game-theoretic simulation, ranging from utility generation, through choice design and Bayesian model estimation, to Nash equilibrium computation. After analyzing numerous equilibria build upon actual retail prices and costs of notebooks, we found that a deterministic choice rule generally led to equilibria with lower prices and profits but at the same time demonstrated a much greater stability in prices across various levels of preference heterogeneity and disturbance. This is crucial, as price was the main driver of profits, and held true even when Bayesian posterior means were employed instead of draws.

3 - . . . and where do you buy your t-shirts? Understanding consumers' fashion store preferences using a discrete choice experiment
Helene Ida Kleiber, Christoph Herrmann, Katharina Friederike Sträter

The fashion industry is one of the most important sectors of the global economy. At the same time, it is associated with major social and environmental sustainability problems. Thereby, particularly online shop-based ultra-fast fashion concepts are coming under increasing public scrutiny. However, whereby there is a substantial body of research dealing with consumer preferences regarding the characteristics of clothing items, little is known about preferences regarding sustainability- and non-sustainability-related fashion store characteristics. This study aims at bridging this gap using a discrete choice experiment, in which 776 respondents from Germany had to made hypothetical choices between two fashion stores, differing among others in price, company headquarters, distribution channels, as well as social and environmental certifications. The data was analyzed using a mixed logit model and results show that respondents are gaining utility from and are willing to pay more for ecological and social certification of the store, hybrid distribution of the products including stationary stores, and German headquarters. Whereby the preference regarding sustainability related certificates increases with a positive orientation towards slow fashion, environmental awareness in general appears to be in a tradeoff with price sensitivity. Thus, standardized store certifications should be established, while highlighting fashion's environmental impact can foster slow fashion awareness.

4 - Decentralized Ranking and Pricing at an Online Marketplace
Alireza KabirMamdouh, Gurhan Kok

In an online marketplace such as Amazon.com, third-party sellers and a marketplace operator compete to sell the same or near-substitute products. As the higher/prominent positions on the web page capture most of the sales and customer attention, the vendors compete to win those positions by offering more attractive prices. We study the positioning/ranking policy of the marketplace operator (MO) and its impact on pricing competition among the sellers. We model the price competition of two sellers under two ranking policies that MO can implement, named deterministic ranking (DR) and probabilistic ranking (PR). Under DR, the seller with the lowest price always gets the highest ranking. Under PR, however, the ranking is a randomized function of prices where a lower price implies a higher ranking. We characterize the unique Nash equilibrium of pricing under PR and the range of prices in the mixed-strategy equilibrium under DR. We show that DR leads to lower prices and lower seller profits than PR. The preference of MO over ranking policies is dependent on the profit margin and cost of the products. Unexpectedly, MO's profit is higher under PR when the profit margin of the product is relatively high. In general, MO can increase supply-side profits with a less competitive ranking rule and a higher commission rate. These results suggest that Amazon.com and other marketplaces can increase their own and sellers' profitability by switching to probabilistic ranking policies.

■ TD-48

Tuesday, 14:30-16:00 - Room: Parkinson B09

Bridging explainable decision-making and mathematical optimization I

Stream: Transparent and Fair Decision Making with Mathematical Optimization
Invited session
Chair: Vanesa Guerrero
Chair: *Jasone Ramírez-Ayerbe*

1 - Counterfactual explanations for uncertain data using k-Nearest Neighborhood classifier
Marica Magagnini, Emilio Carrizosa, Renato De Leone

Data collection can often involve uncertain values due to different factors. Actually, feature uncertainty in data reflects the inherent variability and noise present in real-world scenarios. This makes it a common challenge in machine learning. Similarly, the explainability of artificial intelligence algorithms has become a key issue in the development of the field. Counterfactuals are very popular explanations; they provide valuable information that allows the user to take action on their own features and thus change the prediction in a decision-making scenario. In sensitive contexts, such as those involving uncertain data, the generation of robust explanations must be able to account for the uncertainty in the data. We formulate an optimization problem to yield counterfactual explanations when the k-Nearest Neighborhood classifier handles data with uncertain features. We model the data with feature uncertainty as convex sets. The designed counterfactual mimics the same convex representation as its original reference instance, providing a robust explanation. We propose an endogenous solution of the problem and we present a constructive heuristic strategy to provide exogenous counterfactuals that shorten the distance from the input compared to endogenous ones. The heuristic methodology follows the Gaussian Variable Neighborhood Search.

2 - Robustness in counterfactual analysis applied to GLMs
Antonio Navas-Orozco, Emilio Carrizosa

In a Generalized Linear Model (GLM), finding a counterfactual decision of a record amounts to finding a vector with maximal outcome at a distance small enough of the record. In this paper, we extend this problem and address the challenge of building robust counterfactual decisions. Robustness is understood as guaranteeing that the predicted outcome for the counterfactual decision remains sufficiently high when the nominal probability distribution (the empirical distribution for the given training sample) is replaced by a probability distribution with the same support but different frequencies. Exploiting the structure of the Exponential Family, the problem of finding a robust counterfactual decision is expressed as a biobjective bilevel nonlinear optimization problem, whose structural properties are studied, and a numerical method is proposed.

3 - Prescriptive models with many information sources
Jose Carlos Castro, Vanesa Guerrero, Emilio Carrizosa

In many real-world scenarios, data are collected from diverse sources, some of which can be costly to access in terms of resources or time. This often leads to incomplete datasets in the sense that blocks of features are available only for some of the observations, thus yielding a block-missing data set. Rather than discarding or imputing missing data, in this work we propose a greedy tree-based method that makes use of all available data to train a predictive model.

At each step, this greedy algorithm evaluates the option of making a split based on a block of features, aiming to balance predictive accuracy with the cost of accessing additional information. Designed for both classification and regression tasks, our approach integrates an adaptive decision-making mechanism to optimize the trade-off between data completeness and prediction performance.

4 - Explaining decisions: from classification to other data-driven optimization problems
Jasone Ramírez-Ayerbe, Emma Frejinger

Counterfactual analysis has emerged as a powerful tool in the expanding field of Explainable Artificial Intelligence. Beyond classification, recent methodologies have extended its application to various optimization problems, including contextual settings. In this talk, we discuss the latest advancements in the field, with a special focus on a novel approach explaining decision problems under endogenous uncertainty.

■ TD-49

Tuesday, 14:30-16:00 - Room: Parkinson B10

Analytics Applications

Stream: Analytics
Invited session
Chair: João Alexandre Antunes

1 - Solving Skilled Labor Shortages: A Data-Driven Approach
Violeta Cvetkoska, Vidmantas Tūtlys, Jonathan Winterton

This study develops a comprehensive, data-driven analytical framework to assess and forecast skilled labor shortages across European destination and transition countries (France, Germany, Italy, Poland, Lithuania, Norway, and the UK) and selected countries of origin (Ukraine, Türkiye, North Macedonia, and Ethiopia). By integrating descriptive, diagnostic, and predictive analytics, the research provides actionable insights for policymakers, industry leaders, and educational institutions to address structural workforce imbalances. The descriptive phase synthesizes statistical data, employer surveys, and expert interviews to identify sectors facing acute skill deficits. The diagnostic phase uncovers systemic drivers, including rigid qualification frameworks, weak industry-education collaboration, training-labor market mismatches, and external shocks such as geopolitical conflicts, environmental disruptions, and large-scale migration. The predictive phase leverages advanced regression model to forecast labor market trends and simulate the impact of targeted interventions. Scenarios explore the effects of wage adjustments, workforce upskilling, streamlined credential recognition, and policies fostering circular migration. By systematically comparing labor dynamics across national contexts, the study offers a strategic roadmap for building adaptive, sustainable, and resilient European labor markets in an era of workforce volatility.

2 - Discrete Event Simulation of the market authorisations process of new food and feed in GB
Katie Mears

Since the UK left the EU, the Food Standards Agency (FSA) - alongside Food Standards Scotland (FSS) - has taken on responsibility for running the process for granting market authorisations for the sale of certain food and feed products in Great Britain (GB). The regulatory framework was inherited from the EU but adjusted to work for the GB government starting from January 2021. The process is long and complex which has required the FSA to introduce new practices to be able to manage the number of applications being submitted for approval. As this is a relatively new process for the FSA and FSS we have a programme of continuous improvements and modernisation to enable us to deliver an effective, proportionate and transparent system which runs as quickly as possible. The Operational Research team within the FSA has been tasked with modelling the current process and estimating the number of Full Time Equivalents (FTEs) required at different stages to ensure the process run smoothly and testing how changes to the process would impact the system. This paper is about how we undertook this complex analysing using discrete event simulation within Simul8 and following the PartiSim methodology to work with a wide range of stakeholders.

3 - Data-driven optimization for wildfire suppression resource deployment: A case study of Alberta wildfires
Yasser Zeinali, Ilbin Lee, Mostafa Rezaei, Armann Ingolfsson

Wildfires pose a severe global threat, with North America experiencing increasing wildfire activity. Canada reports over 8,000 wildfires annually, burning millions of hectares, with a record-breaking 18.5 million hectares affected in 2023. This escalating crisis places intense pressure on wildfire management agencies to develop effective suppression resource allocation strategies. In collaboration with the Alberta government, we present a data-driven framework for optimizing wildfire resource deployment. Our approach integrates predictive modeling, queueing theory, and robust optimization. We predict daily resource-hour requirements and the number of wildfires requiring specific resources. These forecasts inform a queueing model that estimates transient waiting times within a robust optimization framework, ensuring efficient resource allocation. Although our case study focuses on Alberta, the methodology is adaptable and can be tailored to address wildfire management challenges in other regions.

4 - From Waste to Resource: How Spatial Characteristics Shape Composting Adoption
João Alexandre Antunes, Vera Miguéis, Jorge Grenha Teixeira, Susana Freitas, Luís Campos

Municipal solid waste (MSW) generation is increasing, representing a critical issue for societies and the environment. A relevant portion of MSW is organic waste, generally ending in landfills and generating high environmental impacts. Home composing avoids landfilling by recycling organic waste in individuals' homes. However, the adoption of this behaviour is not yet widespread and has strict requirements. Moreover, the literature on composting behaviour is very incipient. Therefore, the main aim of this work is to understand how the spatial characteristics of individual's residence areas impact the adoption of home composting practices. Characteristics, such as area type (e.g. buildings or sparse residential), green area percentage and vegetation quantity were obtained by image processing of satellite images, using supervised and unsupervised machine learning models. These characteristics, together with others collected from a survey (e.g. household type and existence of selective food waste collection services) were then used to explain individuals' behaviours. For this purpose, decision tree and logistic regression algorithms were adopted. We found that dense residential areas prevent the adoption of home composting behaviour, while the existence of a garden acts as a driver of behaviour adoption. Based on these results, we can guide the decision process of waste management organisations when assessing certain regions for the implementation of composting programmes.

■ TD-50

Tuesday, 14:30-16:00 - Room: Parkinson B11

Systems Thinking 2

Stream: Systems Thinking
Invited session
Chair: Matt LLoyd

1 - An Introduction to Systems Thinking
Matt LLoyd

New to the EURO conference this year is a stream dedicated to the growing OR discipline of Systems Thinking. This is a set of approaches to solving problems and supporting decision makers that can help to unravel the particular problems that come from dealing with complex, inter-related systems. These approaches are complementary to mathematical techniques and are particularly appropriate where human factors and perceptions of what is good can be as important as the optimum mathematical solution of the problem.

This workshop will provide an introduction to systems thinking approaches for both practitioners and practice-focused academics who

deal with complex, systemic, ethically difficult or politically charged problems and who want to get a better understanding of where these approaches might be useful to them and how to apply them to real problems

2 - Critical Systems Thinking: Aspiring to Russ Ackoff's Vision of OR
Mike Jackson

In 1979 Russ Ackoff turned his back on OR, declaring that 'the future of operational research is past'. He condemned its commitment to optimization and objectivity in a world of rapid change and multiple values. Instead, he embraced systems thinking which he hoped to build into a holistic, interdisciplinary, experimental science capable of addressing the most important strategic and societal problems. His 'interactive planning' methodology, seeking to explore purposes and encourage continuous learning and adaptation, was an expression of this vision. Since 1979, OR has responded to Ackoff's critique. In particular, 'Soft OR' has been developed as a complementary approach to the traditional 'hard' approach. Soft OR, incorporating a variety of problem structuring methods, adds an ability to cope with ill-structured issues to OR's traditional competence with structured problems. OR, however, still falls far short of realizing Ackoff's vision. It is 'critical systems thinking' that aspires to completely fulfil Ackoff's ambition. Critical systems thinking adopts a pragmatist approach to multidimensional complexity, is multiperspectival, multimethodological, flexible, and seeks to ensure multifaceted systemic improvement. This presentation demonstrates how critical systems thinking draws upon Ackoff's ideas and develops them. It reflects on what is being done to translate those ideas into practice to tackle significant strategic and societal problems.

■ TD-51

Tuesday, 14:30-16:00 - Room: Parkinson B22

Advances in nonlinear multiobjective optimization

Stream: Multiobjective and vector optimization
Invited session
Chair: *Titus Pinta*

1 - An Iterative Process for Non-smooth Multi-objective Optimization Problem Via Subdifferential Set Approximation
Dinesh Kumar, Geetanjali Panda

This work presents an iterative technique for unconstrained multiobjective optimization problems. The objective functions are assumed to be convex but need not be differentiable. This technique provides a sequence of points that converge to its Pareto critical point (a necessary condition of a weak Pareto optimal point) considering reasonable assumptions. Initially, an appropriate subproblem is presented at each iteration in order to find the direction vector by utilizing the subdifferential of each objective function at that point. Subsequently, the method is updated in order to determine the descent direction in an explicit form. A set of numerical examples is presented to validate the suggested approach. This iterative scheme does not rely on any predetermined parameters.

2 - A Newton-type method for non-smooth vector optimization
Titus Pinta

We propose a new algorithm for determining efficient solutions to non-smooth multiobjective optimization problems based on Newton's method. The key insight comes from the fact that the search for such points can be recast into a problem of finding the roots of an underdetermined system of equations, with half of the variables lying in the standard simplex. Then, the classic Newton algorithm can be easily generalized to the underdetermined framework by employing pseudo-inverses, while the constraints can be handled by simple projections. This algorithm is then extended to work with arbitrary partial orderings induced by convex cones by replacing the simplex constraints with more general ones. In order to handle non-smooth problems, the notion of Newton differentiability suffices for the analysis of the algorithm, which achieves super-linear convergence. To showcase the algorithm, numerical tests are provided, illustrating the fact that the proposed method, while resembling a scalarization technique, does not fail in the well-known pathological counter-examples to such techniques.

3 - Bilevel Gradient Algorithms for Optimization over the Pareto Set
Yumi Kitazume, Takayuki Okuno

A multi-objective optimization problem is a classical optimization problem that seeks to optimize multiple objective functions simultaneously and has numerous practical applications. In practice, the primary goal of solving such problems is to identify the so-called Pareto set and then determine an optimal point according to specific criteria by decision-makers. In this research, we aim to optimize a scalar function over the Pareto set. To address this problem, we propose a new approach based on three steps. First, we formulate the problem as a bilevel optimization problem, where the lower-level problem is a multi-objective optimization problem. Second, we transform the lower-level problem into a single-objective (possibly nonsmooth) problem using a scalarization method for multi-objective optimization. Third, we construct a certain unconstrained optimization problem by approximating the lower-level solution using a finite number of iterations of a gradient algorithm combined with a smoothing technique, and then apply a gradient algorithm to the obtained problem. We establish global asymptotic convergence results under mild assumptions and further demonstrate the efficiency of the proposed approach through numerical experiments.

4 - A new F-E-objective approach and optimality conditions for E-differentiable interval-valued multiobjective optimization problems
Najeeb Abdulaleem

The increasing reliance on optimization models for decision making has created a demand for tools that can formulate and solve a broader range of models related to real-world processes and human activities, especially in situations where hypotheses cannot be verified in the traditional sense of classical optimization. One effective approach to addressing real-world extremum problems under uncertainty is interval-valued optimization. In this paper, a nonconvex E-differentiable vector optimization problem with multiple interval-valued objective functions and both inequality and equality constraints is considered. We derive the E-Karush-Kuhn-Tucker (E-KKT) necessary optimality conditions for these interval-valued multiobjective programming problems. Further, we propose a new methodology termed the F-E-objective function approach. This method transforms the original vector optimization problem into an equivalent vector optimization problem with interval-valued F-E-objective functions, ensuring equivalence under F-E-convexity assumptions. The proposed approach is demonstrated to be effective in solving nonlinear, nonconvex interval-valued optimization problems. Furthermore, we illustrate that, under specific conditions, the introduced method enables the resolution of complex nonlinear problems by leveraging techniques designed for linear interval-valued optimization.

■ TD-53

Tuesday, 14:30-16:00 - Room: Liberty Moot Court

New Trends in Game Theory VII

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Songsong Liu*

1 - Deceptive Reviews in E-Commerce Markets: The Blockchain Solution and its Implications
Boru Li, Yong-Hong Kuo, Jie Wang

Manipulation of ratings and counterfeit reviews is increasingly distorting consumer perceptions and driving up verification and marketing costs for sellers on e-commerce platforms. This study investigates blockchain technology as a potential remedy. We offer a detailed analysis of how blockchain can deter fake reviews by examining the decision-making behaviors of both consumers and online sellers. Empirically, we demonstrate that variations in review authenticity significantly shape consumer purchase intentions by influencing perceptions of product and seller credibility. Building on these findings, we model sellers' strategic behavior. Rather than only considering a conventional e-commerce environment, we propose an alternative scenario that adopts blockchain into platforms to evaluate three strategic options: manipulating ratings, refraining from manipulation, and adopting blockchain technology. The study reveals that inflating product ratings is not always advantageous for sellers, particularly for products within a specific quality range, where abstaining from fake ratings proves more optimal. However, the incentive to adopt blockchain varies, with sellers of medium- to high-quality products being more inclined toward its implementation. Our analysis and empirical validation confirm the robustness of these findings, offering meaningful insights into how blockchain can enhance the credibility and trustworthiness of e-commerce platforms.

2 - Optimizing Punitive Damages in Copyright Enforcement: Balancing Deterrence and Market Participation
I-Hsuan Hong, Fong-Yu Chen, Wayne Fu, Jack C.P. Su

The growing emphasis on intellectual property rights necessitates strong legal frameworks and penalties to deter piracy. This study examines the impact of punitive damages in copyright infringement cases, analyzing their effects on studios, legal and illegal platforms through analytical modeling and empirical research. We develop a two-stage Stackelberg game model, where studios set licensing fees, while legal and illegal platforms determine pricing and piracy strategies. Consumers choose between legal consumption, piracy, or abstention based on their perceived utility. Using backward induction, we derive equilibrium decisions and evaluate how punitive damages influence revenue, demand, and pricing. To validate our model, we conduct an empirical study. Findings show that higher punitive damages reduce piracy by increasing search costs for illegal content, promoting legitimate consumption. However, excessive penalties may have diminishing returns, discouraging overall market participation. These insights help optimize punitive damages, ensuring penalties deter piracy without stifling consumer engagement or driving piracy underground.

■ TD-54

Tuesday, 14:30-16:00 - Room: Liberty 1.08

Stochastic models in service operations

Stream: Stochastic modelling
Invited session
Chair: Raik Stolletz

1 - Setting period wise staffing levels simultaneously when demand is dynamic
Tim Weber, Raik Stolletz

Staffing determines the number of employees that should be present in a given period given stochastic demand. The less servers (employees) are working in a given hour, the longer customers have to wait until service and the higher customer dissatisfaction. Thus, the goal is to minimize the number of servers, while still adhering to some service level constraint. This trade-off of personal costs and a certain service level is affected by time-dependent demand. Prominent staffing methods, such as the Stationary Independent Period by Period (SIPP) approach determine staffing requirements for each period in isolation. However, a high demand in a certain period may affect the performance measures in the succeeding period. We propose a staffing method for an Mt/M/ct system that considers the performance over all periods and optimizes staffing levels simultaneously over all periods of the planning horizon. We integrate the Stationary Backlog Carryover (SBC) approach into a nonlinear optimization model. A linearization of this model enables us to determine staffing levels efficiently. The numerical study analyzes the effectiveness of this approach. In comparison to the SIPP approach, we demonstrate the changes in the structure of the staffing levels for different realistic demand patterns.

2 - Performance Analysis and Optimization of a Hybrid Finite Markovian Queue with Retrial and Balking
Shobha Rani

In classical Markovian retrial queues, the completion of a service does not immediately trigger the commencement of a new service. Instead, customers who do not receive service on their first attempt rejoin the standard queue after a random amount of time. This paper examines an M/M/1/K queueing model incorporating both retrial and balking with a limited orbit and a finite queue capacity. If the server is occupied upon a customer's arrival, the customer may choose to balk the system. The model is formulated using the birth-death process, where transition rates define the governing equations. A recursive approach is employed to analyze the steady-state queue size distribution and various system performance metrics. The balking rate is considered as a decision variable, and we analyzed both the Nash equilibrium and the socially optimal balking rate under a cost model. Additionally, the total cost function is optimized to determine the cost-effective operational strategy.

3 - Reliability Modeling of k-out-of-n: G Systems with Repair Delays Under N-policy
Akhil Vijayan R, Manikandan Rangaswamy

We consider the reliability analysis of a k-out-of-n: G system under the N-policy of repair and the activation time of repair facility. The k-out-of-n: G system, which is a widely used configuration in reliability engineering, requires atleast k components to function properly for the entire system to be considered operational. The N-policy introduces a repair mechanism wherein the system initiates the repair only once the number of working components reduces to a specific threshold N due to failure, which is critical in optimizing the repair process. In this study, we incorporate both repair and activation time delay of the repair facility into the reliability model, acknowledging the uncertainty in the repair process and the time required to activate the repair facility. Using a combination of probabilistic methods and mathematical modeling, we derive the transient probabilities of the system. We evaluate key reliability metrics and explore the impact of varying the threshold N and different parameters on the system performance. We delve into a cost optimization problem to obtain the optimal threshold N in this model. Our results provide valuable insights into how the N-policy and activation time influence the overall system reliability, offering guidance for the design and optimization of real world problems employing repair strategies. The findings contribute to the development of more efficient maintenance policies in industrial systems.

4 - Optimizing a human-centric order picking system via simulation
Rina Mary Mazza, Francesca Guerriero, Pasquale Legato

Order picking is deemed the most costly and labour-intensive process in a distribution warehouse and the backbone of successfully fulfilling client orders. Whether it be a manual, automated or robot-collaborative system, mastering the order picking process means improving the overall supply chain and business results. In the recent literature and in compliance with the Industry 5.0 paradigm, speeding up order process and keeping it accurate has been coupled with worker well-being. Both planning activities and operational policies are being designed to address this matter. Along this line of work, we present a mathematical programming model to optimize the slot location assignment in a real-world manually-operated and rack-based facility with respect to both economic and workforce wellness criteria. We then solve this

model with an iterated local search inspired metaheuristic and validate the corresponding solution, in a stochastic and dynamic environment, via discrete-event simulation. The simulation stage of the proposed approach allows accounting for additional well-being amplifiers during order picking, such as proper queueing policies and list assignment in proximity of the end of a shift or day. To finish, we detail on our current experience and discuss preliminary numerical results.

■ TD-55

Tuesday, 14:30-16:00 - Room: Liberty 1.09

Game Theory, Contracts, and Economic Models for Humanitarian Aid

Stream: Humanitarian Operations
Invited session
Chair: Milad Keshvari Fard

1 - A Tripartite Sequential Game for Relief Prepositioning with Framework Agreements and Catastrophe Insurance
Jianfang Shao

Stockpiling relief supplies in central warehouses is a good alternative for relief organisations tasked with responding to complex and sudden disasters, these stockpiles, however, can become huge economic burdens with the potential for waste. Cooperation between relief organisations and businesses, such as suppliers and insurance companies, may help to share risk and manage the uncertainty of relief response. This paper establishes cooperation mechanisms for relief organisations through a framework agreement with a supplier and a catastrophe insurance contract with an insurance company. A tripartite sequential game model (SGM) is established for the relief organisation, the supplier and the insurance company. We consider two contexts, one where the relief organisation has no budget constraint and one where it does. With this cooperation mechanism, the relief organisation minimises the social costs of relief prepositioning, including its own storage, framework agreement and insurance costs, while the supplier and insurance company maximise their profits. We explore the practicalities of cooperation mechanisms involving three parties and compare these with two-party cooperation agreements using a benchmark model (BM) through a case study in Shenzhen, China. Results show that the designed three-party cooperation mechanism can achieve a win-win-win situation for all parties from a long-term and sustainability perspective.

2 - Dynamic-Priced Contracts for Uncertain Episodic Service Demand
Shraddha Rana, Luk Van Wassenhove

Following natural disasters and man-made disruptions, the uncertain, episodic, and time-sensitive demand for relief services makes it difficult for humanitarian actors to compete with private-sector customers in securing commercial service capacity, leading to high costs.

We study a case of transportation service procurement using dynamic-priced contracts to improve service-level while reducing costs in order to satisfy emergency demand. In particular, we study truckload procurement for The US Federal Emergency Management Agency(FEMA) and answer the following research questions: 1) How effective and efficient is FEMA's current truckload procurement process compared to the private-sector shippers? 2) How should FEMA design a dynamic-priced truckload procurement contract for uncertain episodic disaster demand in the future?

We thus contribute to the disaster procurement, truckload procurement, and dynamic-pricing literature by: i) studying truckload transportation service procurement for FEMA, without capacity guarantee; ii) considering uncertain episodic demand in response to disasters; iii) modeling a dynamic-priced truckload contract; iv) examining the case where the buyer, i.e., FEMA offers the price as opposed to the seller, i.e., carriers and brokers.

Additionally, we explore how our insights can be used for dynamic pricing for other types of service procurement in a humanitarian setting, given the prevalence of uncertainty in demand.

3 - Navigating Crypto Philanthropy: Should Nonprofits Self-Manage Their Crypto Fundraising or Rely on Third-Party Platforms?
Milad Keshvari Fard, Jingshu Liu

Nonprofit organizations (NPOs) face persistent funding challenges, worsened by global crises and declining contributions from major donors. To mitigate these issues, many NPOs have embraced cryptocurrencies as an alternative funding source. While most rely on third-party platforms like The Giving Block to handle crypto donations, this approach incurs substantial fees and limits donor engagement. An alternative is self-managed crypto fundraising, which allows NPOs to retain control, reduce costs, and potentially attract more contributions by signalling innovation and financial efficiency. This study investigates the financial implications of self-managed crypto fundraising compared to third-party outsourcing. Using data-driven mathematical modelling on over 28 cryptocurrency donation campaigns from 2018 to 2024—encompassing more than 300,000 transactions across 300 tokens—we evaluate expected financial returns under different liquidation strategies. Our findings indicate that self-management can significantly enhance fiat returns, particularly when employing simple trading heuristics like the Triple Exponential Moving Average. Even with immediate liquidation, financial gains remain substantial. Additionally, our results suggest that both small and large NPOs can benefit from self-management, albeit in different ways, making it a viable strategy for optimizing cryptocurrency fundraising efforts.

4 - Relief item priority dynamics in a bi-level distribution-allocation problem
Yu Fan

In humanitarian logistics (HL), prioritizing of relief item distribution under limited transportation capacity is an important and practical problem that relief organizations face. The priority not only depends on the dynamic demand urgency, but also on the different equity concerns between distribution managers (high-level) and point of distribution (POD) managers (low-level). In this paper, through field investigations, we adopt deprivation cost to capture the dynamic priority among different relief items like drinking water or tents, and envy to represent the equity perceptions of victims, based on which we study a bi-level distribution-allocation problem to answer the following research questions: (1) Which kind of relief item at which time point should be distributed in priority with limited transportation capacity? (2) What's the impact on distribution strategy when there are misalignments between bi-level decision-makers? Should the distribution managers take envy of victims into account? We build a non-linear model which minimizes the sum of deprivation cost of different relief items and the possible penalty caused by envy. A case study based on real-world data is conducted to show the feasibility of our method and model. Summarizing, this paper presents an original approach to incorporate the dynamic priority of relief item distribution in a bi-level system, taking a 'people-centered' perspective.

■ TD-56

Tuesday, 14:30-16:00 - Room: Liberty 1.11

Routing with Time Windows

Stream: Vehicle Routing and Logistics
Invited session
Chair: Roshan Mahes

1 - Good things come to those who wait: improvements on the VRP using wait time and time window optimisation
Ruth Walton, Ying Tan, , Louisa Sober

In collaboration with a multinational logistics company, the Datasparq team have developed an advanced vehicle routing optimisation product using an ALNS framework. This optimiser generates improved strategic routing plans for vehicle routing problems with capacity constraints and time windows across a number of different clients. Some recent developments of this optimisation product have been focussed around the flexibility of time windows, both of which have delivered significant efficiency gains for our clients. The first is the incorporation of wait time, which effectively functions as a soft widening of time windows. This configurable feature allows the client to specify a maximum amount of wait time and in one example in grocery backbone haulage, this feature has led to an annual cost savings of 3.7%. The second innovation is time window optimisation, which helps clients understand the potential savings associated with adjusting their delivery windows. Recognising that fully flexible time windows are not operationally feasible, we have developed an approach to identify the most efficient operational window within a wider time horizon, offering targeted recommendations for time window adjustments. This method has demonstrated annual savings of up to 1.5% for a national hardware chain. Our presentation will outline the technical implementation of these features, their impact on real-world logistics operations, and insights gained from working with diverse clients.

2 - Routing a mixed fleet for on-site services considering EV charging and time windows
Jiyin Liu, Vidura Sooriyaarachchi, Rupal Mandania

This study addresses a problem of scheduling on-site service tasks and routing the vehicles that technicians drive to the sites to perform the tasks. With increasing number of Electric Vehicles (EVs) in the fleet, EV charging needs to be considered in the planning in addition to customer time windows and other constraints. The objective is to minimise travel cost as well as the extra cost for charging EVs during the day. The problem is formulated as a mixed-integer linear programming model. Considering the complexity of the problem, a variable neighbourhood search-based heuristic is applied to solve the problem of practical size. The heuristic searches for the best allocation of tasks and the best sequences of tasks in vehicle routes. An efficient dynamic programming algorithm is developed to check feasibility and optimising the charging for a given route. This algorithm is imbedded in the heuristic to calculate the objective value for each for each solution searched. Results of computational experiments will be presented to demonstrate the effectiveness of the method and the impact of problem parameters on the solution.

3 - Vehicle Routing Problem with Time Windows on a Signalized Road Network
Tsung-Sheng Chang, Yen-Yu Chen, Pei-Yu Sung

This research investigates the Vehicle Routing Problem with Time Windows (VRPTW) under pre-timed traffic signal conditions. Traditional vehicle routing models often neglect the impact of signal control, leading to suboptimal or infeasible solutions that violate time window constraints. Additionally, previous studies have struggled with accurately estimating link travel times. While some research has developed travel time prediction methods, these are primarily applied to the Shortest Path Problem and not to vehicle routing. To bridge this gap, this study integrates link travel time estimation into VRPTW within signalized road networks. A detailed graph structure is formulated to represent various vehicle movements through signalized intersections. To accurately capture the impact of pre-timed signals, piecewise linear functions are developed to model link travel times. The VRPTW is then formulated as a Mixed-Integer Linear Programming model, explicitly incorporating signalized road networks and strict time window constraints. A branch-and-price solution algorithm is designed to efficiently solve large-scale instances.

4 - Dynamic time-window updates in last-mile delivery: Follow Your Parcel
Roshan Mahes, Alex Kuiper

Accurate delivery time windows are crucial for customer satisfaction in last-mile logistics, influenced by factors such as route optimization and driver behavior. This work introduces novel analytics to study route performance, uncover route adherence, and explore their interdependencies, classifying four types of routes. These insights are used to provide a comprehensive methodology for generating time windows and time-window updates.

Real-life data shows that exponential distributions effectively model the time between consecutive deliveries, with means decreasing throughout the day. We approximate these using a regression model based on the position in the route and the route length. Next, each customer receives an individual expected delivery moment within a prediction interval. Besides the speed of generating these intervals, they outperform statically generated intervals of, say, 2 hours for nearly all route types. Moreover, we further leverage this approach by dynamically providing updates, which can be implemented as push or live updates.

Concluding experiments confirm the effectiveness of reducing time-window width during the route without significantly jeopardizing the performance of delivering within these intervals. Finally, to meet customer expectations for more precise delivery information, PostNL, the leading postal and parcel delivery company in the Netherlands, has implemented a customized version of the proposed methodology.

■ TD-57

Tuesday, 14:30-16:00 - Room: Liberty 1.12

Air transportation II

Stream: Transportation
Invited session
Chair: Lisanne Heuseveldt

1 - A Mathematical Model for Multi-Objective Airport Slot Scheduling with Endogenous Declared Capacity Definition
Davood Mohammadi, Burak Boyaci, Konstantinos G. Zografos

This research proposes a multi-objective formulation of the airport slot scheduling problem with endogenous declared capacity definition. The proposed mathematical model comprises five objective functions minimizing (i) the total number of rejected requests, (ii) total displacement, (iii) maximum displacement, (iv) waiting time, and (v) capacity utilization. We implement an accelerated version of the augmented [U+03F5]-constraint method to solve the problem. Subsequently, to extract representative solutions from the set of non-dominated solutions, we solve an optimization model that minimizes the coverage gap. We present computational results from the application of the proposed model on a synthetic dataset.

2 - Linear Lexicographic Optimization and Preferential Bidding System
Nour Elhouda Tellache, Frédéric Meunier, Axel Parmentier

Some airlines use the preferential bidding system to construct the schedules of their pilots. In this system, the pilots bid on the different activities and the schedules that lexicographically maximize the scores of the pilots according to their seniority are selected. A sequential approach to solve this maximization problem is natural: The problem is first solved with the bids of the most senior pilot, and then it is solved with those of the second most senior without decreasing the score of the most senior, and so on. The literature admits that the structure of the problem somehow imposes such an approach. The problem can be modeled as an integer linear lexicographic program. We propose a new efficient method, which relies on column generation for solving its con'tinuous relaxation and returns proven optimality gaps. To design this column genera'tion, we prove that bounded linear lexicographic programs admit "primal-dual" feasible bases, and we show how to compute such bases efficiently. Another contribu'tion on which our method relies is the extension of standard tools for resource-constrained longest path problems to their lexicographic versions. This

is useful in our context because the generation of new columns is modeled as a lexicographic resource-constrained longest path problem. Numerical experiments show that this new method is already able to solve to proven optimality industrial instances provided by Air France, with up to 150 pilots.

3 - Optimizing Maintenance Facility Locations for Regional Airlines: Incorporating Seasonality in Hub Selection
Konstantia Kontodimou, Stavroula Bagioneta, Konstantinos Kepaptsoglou

Airlines streamline maintenance operations and adapt their hub configurations based on operational requirements to enhance efficiency and cost-effectiveness. This study develops an optimization model to design a cost-effective and environmentally sustainable network of maintenance facilities for a Greek regional airline, tailored to its flight routes. The model employs mixed-integer linear programming (MILP) to minimize total costs, including facility construction, operational expenses, environmental penalties, and distance-related costs. Constraints ensure operational feasibility by considering capacity limits, mandatory maintenance frequency, and geographic restrictions. The model prioritizes hubs with high overnight aircraft activity while accounting for regional labor and infrastructure costs. Additionally, it incorporates seasonality, recognizing fluctuations in air traffic due to tourism-driven demand in Greece. By analyzing seasonal operational data, the study explores the feasibility of temporary maintenance hubs activated during peak summer months. Results suggest Athens, Thessaloniki, and Heraklion as optimal year-round maintenance hubs, with select island airports serving as seasonal hubs to enhance network resilience and cost efficiency. This study advances facility location optimization by integrating dynamic demand fluctuations, offering a framework applicable to aviation and other industries with seasonal maintenance needs.

4 - Disruption management in airline luggage handling using local search
Lisanne Heuseveldt, Marjan van den Akker, Ali Poursaeidesfahani, Philip de Bruin

Flight times are influenced by many factors. Examples are weather conditions or congestion at the airport, leading to ATC delays or limited gate availability. Since COVID-19, ground personnel for loading and unloading luggage to and from an aircraft are scarcely available, so we need to deploy them efficiently. Because of this scarcity, the process is highly sensitive to the variation of arrival times. To deal with this, we develop a fast local search algorithm to (re)schedule the allocation of the luggage handlers.

We consider the assignment of luggage handlers to tasks arising from arriving and departing aircraft on the day of operations. We aim to make real-time updates that solve disruptions and are cost-efficient. This problem can be considered as a technician routing and scheduling problem (TRSP), where we consider teaming, skill and time window constraints in a dynamic setting. We have to synchronise multiple tasks corresponding to the same flight, which is a new aspect in regard to TRSP literature. Our algorithm proposes delays or cancellations of flights; these levers are often unexplored from a ground operations perspective.

In the dedicated local search, we focus on conflicts caused by disruptions and solve these using a simulated annealing algorithm. We show that this solves the problem in real-time. We will present computational results from experiments with real-life data provided by KLM Royal Dutch Airlines.

■ TD-58

Tuesday, 14:30-16:00 - Room: Liberty 1.13

Machine Learning and Artificial Intelligence

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Stefan Voigt*

1 - An Enhanced Metaheuristic-Machine Learning Algorithm for Multi-Trip Freight Routing in Portsmouth's Consolidation Center
Mohanad AL-Behadili, Djamila Ouelhadj, Andrew Bullock, Graham Wall, Christopher Bayliss, Graham Fletcher

This study provides the analysis of the potential sustainability impacts (economic, environmental, social) of implementing a freight consolidation centre on the outskirts of the city of Portsmouth. This research is part of the Solent Future Transport Zone project (FTZ) funded by the UK's Department for Transport and led by Solent Transport. To analyse the impact of adopting a freight consolidation centre, the freight distribution is modeled as a Multi-Trip Capacitated Vehicle Routing Problem with Time Constraints (MCVRPT). To solve this problem, we propose an Enhanced Jaya optimisation method, integrating the Greedy Randomised Adaptive Search Procedure (GRASP) with Machine Learning (Jaya-GRASP-ML) to generate high-quality solutions. Machine learning guides the local search in the metaheuristic by adaptively selecting improvement operators based on their past performance to enhance the quality of the solutions. This approach considers practical constraints, such as vehicle capacity and time limitations, to enable multiple trips per vehicle. Furthermore, this study aims to validate the effectiveness of the model and Jaya-GRASP-ML through extensive computational experiments, assessing both the solution quality and the sustainability impacts.

2 - AI and Logistics - A short survey and according recommendations
Dominik Berbig, Christian Dietsche

Everyone has been aware of the existence of AI and its powerful capabilities at least since the publication of OpenAI's ChatGPT. But it is not only since then that AI has been playing an increasingly important role in the economy and therefore also in supply chains. There seems to be a huge number of different tools, each of which is suitable for a specific task within the supply chain. Be it in purchasing, in production or even in crisis management to support quick decisions. There are many proof-of-concepts that show the benefits these tools can bring to their tasks, as well as theoretical considerations in the literature. However, a closer look reveals that these considerations usually only apply to a single purpose or part of the supply chain. The overarching strategy of how, in what order and for which use cases AI tools should be deployed seems to be disregarded. Literature research and a recent survey of German, Austrian and Swiss logistics companies confirm this finding. The question therefore arises: What could a roadmap to AI for logistics look like? What could a general strategy for a sensible and sustainable entry into AI look like, especially for small and medium-sized companies? To this end, we are not only conducting a literature review, but also a survey of different regional companies. In our presentation, we will give deeper insights into our qualitative findings, first recommendations and an outlook on next steps.

3 - Machine learning meets optimization: Edge classification for routing problems
Stefan Voigt, Johannes Gückel, Pirmin Fontaine

Routing problems, such as the Traveling Salesman Problem (TSP) and the Capacitated Vehicle Routing Problem (CVRP), pose significant computational challenges due to their large search spaces. Traditional optimization methods, including exact solvers and (meta)heuristics, often struggle with efficiency as the problem size grows. In this study, we propose a novel machine learning-based approach to classify edges within routing problems, predicting the likelihood of each edge being part of an optimal solution. By using supervised learning techniques, we systematically reduce the search space, enhancing both solver performance and heuristic efficiency. We evaluate multiple machine learning models, analyzing their predictive accuracy and impact on solution quality of solvers and state-of-the-art metaheuristics. Our results demonstrate that incorporating machine learning-based preprocessing significantly improves computational efficiency without compromising solution optimality. Additionally, we provide insights into the key factors influencing edge selection and discuss implications for real-world logistics and transportation applications.

4 - Why Not Use Street Network Data for Visually Attractive Waste Collection Routes?
Byung-In Kim, Seungyeop Lee, Sangil Han

The residential waste collection problem (RWCP) is an arc routing problem where vehicles must service road segments under capacity and operational constraints. Traditional approaches focus on cost minimization, but factors like turn penalties, workload balance, and visual attractiveness (VA) impact feasibility. Street network data (SND) is essential for generating practical, visually appealing solutions, yet it has mainly been used for origin-destination (OD) matrix calculations rather than clustering and routing. This study leverages SND with a graph partitioning algorithm to create visually attractive clusters and integrates VA and turn penalties into an optimization framework. The arc overlapping index (AOI) quantifies resident inconvenience from odor, noise, and frequent truck visits. A multi-objective mixed-integer linear programming model optimizes routing within each cluster. The proposed matheuristic balances operational efficiency with practitioner acceptance. New RWCP benchmark instances, incorporating real-world data, validate the approach. Results show significant VA improvements with minimal cost increase, offering a scalable, practical solution.

■ TD-59

Tuesday, 14:30-16:00 - Room: Liberty 1.14

Innovations for a Greener City and Sustainable Urban Logistics II

Stream: Transportation
Invited session
Chair: *Stefan Spinler*

1 - Sensor placement strategies for dynamic waste collection
Dilay Aktas Dejaegere, Pieter Vansteenwegen

Waste collection is an essential urban service that needs to balance operational costs and service levels. Traditionally, it relies on heavy vehicles operating on fixed routes and frequencies based on historical data. However, waste generation is highly unpredictable due to various factors. This leads to overflowing bins or operational inefficiencies such as underutilized vehicle capacities or more frequent collections than needed. With the smart city technologies, sensor-equipped trash bins can offer real-time waste data to perform dynamic collection planning. To make the most out of this technology, studies on smart waste collection typically assume full sensor coverage, i.e., sensors providing waste volume updates for all bins. However, installing and maintaining sensors require significant investment and the operational benefits of equipping some bins might not justify these costs. In this work, we explore different sensor placement strategies for a dynamic waste collection system, where only a subset of bins has sensors while others rely on predictions from historical data. The dynamic waste collection decides when to visit each bin and in which order, in a rolling horizon principle. We conduct experiments to evaluate the performance of different sensor placement strategies under dynamic waste collection scheme.

2 - A Two-Stage Stochastic Programming Approach for the Dynamic Relocation of Free-floating Shared Cars
Rym M'Hallah, Mehmet Serdar Erdogan

This research addresses a strategic problem of a one-way business to consumer shared car system: optimizing inventory levels and dynamically relocating shared cars to balance demand and supply. It proposes a two-stage stochastic program, under the assumption that cars can be relocated using teleoperation. Next, it adapts the model to account for relocation constraints such as a finite number of staff and their routing using shared vans. Finally, to assess the suitability of strategic solutions at the operational level, this paper proposes a discrete-event simulation that mimics the operation of a one-way car sharing system. It explores the models and simulation on a use case of London to investigate the impact of staff and fleet size on key performance indices and draws useful managerial insights.

3 - An actor-critic model for real-time heavy-duty electric vehicle charge scheduling with flexible pricing at Community Charging Hubs
Alexander Rose, Stefan Spinler

Achieving climate targets for road transport depends on the rapid adoption of heavy-duty battery electric trucks and buses. Ensuring the economic viability of this transition will require cost-competitive Community Charging Hubs, coordinated and shared between commercial neighbors. At these hubs, vehicle arrival times, charging demands, electricity rates and renewable energy potentials are subject to stochastic uncertainties, requiring real-time dynamic algorithms and predictability through reservation options. We extend existing research by applying an actor-critic model to jointly optimize the charging schedule and pricing for each period under uncertainty, considering both reservations and spontaneous charging demands. Our actor decides on charging power and pricing actions through reinforcement learning with proximal policy optimization, thus handling the high-dimensional, continuous action space of trucks, buses and municipal vehicles charging at different charger types. Our critic learns the charging state value function to evaluate and update the actor's policy parameters, also considering dynamic pricing schemes to incentivize user flexibility in charging schedules. We model uncertainties using real-world telemetry data and electricity rates for a charging hub in Switzerland. Our results show a 50 percent reduction in grid load and charging rates compared to first-come, first-served and priority-based charging algorithms.

4 - Cold-Chain Logistics Optimization: A Literature Review on OR Techniques
Yashoda Devi, Pratik Maheshwari

Despite existing studies, several research gaps persist, necessitating an existing literature review of cold-chain logistics optimization. The literature remains fragmented, and only a few studies have comprehensively reviewed cold-chain logistics optimization using operational research (OR) techniques. Henceforth, the researchers need to compile and provide critical debate on OR techniques on various aspects of the cold chain. Therefore, this study applies the PRISMA method for the literature review and examines the literature from various perspectives. It provides integration of advanced technologies, comprehensive cost considerations, sustainability, and environmental impact. This study makes both theoretical and practical contributions. Theoretical contributions include mapping OR techniques to identify trends, classifications, methodologies, and research gaps while synthesizing existing studies and providing a roadmap for future research. Additionally, it offers policy implications for sustainable cold-chain logistics. On the practical side, it provides actionable insights to enhance sustainability and efficiency in cold-chain operations.

■ TD-60

Tuesday, 14:30-16:00 - Room: Western LT

DEA applications in Environment and Sustainability I

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: *Behrouz Arabi*

1 - Optimizing resource reallocation of municipal solid waste incineration during operations shutdown: A CRA-ZSG downsizing model
Ming Cheng Wu, Dong Shang Chang

Municipal Solid Waste Incineration (MSWI) is essential for urban waste management, balancing renewable energy generation and environmental sustainability. However, aging MSWI facilities require periodic maintenance, posing a challenge in equitably reallocating fixed incineration capacity among operational plants. We propose a Centralized Resource Allocation with Zero-Sum Gains (CRA-ZSG) downsizing model, integrating ZSG variables and enhancing the resource reallocation framework with slack-based measurements. This model enables a central decision-maker to optimize overall efficiency and reallocate resources from closed to operational plants. Additionally, we analyze the effects of different ownership structures and the decommissioning of the oldest MSWI plant in Northern Taiwan on cross-regional resource reallocation strategies. Three policy paradigms are compared: capacity-constrained reallocation, fairness-driven reallocation, and self-sufficiency-prioritized reallocation. Each paradigm aims to enhance the overall efficiency of MSWI operations.

2 - Navigating the Green Frontier: A Comparative Analysis of Agri-Food Sustainability between the UK and Europe
Behrouz Arabi, Sonal Choudhary, Mehdi Toloo

Sustainability in agri-food production presents a significant challenge, particularly in balancing economic productivity with environmental stewardship amid climate change, economic volatility, and geopolitical instability. Assessing sustainability requires incorporating multiple input, output, and undesirable output factors into the models. This research introduces a sophisticated weight-restricted Directional Distance Function (DDF) model, designed to integrate undesirable outputs within a Data Envelopment Analysis (DEA) framework to evaluate and compare the sustainability performance of agri-food production systems in the UK and selected European nations. Conventional DEA, including DDF models, often encounter infeasibility issues when incorporating weight restrictions. To address this, we propose a novel methodological approach that integrates an enhanced Analytic Hierarchy Process (eAHP)-derived weights into DDF models, providing a more precise representation of the trade-offs between economic outcomes, resource inputs, and environmental impacts in measuring agri-food sustainability at the national level. Our empirical research spans the years 2010 to 2021 and assesses sustainability performance using a comprehensive dataset that includes key economic, social, and environmental factors. The findings highlight significant variations in sustainability performance across nations.

3 - Hybrid AI Model for Water Quality Prediction Using Satellite and Drone Spectral Data
Hocine Dai, Akli Abbas

Water quality monitoring is a critical environmental challenge, requiring accurate and scalable assessment methods. Traditional in situ measurements are costly and limited in spatial coverage, while remote sensing offers a promising alternative. This study proposes a hybrid AI model that integrates satellite and drone-based hyperspectral/multispectral imagery with in situ physico-chemical water quality parameters (pH, turbidity, COD, conductivity, etc.) to enhance prediction accuracy. The methodology involves data fusion, where spectral reflectance from sensors such as Sentinel-2, Landsat-9, and PRISMA is combined with ground truth measurements from global water quality databases. We apply machine learning (Random Forest, XGBoost) and deep learning (CNN, Transformers) to predict key water quality indicators. Preliminary results demonstrate that super-resolution processing improves spectral data usability, and hybrid models outperform traditional statistical approaches. This work highlights the potential of AI-enhanced remote sensing for real-time, cost-effective water quality assessment, paving the way for automated monitoring systems at large scales.

Keywords: Water Quality Prediction, Hyperspectral Remote Sensing, Machine Learning, Deep Learning, AI, Sentinel-2, PRISMA, Super-Resolution, Data Fusion.

4 - Analysis of environmental variables in the regulatory context of the operational costs of brazilian electricity distributors, based on the 3cptr
Bruno Vilela, Tatielle Menolli Longhini, Marcelo Azevedo Costa

From the third cycle of periodic tariff reviews (3CPTR) onward, the National Electric Energy Agency (NEEA) adopted the Data Envelopment Analysis (DEA) methodology to define the operating costs of electricity distribution companies, segmenting them into manageable and non-manageable items through benchmarking. Despite the consensus that environmental factors influence costs and operational efficiency, the regulatory model does not explicitly consider them. This study analyzes the Technical Notes from Public Hearings 040/2010 and 023/2014, as well as Public Consultation 062/2020, showing that second-stage models incorporating environmental variables exhibit low statistical significance and, in some cases, counterintuitive or overestimated results. The lack of methodological consensus highlights the need for further research on the impact of these variables on distribution companies' efficiency. In the absence of robust evidence, NEEA continues to use confidence intervals to mitigate uncertainties in efficiency estimates.

■ TD-61

Tuesday, 14:30-16:00 - Room: Maurice Keyworth G.31

Behavioural aspects of strategic planning

Stream: Behavioural OR
Invited session
Chair: Martin Kunc

1 - Effects of Generative AI on scenario thinking
Megan Crawford, Nicholas Rowland, Luciana Blaha, Elena Fitkov-Norris

This project focuses on the role of generative AI (GAI) in scenario thinking. Specifically, this investigation is experimentally testing the impacts of GAI use on the various cognitions that comprise "scenario thinking". The purpose is to help inform the growing use of GAI tools in strategy spaces. GAI is projected to continue growing in popularity as a strategy tool for senior executives and management to aid decision-making (Ferrer I Pico et al, 2025; Garvey & Svendensen, 2024). Yet, available data in support of GAI as an "effective" foresight tool remains minimal with mixed results, and largely focuses on the generative properties of the LLM rather than the human cognitive features. Scenario thinking is the primary cognitive effort employed when engaging in scenario planning (Cairns & Wright, 2011). Scenario thinking is informed by experience, knowledge, higher-order cognitions, problem solving, and more (Schacter, et al. 2017). A series of laboratory-based experiments are measuring the known selection of higher-order cognitive markers to scenario thinking, including creativity, causality, probability, episodic future thinking, mental simulation, parallel thinking, counterfactual thinking, and more (see Epstude, 2008; Guilford, 1950; Hastie, 2015; Torrance, 1988). These experimental studies are part of a larger grounded theory investigation

2 - Exploring the concepts of plausibility and believability in the presentation of scenario narratives
Frances O'Brien, Eleanor Reynolds, Maureen Meadows

Scenarios are stories about alternative possible futures which capture key uncertainties. Literature reports plausibility as one of the key criteria in considering what makes a good scenario. This paper explores the development of scenario narratives from the perspective of the developer and the consumer/user to consider the relevance of plausibility. The paper also explores what can be learnt about the development of scenario narratives from other fields such as music, storytelling, visusalisation design and neuroscience.

3 - Scenario thinking as a potential intervention to address cognitive bias in students
John McCarthy, Barry Prendergast

In recent times, there has been a notable increase in what scholars and practitioners have termed "wicked problems." These problems are characterized by exceptional interdependence, unpredictable and chaotic volatility, and contradictions that make them difficult or sometimes seemingly impossible to solve. Because of this, strategic management programs have come under criticism for not providing the correct tools and learning opportunities to equip future managers to address these increasingly complex environmental challenges. Consequently, identifying and overcoming cognitive biases has been recognized as an important aspect of tackling these issues. In this proposed study, we aim to investigate the role of scenario planning training as a potential intervention to address cognitive bias in students. By adopting a quasi-experimental design, the study seeks to target long-standing gaps in the strategic management literature, including increased calls for experimental approaches within the field (Bolinger et al, 2022), a shift in the unit of analysis from firms to individuals (McKiernan, 2017), and a deeper exploration of the mechanisms of cognitive change in scenario planning participants (Frith & Tapinos, 2020). Additionally, it aims to provide interdisciplinary insights by contributing to the fields of prospection in psychology, and problem based learning and authentic assessment in education.

Tuesday, 16:30-17:30

■ TE-01

Tuesday, 16:30-17:30 - Room: Great Hall

Ulrike Leopold-Wildburger

Stream: Plenaries
Plenary session
Chair: *Rita D'Ecclesia*

1 - Some Results from Behavioural Economics
Ulrike Leopold-Wildburger

While methods of OR represent the field of a science for delivering better decisions using optimal or near-optimal solutions to complex decision-making problems our actual behavior in practical applications quite often have to deal with non-fully rational decision makers. We try to make aware the tension between the two scopes and we will support this research by some examples.

Coming from the field of OR we are always aware that techniques such as mathematical modeling, statistical analysis, and mathematical optimization are engaged in applications of advanced analytical methods with the aim to make better decisions. However, in everyday life OR is not executed in its pure version but often connected with other fields and disciplines, as psychology and behavioral sciences, microeconomics and even nowadays integrating neuroscience.

Some characteristic examples from the field of game theory will be prepared and checked with the actual behavior of decision makers in specific economic situations. We will deal with topics as cooperation and fairness as well with dynamic systems and we will try to compare theoretical concepts with empirical data. We will try to understand and explain some specific situations with the help of some experimental studies.

Wednesday, 8:30-10:00

■ WA-01

Wednesday, 8:30-10:00 - Room: Great Hall

Leonidas Sakalauskas

Stream: Keynotes
Keynote session
Chair: Gerhard-Wilhelm Weber

1 - OR behind modeling and simulation of social-behavioral phenomena
Leonidas Sakalauskas

The application of digital models to study social sciences and humanities issues has been undergoing rapid development during the last decades. It is natural to assume that in the current historical time when many delicate socio-political and technogenic challenges have to be dealt, it is essential to resort to OR to overcome them. The paradigm for understanding today's social-behavioral phenomena is created and studied based on digital operationalization, multi-agent modeling, neutrosophy, structural equation modeling (SEM), and reflexive game theory. The "tragedy of the commons" in physical and digital spaces (G. Hardin, 1968, G.M. Greco and L. Floridi, 2004) is taken as a subject for consideration, emphasizing the role of consensus among agents (individuals, users, customers) regarding their collective decision making. The role of cybernetic law of requisite variety and impossibility theorems (including Arrow and Fisher-Lynch-Paterson theorems), is explored in constructing consensus algorithms (V. Gisin, 2023). Conjectures, the solution of which opens the way to solving the challenges of social-behavioral phenomena using evidence-based tools, are formulated and discussed as well.

■ WA-03

Wednesday, 8:30-10:00 - Room: Esther Simpson 1.01

Celebrating 50 Years of EURO (session 1)

Stream: Celebrating 50 Years of EURO
Invited session
Chair: Richard Eglese
Chair: Frits Spieksma

1 - Professor Jean-Pierre Brans about the early days of EURO
Jean-Pierre Brans

This communication includes first how Professor Hans Zimmermann in 1972/73 suggested to establish a European OR association including all the national European OR scientific societies. This initiative has been essential for the birth of EURO. After a meeting devoted to this subject Professor Jean-Pierre Brans proposed to organize the first European conference on OR in Brussels in January 1975. Some amusing souvenirs of this conference will be reminded. It has been a fair success and a promising starting event for the enthusiastic early days of EURO and its brilliant future.

A lecture on Prof. Jean-Pierre Brans will be given by Prof. Cathal MacSwiney Brugha.

Many thanks to him for this important service.

2 - Some special moments of memory
Ulrike Leopold-Wildburger

Starting with the surprisingly actual research by Fibonacci we will demonstrate a great variety of ideas our field Operations Research is still using in growth theory and related topics. As a next step Bernoulli will bring us to probability theory which had been used since then in an astonishing way. And finally we intend to honor John von Neumann with his research as the very start of Operations Research and the basis of modern mathematical economics.

Within our EURO community we are able to cite quite a number of excellent researchers of the 20th century and their work and merits.

3 - Four Presidents and a Secretary: Five UK contributors to EURO
Graham Rand

To contribute to EURO's 50th anniversary celebrations, being held in the UK, this talk will outline the contributions made to EURO by leading members of the Operational Research Society (four Presidents and a Treasurer) as Executive Committee members. Roger Eddison was EURO's founding Secretary, one of a quartet on the first Executive Committee who were so influential in those early years. He has been followed by four UK presidents: Rolfe Tomlinson, Maurice Shutler, Val Belton and Richard Eglese. Time will prevent detailed biographical reflections, though comments will be made about their other OR contributions. Even briefer reference will be made to one Treasurer and three vice-presidents of EURO.

4 - EURO 1995 in Jerusalem Israel
Roman Slowinski, Zilla Sinuany-Stern

EURO 1995 in Jerusalem was an unforgettable conference. We celebrated the 20th anniversary of EURO at that time. Zilla Sinuany-Stern was the Chair of the Organizing Committee, and Roman Słowiński was the Head of the Program Committee. The leading theme of the conference was "OR: Towards Intelligent Decision Support". Plenary sessions were delivered by several leading OR scholars, including Zilla's friend Robert J. Aumann from the Hebrew University in Jerusalem, who later received the Nobel Prize in Economic Sciences in 2005 for his work in game theory. Another notable speaker and Zilla's friend was William W. Cooper, co-author - together with Professors Charnes and Rhodes - of the most cited article in OR journals, on DEA, published in 1978 in EJOR. Among the invited speakers was also Roman's friend, Zdzisław Pawlak from the Polish Academy of Sciences, the founder of rough set theory. Many other well-known and excellent speakers participated in EURO 1995. For the first time in the history of EURO conferences, the Program Committee invited the EURO Working Groups to organize invited sessions and deliver semi-plenary talks through their representatives. Before the conference, we printed a book in Poland featuring 20 plenary and semi-plenary lectures, which was distributed to all participants at the Jerusalem conference. Beyond the outstanding scientific program, the social program was exceptional. We had excursions to Tel Aviv and Jerusalem. The Mayor of Jerusalem hosted us at the David Tower, offering warm greetings. A light and sound show about the history of Jerusalem was also presented. A gala dinner celebrating the 20th anniversary of EURO was held at the Israel Museum in Jerusalem. Just beforehand, the Shrine of the Book was specially opened for us, displaying the famous Dead Sea Scrolls, accompanied by a brief lecture on the exhibits. The Hebrew University hosted the conference at its Givat Ram campus. We worked with the event management company Ortra, Ltd.

■ WA-07

Wednesday, 8:30-10:00 - Room: Clarendon GR.01

Understanding and Measuring Risk: Macroeconomic and Financial Perspectives

Stream: Risk Management in Commodities and Financial Markets
Invited session
Chair: Elena Diaz

1 - Delist or not to delist? A capital access perspective
Lucia Ludovici, Rita D'Ecclesia, Gianluca Vagnani

The voluntary delisting decision has gained attention due to its significant impact on firms' operations, market presence, and shareholder wealth. This study introduces a delisting model based on firms' pledgeable income, which depends on stock liquidity: high liquidity reduce private benefits for managers, making it more advantageous for firms to stay listed. Our central hypothesis posits that firms may opt to delist when they face significant challenges in securing new capital infusions. Building on the framework proposed by Tirole in The Theory of Corporate Finance, we derive two key propositions. The first proposition states that a firm is more likely to delist when the net benefits of remaining publicly traded fall below the utility derived from being privately held. The second proposition highlights the role of stock market liquidity: higher levels of market liquidity enhance the effectiveness of external monitoring, thereby increasing the net benefits of remaining listed and reducing the incentives for voluntary delisting. These theoretical propositions were empirically tested on a sample of 4476 U.S. firms, spanning the period from 1989 to 2023. This paper extends the market monitoring model of Tirole and Holmstrom to delisting. While existing studies focus on the costs and benefits of being listed, this work introduces a firm-level delisting model incorporating market monitoring.

2 - How bad is myopia for a mean-variance investor?
Jinye Du, Zhongfei Li, Moris Strub

The mean-variance framework is widely used in portfolio selection but often overlooks the investment horizon. Current investment practices rely on myopic mean-variance approaches that neglect long-term considerations. Existing algorithms solve single-period mean-variance problems and extend the solution over time. This paper contributes to the existing research by incorporating a time dimension. In this paper, we derive a equilibrium mean-variance strategy under time-varying constrain for terminal wealth and compare the out-of-sample performance of the myopic strategy, dynamic mean-variance strategy and equilibrium mean-variance strategy with three 1/N-type strategies. The preliminary results demonstrate that the dynamic mean-variance strategy outperforms the myopic approach in out-of-sample scenarios. Additionally, we highlight the benefits of optimization in a dynamic context compared to naive diversification.

3 - The Role of Regulation in Accelerating the Full Transition from Fossil Fuels
Ioannis Paraskevopoulos

This paper integrates theoretical modeling with longitudinal empirical analysis to examine how carbon pricing affects energy transition dynamics. We develop a stochastic model that distinguishes between economic stranding points (when fossil assets become unviable) and full transition periods (time to complete infrastructure transformation), deriving closed-form solutions that link these metrics to company characteristics and regulatory parameters. Testing our model's predictions with panel data from nine energy companies observed monthly from 2015-2025 (1,107 observations), we find that a 1 percentage point increase in fossil exposure decreases economic stranding points by 0.186 years (elasticity: -0.84) while widening implementation gaps (elasticity: 1.41). A EUR 10 increase in carbon prices accelerates economic stranding by 0.76 years. Our analysis reveals a policy paradox: stronger carbon pricing effectively signals the need for transition, particularly for carbon-intensive companies, yet implementation gaps have widened rather than narrowed over the decade. This suggests that while carbon pricing creates appropriate economic signals, complementary policies are needed to address the growing implementation challenges faced by companies with high fossil exposure. These findings inform regulatory design by quantifying how different policy levers affect both the economic incentives and practical barriers to energy transition.

4 - Disentangling oil price uncertainty
Elena Diaz, Juncal Cuñado, Fernando Perez de Gracia

This paper examines the macroeconomic impact of oil price uncertainty using a Factor-Augmented Proxy VAR (FPVAR) framework. We construct a dynamic factor model (DFM) to decompose daily implied volatility indexes—VIX, MOVE, and OVX—into a common uncertainty factor and an idiosyncratic oil uncertainty component. The proxy variable for oil uncertainty shocks is derived from the unexpected changes in the idiosyncratic oil uncertainty factor. Monthly macroeconomic data, including U.S. industrial production, inflation, interest rates, and real stock returns, are used to estimate the VAR. Our findings reveal that oil uncertainty shocks have significant effects on economic activity, particularly by lowering output and stock returns while increasing inflation and interest rates. A historical decomposition highlights the contribution of oil uncertainty shocks to past macroeconomic fluctuations. The results provide empirical support for using implied volatility measures to isolate oil uncertainty from price level changes and differentiate it from broader macroeconomic uncertainty.

■ WA-08

Wednesday, 8:30-10:00 - Room: Clarendon SR 2.08

Decision aiding under uncertainty 1

Stream: Multiple Criteria Decision Aiding
Invited session

Chair: Sarah Ben Amor
Chair: *Renata Pelissari*
Chair: *Betania Campello*

1 - Toward Sustainable Aviation: A Multi-Criteria Decision-Making Framework for SAF Pathways Evaluation
Ahmed Bushiha, Mohamed Haouari, Afnan Eliyan

The aviation industry is among the fast-growing sources of global greenhouse gas emissions, primarily due to its dependence on conventional fossil-derived jet fuels. The combustion of these fuels is the primary contributor to aviation-related emissions, making the transition to low-carbon alternatives essential for minimizing environmental consequences. Sustainable Aviation Fuels (SAFs) have presented as a viable alternative, offering the potential to cut emissions while maintaining operational efficiency. However, selecting the most suitable SAF pathway is complex due to trade-offs across environmental, economic, and technical factors. This research develops a customized Multi-Criteria Decision Making (MCDM) framework to objectively evaluate nine certified SAF pathways. The Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) method is utilized using interval data to address uncertainty, with three sets of objective weights (representing optimistic, pessimistic, and average scenarios) generated through the Coefficient of Variation (COV) method to ensure robust results. A group decision-making technique is then used to aggregate the scenario outcomes and determine the final ranking. This study is original in its objective approach, eliminating the subjective biases often found in SAF assessments. Using interval data and multiple weighting scenarios makes the evaluation more accurate and adaptable under uncertainty.

2 - Comprehensive review of SMAA descriptive measures
Sarah Ben Amor, Betania Campello, Renata Pelissari, Bianca Santos Serafim, Yan Xu

Stochastic Multi-criteria Acceptability Analysis (SMAA) is a family of methods that enables decision analysis under uncertainty without requiring precise framework. The SMAA framework includes various descriptive measures that support decision-making in such contexts. This study provides a comprehensive review of these measures by extending previous literature reviews, which covered studies up to 2018, with an updated analysis of newly published research. Our systematic search identified 74 articles published in international journals. Each paper was reviewed to extract new descriptive measures proposed within SMAA-based methodologies. Through this process, we compiled a set of key measures, including among others the traditional ones rank acceptability indices, confidence factors, central weight vectors, and pairwise winning indices. Based on this set, we conducted

a detailed study to examine their theoretical foundations, practical applications, and the challenges involved in their implementation and interpretation. Furthermore, we provide comparative insights into their suitability for different decision-making contexts. By updating the literature and offering a structured classification of SMAA descriptive measures, this work enhances the understanding of SMAA-based methodologies and supports their application in multi-criteria decision-making (MCDM).

3 - An Analysis of the SAPEVO-PC-WASPAS Hybrid Multicriteria Method in the Selection of Virtual Reality Glasses for Applications at the Center for Naval Systems Analysis
Thaís Evelin Santos de Oliveira, Gilson Brito Alves Lima, Marcos Santos, Igor Pinheiro de Araujo Costa, Giovanna Moura, Daniel Pereira, Gabriel Custódio Rangel

The rapid advancement of virtual reality (VR) technology has transformed various industries, especially training and simulation. Selecting the most suitable VR glasses for specific applications is complex due to multiple technical and operational criteria. This study tackles this challenge using a hybrid multi-criteria decision-making (MCDM) approach, combining SAPEVO-PC and WASPAS methodologies to optimize VR glasses selection for the Center for Naval Systems Analysis (CASNAV), a key institution in the Brazilian Navy focused on simulation-based training. The proposed methodology structures decision-making through expert evaluations and multi-criteria analysis, ensuring transparency and consistency while balancing qualitative and quantitative factors. It identifies and prioritizes VR glasses that align with CASNAV's operational needs, considering software compatibility, resolution, field of view, weight, connectivity, and cost. This research holds academic and practical significance. Academically, it advances hybrid MCDM applications in complex decision-making. Practically, it enhances VR-based military training by reducing costs, improving efficiency, and optimizing immersive learning. The proposed approach is adaptable to other strategic environments, reinforcing its broader applicability in selecting advanced technologies.

■ WA-09

Wednesday, 8:30-10:00 - Room: Clarendon SR 2.01

Optimization methods and models for finance

Stream: OR in Finance and Insurance
Invited session
Chair: Paolo Falbo

1 - Stochastic Optimization for Efficient Incentive Policies of Renewable Energy Communities
Alessandra Ruffini, Paolo Falbo, Carlos Ruiz

In our study, we extend the formulation of a bi-level problem to explore the dynamics between a policy maker (upper level) and Renewable Energy Community (REC, lower level). We introduce stochastic optimization, departing from deterministic approaches, and, following the approach of Falbo et al. (2023), we augment the objective functions to incorporate both expected value and Conditional Value at Risk (CVaR). At the upper level, the central authority determines a sharing rule for self-consumption incentive to maximize the REC self-consumption expectation, fostering fair distribution among participants. At the lower level, RECs are modelled with heterogeneous agents, with households installing photovoltaic plants (PV) and biogas producers installing biodigestors and turbines. This choice reflects the prevalence of PV in urban settings and of biogas in agricultural contexts. Households and biogas producers seek to maximize profits within capacity and budget constraints, leading to pure Nash equilibrium. This bi-level problem is implemented in Python using Pyomo. By implementing stochastic optimization, CVaR, and by leveraging scenario simulations through Markov Chain Bootstrapping, we uncover intricate dependencies among variables, shedding new light on REC member interactions. Therefore, our study offers a nuanced understanding of the interplay between policymakers and RECs, providing valuable insights for sustainable energy policy design and implementation.

2 - Optimal Investment and Fair Sharing Rules for Incentives in Virtual Renewable Energy Communities
Paolo Falbo

This paper examines two interconnected challenges in Renewable Energy Communities (REC) optimization: investment in renewable technologies and equitable sharing of incentives, offered (by a central authority) under the Virtual Framework of self-consumption. Focusing on a REC composed of a household and a biogas producer—common in rural and urban contexts—we analyze how investment decisions and incentive-sharing mechanisms impact community profitability. The household invests in photovoltaic panels to reduce energy purchases and monetize surplus generation, while the biogas producer either converts biogas into electricity or sells it on the gas market.

We model this interaction as a leader-follower problem: an administrator (leader) defines the incentive-sharing rule, while an household and a biogas (followers) determine their optimal investments. Modeling the objective of the leader as a Nash bargaining problem and a Nash equilibrium for the followers' static game, we provide insights into optimal REC design and policy implications for fostering sustainable community energy systems.

The model is applied to the case of a REC, under realistic data about the random variables and investment costs. We obtain deep insight of key relevance to address both the organization of a REC, the optimal investment decisions for the members and the incentive policy design for the central authority.

3 - Fear-Driven Pricing of Nuclear Stocks
Kevyn Stefanelli, Roy Cerqueti

Recent breakthroughs in nuclear energy technology have introduced a strong contender in the race to dominate the energy landscape of the coming century. However, public fear of nuclear power remains deeply ingrained, posing a significant barrier to its widespread adoption. In this paper, we price nuclear energy stocks by accounting for their vulnerability to nuclear- related fear, alongside conventional demand and supply fluctuations in energy markets. Unlike standard stock price processes, energy prices exhibit stochastic jumps, requiring specialized modeling techniques. Nuclear energy adds further complexity due to catastrophic risk and widespread regulatory and public apprehension regarding its adoption. To capture these dynamics, we propose a pricing model that incorporates a Doubly Stochastic Poisson Process (DSPP) to account for stochastic jumps, where the intensity itself follows a random process. The stochastic parameter is estimated using sentiment analysis, which tracks the evolution of nuclear fear over time. Our findings provide insights into how geographical and regulatory differences among companies drive variations in the impact of nuclear fear on asset prices, offering a novel perspective on the valuation of nuclear energy investments.

■ WA-10

Wednesday, 8:30-10:00 - Room: Clarendon SR 1.06

Pairwise comparisons and preference relations 2

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Jiri Mazurek
Chair: *Konrad Kułakowski*
Chair: *Matteo Brunelli*

1 - On the extension of the notion of transitive closure in preference graphs
Alexis Tsoukias, Meltem Ozturk

In this talk we present an extension of the notion of transitive closure (and negative transitive closure) on graphs aiming at representing preference statements under form of binary relations. For this purpose we use signed graphs (positively and negatively). On the one hand we obtain an extended model for adding or eliminating positive and negative reasons for or against a preference statement and the other hand we show how this can be used for the design of decision support procedures.

2 - A geometric characterization of Pareto optimal weight vectors for 4x4 pairwise comparison matrices
Kristóf Ábele-Nagy, Sándor Bozóki, Zsombor Szádoczki

Pairwise comparison matrices, as Saaty proposed them half a century ago, have become a central concept in preference modelling and decision support. A weight vector is called Pareto optimal (efficient) if no other weight vector exists such that the ratios of its coordinates are at least as close to the matrix elements, and at least one of them is strictly closer. Despite the natural and simple definition, the geometric characterization of Pareto optimal weight vectors has just begun. We show that, if there is no consistent triad, then the set of normalized, Pareto optimal weight vectors is the union of three tetrahedra, the vertices of which correspond to weight vectors calculated from special spanning trees, 4-paths. Each tetrahedron is associated to a Hamiltonian cycle. If there are consistent triad(s) in the matrix, some tetrahedra collapse to smaller dimensions. If the matrix itself is consistent, all the three tetrahedra collapse to a single point.

3 - Tensor Basis for Pairwise Comparisons
Konrad Kułakowski, Ryszard Smarzewski

In the presented study, we construct the first orthogonal basis for the space of additively consistent matrices in the context of pairwise comparisons. This achievement resolves a long-standing problem concerning the logarithmic least-squares method by Koczkodaj and Orłowski (1997). Our approach relies on a tensor-based representation of the best additively consistent approximations of skew-symmetric matrices. The proposed orthogonal basis enables a novel logarithmic consistent projection and provides a new perspective on the orthogonal windowing of pairwise comparison matrices. We compare our approach with the established windowing methods of Saaty and singular value decomposition (SVD), deriving new composite formulae for logarithmic, Saaty, and SVD projections. These results are supported by theoretical analysis and numerical examples. Furthermore, we discuss the implications of different matrix norms in approximation quality and propose directions for future research on weighted inner products and alternative consistency measures in pairwise comparisons.

4 - Using pairwise comparisons to estimate basic probability assignments in evidence theory
Matteo Brunelli

We consider the problem related to the elicitation of basic probability assignments within the Dempster-Shafer evidence theory. So far, most of the methods for their estimation is data-driven, and very few proposals have been presented to capture subjective beliefs. We proposes an approach based on pairwise comparisons. The approach is based on the well-established body of knowledge on thetheory of pairwise comparisons and shows its flexibility as it can incorporate multiple representations for the subjective judgments and multiple experts, just to cite two possible extensions. Moreover, this application of pairwise comparisons has the potential to trigger new theoretical developments.

■ WA-11

Wednesday, 8:30-10:00 - Room: Clarendon SR 1.03

Resource and treatment planning

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: Vera Tilson

1 - Data-driven Stochastic Optimization for Mental Health Crisis Call Center Scheduling
Shenghan Xu, Alireza Boloori

Efficient scheduling and capacity planning are essential for mental health crisis call centers to handle the rising demand for timely and effective support. This study addresses resource allocation challenges by introducing a two-stage stochastic programming model to optimize operator assignments. It aims to bridge the gap between fluctuating demand and the need for consistent service quality, focusing on mental health crisis intervention where accessibility and responsiveness are crucial. The study explores balancing operational efficiency with high service levels under uncertainty in call arrival rates and diverse patient needs. The proposed model incorporates real-world demand data, simulating various scenarios to capture call volume and service time uncertainties. A 90% call answer rate is a benchmark to ensure accessibility and customer satisfaction while integrating cost considerations to align with organizational goals. Through comprehensive data analysis and scenario testing, results show that stochastic programming enables effective resource allocation despite fluctuating demand. Key contributions include a robust decision-support framework for scheduling under uncertainty while maintaining efficiency.

2 - Distributionally Robust Chance Constraints for VMAT Treatment Planning
Houra Mahmoudzadeh, Stoyan Hristov, Johnson Darko, Ernest Osei

Radiation therapy (RT) seeks to irradiate a cancerous tumour while minimizing damage to the nearby organs at risk (OARs). Throughout a treatment session, a patient's geometry might change unpredictably, which can degrade the treatment quality. Volumetric Modulated Arc Therapy (VMAT) is a modern form of RT in which the beam follows a path around the patient while continuously delivering radiation. Despite better OAR sparing and shorter treatment times, VMAT planning results in a large-scale nonlinear mixed integer program (NLMIP) that becomes even more complex when geometric uncertainty is incorporated. We propose a distributionally robust chance constraints VMAT model and a heuristic solution scheme that outputs near-optimal treatment plans which are robust to uncertainty in tumour position. Finally, we compare the robustness of nominal, robust, and distributionally robust plans and discuss tradeoffs.

3 - Addressing the Surge in Medical Residency Applications: Policies for Effective Interview Allocation
Vera Tilson, Abraham Seidmann, Edieal Pinker

Medical residency programs are experiencing a significant surge in applications due to increased competition in the medical profession and advancements in technology that facilitate broad application submission. This growing trend creates logistical challenges for programs in selecting candidates from large pools. A key issue is "crowding," where highly competitive candidates receive multiple interview offers, leaving others overlooked and contributing to mismatches and unfilled residency slots. The challenge of managing these increasing application volumes highlights the need for effective strategies to allocate limited interview opportunities and ensure alignment between programs and suitable candidates. This research examines policies to optimize interview allocation, aiming to improve efficiency and match quality in the residency selection process.

4 - Efficient algorithms for online scheduling of patients in an ophthalmology clinic
Vahid Akbari, Sanja Petrovic

Effective patient scheduling in healthcare facilities is a complex task, particularly in environments where patients require multiple-stage medical tests before consulting with their assigned physicians. This study introduces an approach for online patient scheduling by integrating lexicographic multi-objective optimization with heuristic and stochastic techniques. We first develop an offline scheduling model, that maximizes the number of scheduled patients and subsequently minimizes their waiting times. This model is then adapted for online optimization to handle sequential patient arrivals. Additionally, we propose an online stochastic optimization algorithm, incorporating a novel scenario-generation method that anticipates future patient requests based on historical data. To further enhance computational efficiency, we introduce a stochastic heuristic algorithm, which provides high-quality solutions in a fraction of the time required by exact optimization methods. Extensive computational experiments using real-world data from an ophthalmologic clinic demonstrate that the proposed online stochastic scheduling approach reduces patient waiting times while maintaining high resource utilization. Moreover, our findings offer actionable insights for healthcare administrators, particularly in optimizing resource allocation to improve system resilience against increasing patient demand. The developed stochastic heuristic is efficient and can be readily implemented in the clinic.

■ WA-12

Wednesday, 8:30-10:00 - Room: Clarendon SR 1.02

Batch scheduling

Stream: Scheduling and Project Management
Invited session
Chair: Emmanuelle Amann

1 - Volume balancing in the mail sorting process at a French postal company
Emmanuelle Amann, Evgeny Gurevsky, Arnaud Laurent

Since the end of the 20th century, traditional postal operators have faced dual challenges: a sharp decline in mail volumes and an increased number of distribution points. In France, La Poste has to adapt its organization to remain at the cutting edge of customer service. Industrial platforms are the central core of mail delivery, where mails are arranged by routes using sorting machines in the order of their dispatching, to facilitate their distribution by mail carriers. Because of declining mail traffic, sorting machines are underutilized, and outdated sorting procedures are no longer efficient. The issue is to optimize mail processing while maintaining traditional obligations. Route preparation requires a sorting process in two steps. With the current variability of postal traffic, the historical view based on the day of the week may lead to an imbalance in the volume of mail at the outputs of the sorting machine. Obtaining a smooth distribution of the volume in the sorting machine outputs would be of significant interest to improve operation's handling and prevent technical issues. This challenge can be viewed as a variant of the SALBP: allocate a set of mails to containers, while optimizing a smoothness criterion and respecting various industrial constraints. We propose a MILP model and a heuristic approach, to handle academic and industrial instances. The heuristic was implemented at La Poste and has since been used daily by industrial mail platforms in France.

2 - An Optimization Model and Approximate Dynamic Programming Algorithms for a Wafer-Lot Scheduling Problem in Parallel Multi-Chamber Equipment
Sungwon Hong, Younsoo Lee, Kyungsik Lee

In this talk, we address the wafer-lot scheduling problem (WLSP) for parallel multi-chamber equipment in semiconductor wafer fabrication lines. The equipment can process multiple wafers simultaneously, with each chamber handling one wafer at a time. Each wafer lot requires a specific process step, with target production quantities assigned for each step. The goal of the WLSP is to maximize the fulfillment of these target quantities within the planning horizon while adhering to operational constraints. We present a mixed-integer programming model based on a two-level tour structure along with valid inequalities to strengthen the linear programming relaxation bounds of the model. In addition, we propose approximate dynamic programming algorithms that incorporate several upper and lower bounding methods. Computational results show that the proposed algorithms can provide high-quality solutions within a short time for practically sized instances.

3 - Batch scheduling problems using interval and set decision variables with Hexaly
Agathe L'hermite, Léa Blaise

Hexaly is a "model and run" mathematical optimization solver based on various exact and heuristic methods. In this talk, we will focus on how its modelling formalism can be used to express batch scheduling problems using interval and set decision variables. Batch scheduling problems are scheduling problems where tasks can be grouped into batches and made synchronously. These models are very intuitive and compact, thanks to high-level decision variables and set-based operators. A set variable represents a subset of tasks using their indices, representing a batch's content. Interval variables will represent the position in time of the batches. The algorithms implemented within the solver take advantage of these compact formulations based on interval and set decision variables. For example, the solver's local search component comprises various local neighborhoods working on set decision variables. We adapted these existing moves to batch scheduling problems by making them efficiently work on the interval variables as well: whenever the value of a set variable is changed, the value of the interval variable corresponding to the same batch is changed accordingly. These algorithms, as well as other methods implemented, enable Hexaly to achieve very good performances on batch scheduling problems: an average of 4.5% in one minute with up to 100.000 tasks.

4 - Just-in-Time Batch Scheduling Subject to Batch Size
Sergey Polyakovskiy, Rym M'Hallah

This paper considers single-machine just-in-time scheduling of jobs that may be grouped into batches subject to a constraint on batches' weights. A job has a weight, due date, and earliness and tardiness penalties per unit time. A batch's processing time is determined by its jobs. Each job inherits its batch's completion time. The objective is to minimize the weighted sum of earliness and tardiness penalties of all jobs. This problem is challenging: Jobs-to-batch assignment changes the batch's processing time; thus, affects the structure of the entire solution and most importantly of its cost components. To obtain tight dual bounds, we propose a Lagrangian relaxation approach that drops the constraint enforcing the use of each job exactly once and reformulates the problem as the shortest path problem to build a dual solution. To find exact solutions, we incorporate Lagrangian relaxation into a branch-and-bound approach to strengthen relaxation in each node of the search tree. We complement our research with the analysis of computational experiments that evaluate the tightness of our primal and dual bounds.

■ WA-15

Wednesday, 8:30-10:00 - Room: Esther Simpson 1.08

Discrete, continuous or stochastic optimization and control in networks, transportation and design 1

Stream: Combinatorial Optimization
Invited session
Chair: Gerhard-Wilhelm Weber
Chair: Bruno Kamdem

1 - The rescheduling school bus routing problem under a constraint on the number of students with negative impact
Thu Huong Dang, Quy Ta Dinh, Hoang Ha Minh, Tien Mai, Duc Minh Vu

This study presents a case study of the School Bus Routing Problem (SBRP), focusing on improving the quality of student transportation services. Although numerous studies have addressed the SBRP, this study tackles a new variant driven by a negative impact policy to limit the number of continuing students facing extended travel times. We present this variant and propose a mathematical formulation along with a hybrid metaheuristic approach for it. Furthermore, we conduct comprehensive experiments to evaluate algorithms' performance and various configurations of the negative impact policy on both artificial and real instances. Computational results confirm the effectiveness of our hybrid algorithm.

2 - The Attractor-Based Search Algorithm for Probabilistic Traveling Salesman Problem (PTSP)
Weiqi Li

PTSP is one of the most significant stochastic networks. In PTSP, the number of cities is treated as a random variable. We wish to find an a priori tour through all cities with minimum expected cost. Designing effective and efficient algorithms for solving PTSP is challenging, since the computational complexity associated with the TSP is exacerbated by the stochastic element in data. People usually use two types of techniques for PTSP: analytical computation and empirical estimation. The analytical approach computes the cost of an a priori tour using a closed-form expression. Empirical estimation estimates the cost through Monte Carlo simulation. Our presentation introduces the attractor-based search algorithm (ABSA) to solve the PTSP, which combines local search and exhaustive search to find the best a priori tour. In the local search, all search trajectories converge to a small set of suboptimal points, called attractor. The attractor is exponentially smaller than the solution space and thus makes exhaustive search feasible. ABSA first uses a simple multi-start local search to find a set of locally optimal a priori tours through Monte Carlo simulation, and stores their edge configurations in the edge matrix - a data structure for tracking the search trajectories and for reducing the computational complexity of the search space. Then ABSA uses an exhausted search process to find the globally optimal a priori tour in the attractor again through Monte Carlo simulation.

3 - Simultaneous Production and Transportation Problem with Drone and Back Delivery Strategy
Junyan Zhang, Kan Fang

The Simultaneous Production and Transportation Problem (SPTP) in Additive Manufacturing (AM) has gained significant attention for its potential to reduce customer delivery lead times and inventory holding costs. This study extends the SPTP by incorporating a truck-drone delivery system and introducing the back delivery strategy, where the drone can operate deliveries to truck-visited customers. This strategy allows truck to depart before production is completed, with drone finalizing remaining deliveries, thereby reducing the idle time caused by time inconsistency between production and transportation. The objective is to minimize the trip time. To address this problem, we formulate the problem as a MILP model and develop a Branch-and-Bound-based ALNS algorithm. Computational experiments validate the effectiveness of the proposed model and solution approach, demonstrating the benefits of integrating drone and back-delivery strategy into SPTP.

4 - Strategic Crew Pairing in Long-Haul Airline Operations
Mohamed Ben Ahmed, Henning Lied Gullbekk, Trym Wian, Magnus Stålhane

The Crew Pairing Problem (CPP) is an important problem in airline scheduling, where long-haul operations introduce unique complexities. While the goal remains to assign crew to flights at minimal cost while ensuring regulatory compliance, long-haul scheduling must also account for extended duty periods, multiple crew bases, layovers, deadheading, and additional crew regulations, which significantly impact cost and feasibility. This study introduces two network flow models to optimize crew pairing for a transatlantic, low-cost airline. The first model assumes unlimited crew, minimizing pairing costs such as layovers, deadheading, and time away from base. The second introduces limited crew, formulated as a bi-objective optimization problem that balances cost minimization with the number of required crew members. Unlike conventional set-partitioning formulations, our formulations explicitly model deadheading and crew requirements. Both models are non-linear in their initial representation but were transformed into equivalent linear models. Computational experiments on real-world airline data show that both models can efficiently determine crew paring for flight schedules up to 2,000 flights and 7-month planning horizon. The models' results provide insights into crew base allocation strategies, robust scheduling strategies, and cost trade-offs, offering a scalable, exact, and computationally efficient framework for strategic crew planning in long-haul airline operations.

■ WA-16

Wednesday, 8:30-10:00 - Room: Esther Simpson 2.07

Agriculture SCM Optimization

Stream: Sustainable Food & Agroforestry
Invited session
Chair: *Victor M. Albornoz*

1 - Optimizing Agri-food Supply Chain Configuration for Mitigating both Supply- and Demand-Side Risks
Haitao Li

An agri-food supply chain is susceptible to various supply risks due to climate change, natural disasters, pandemic disruptions, and geopolitical conflicts, which directly impact how supply chain functions are operated and the system-wide supply chain cost. We develop a new modeling framework to address the tactical-level food supply chain configuration problem with both supply- and demand-side risks, called FSCCP-SDR, which optimizes the selection of modes with tradeoffs in cost, lead time, loss rate, quality deterioration and lead time variation, and the inventory positioning, to maximize the system-wide total net profit of supply chain . To handle large-size instances of FSCCP-SDR and obtain quality solutions efficiently, we devise a hybrid PSO-GA algorithm that integrates particle swarm optimization (PSO) and genetic algorithm (GA). Our model and algorithms are applied for a case study at a grape processor in China, provide near optimal solutions in reasonable computational time. A comprehensive computational experiment is performed to obtain additional insights on the impacts of demand and supply variations and shelf time and food loss rate on the optimal food supply chain configuration.

2 - From grapes to market: a systematic review of optimization model applications for supporting decision making in the wine industry
Franco Basso

Due to growing operational complexities, increasing competition in the international markets, and rising sustainability concerns, the wine industry faces unique and growing challenges across its supply chain, from grape cultivation to distribution. Despite its potential economic impact, the knowledge of applying optimization models in this field remains fragmented. To address this gap, we conduct a systematic review following PRISMA guidelines that examines 33 articles from 1970-2023. Results show increased research interest since 2014, peaking between 2019-2023, with most studies focusing on cultivation and production, while commercialization and distribution remain underexplored. Identified research gaps include the need for integrated models, probabilistic approaches to uncertainty, and sustainability-driven strategies like circular economy principles. Proposals include resource optimization, strategic planning for technology adoption, and capacity expansion. These advancements aim to enhance resilience, efficiency, and sustainability in the wine supply chain, addressing global market dynamics and environmental challenges.

3 - Modeling a fresh fruit harvesting and distribution problem in resilient agrifood supply chains
Victor M. Albornoz, Alejandro Contreras-Roa

The contribution addresses an integrated modeling approach to support decision-making in a three-echelon agribusiness supply chain to harvest, process and distribute fresh fruits to different markets under disruptive scenarios. The harvest problem includes a delineation of the field into management zones and a harvest scheduling based on optimal harvest time windows for each management zone depending on the quality of the fruit. The processing problem consists of extending the shelf-life of the fruit, a process widely used in the fruit export sector to delay the oxidation of fruits and vegetables. The distribution problem includes possible disruptions in ports and transportation, which is critically important for fresh products. The proposed methodology considers a mixed-integer two-stage stochastic optimization model with the goal of making a resilient planning framework for fresh fruit supply chains. Moreover, the risk-neutral model is extended applying a quantitative risk management formulation based on the use of the Conditional Value-at-Risk (C-VaR) measure. The results obtained when solving a set of instances highlight the importance of the problem and the proposed methodology.

4 - Coordinating Agricultural Trade and Production Policies: A Game-Theoretic Approach to Global Supply Chain Stability
Shivam Sharma, Sobhan Asian, B Vipin, Raghu Sengupta

Host governments face significant challenges in optimizing agricultural domestic support schemes and foreign trade policies to effectively meet rising consumer demand. This research analyzes the alignment of production support and trade policies to minimize market distortions and stabilize supply chains. Taking a global agricultural supply chain management perspective, we propose a framework to address geopolitical uncertainties and policy ambiguities, aiming to reduce uncertainty for exporting and importing countries while fostering a resilient and equitable global agricultural market.

Drawing on real-world practices and empirical evidence from Indian domestic and foreign agricultural policymaking, this study develops a game-theoretical optimization model to analyze domestic production and import volumes across various policy scenarios. It identifies optimal policy combinations to enhance farmer welfare, minimize market distortions, and stabilize supply chains. This research contributes to academic discourse by examining the impact of product-based policies on supply chain dynamics.

The model aids policymakers in designing stable policies that optimize social welfare, meet consumer demand affordably, and enhance stakeholder profitability while reducing trade uncertainty. Producers and importers can leverage these findings to assess profitability under specific trade policies.

■ WA-17

Wednesday, 8:30-10:00 - Room: Esther Simpson 2.08

Combinatorial optimization in distribution and delivery operations

Stream: Combinatorial Optimization
Invited session
Chair: Claudia Archetti

1 - Combining vehicle routing with transportation on a ring in city logistics: a branch-and-price approach
Laurent Alfandari, Paolo Gianessi

In the Multi-commodity Ring Vehicle Routing Problem (MRVRP), goods are collected from virtual gates outside the city, then transit through one or several depots called Urban Distribution Centers before being delivered to customers in either open or closed delivery routes. The reverse pick-up trip from customers to gates via UDCs is also considered. The UDCs are located around the city and connected by a ring using transportation modes with low per-unit emission costs, such as high-capacity trucks or railway shuttles. Such a ring system circulation, together with a fleet of electric vans to perform the routing inside the city, matches increasing urban traffic restrictions that prevent large trucks from getting into the city center. The City Logistics problem that is the closest to the MRVRP is the Two-Echelon Vehicle Routing Problem, but has different features and no ring structure. We consider repositionning constraints at UDCs and design an efficient Branch-and-Price algorithm to solve the problem. The decompositon assigns the routing part to the pricing subproblem. This pricing problem is an elementary shortest path problem with resource constraints solved with Dynamic Programming, accelerated with q-routes and ng-paths. The numerical results show the performance of the method and an extensive sensitivity analysis is carried out on key problem parameters.

2 - Taxi re-positioning considering uncertain driver compliance
Cebrina Lindstrøm, Stefan Ropke

Managing taxi fleets in large cities is challenging, especially when drivers operate independently. This study improves taxi repositioning by predicting demand and providing smart recommendations. Using real-world data from a Scandinavian taxi service, we employ neural networks with LSTM layers to forecast demand and test different strategies, like a simple greedy algorithm and a more structured matching-based approach, to guide taxis to high-demand areas. Since drivers ultimately decide whether to follow these suggestions, we also model their behavior using a probabilistic acceptance strategy. Through a simulation of a real day, we analyze how different approaches impact passenger wait times and overall efficiency. The results show that proactive re-positioning significantly reduces wait times but can increase total driving distance. The greedy algorithm tends to perform better in quickly getting taxis to passengers, while the matching model is more efficient in minimizing unnecessary travel. However, increased mobility comes at a cost, as rerouting leads to longer driving distances. Additionally, driver behavior plays a crucial role, with lower acceptance rates reducing the effectiveness of predictive recommendations. Overestimating demand in such cases helps mitigate inefficiencies.

3 - Large Neighborhood and Hybrid Genetic Search for Inventory Routing Problems
Claudia Archetti, Jingyi Zhao, Tuan Anh Pham, Thibaut Vidal

The inventory routing problem (IRP) focuses on jointly optimizing inventory and distribution operations from a supplier to retailers over multiple days. Compared to other problems from the vehicle routing family, the interrelations between inventory and routing decisions render IRP optimization more challenging and call for advanced solution techniques. A few studies have focused on developing large neighborhood search approaches for this class of problems, but this remains a research area with vast possibilities due to the challenges related to the integration of inventory and routing decisions. In this study, we advance this research area by developing a new large neighborhood search operator tailored for the IRP. Specifically, the operator optimally removes and reinserts all visits to a specific retailer while minimizing routing and inventory costs. We propose an efficient tailored dynamic programming algorithm that exploits preprocessing and acceleration strategies. The operator is used to build an effective local search routine, and included in a state-of-the-art routing algorithm, i.e., Hybrid Genetic Search (HGS). Through extensive computational experiments, we demonstrate that the resulting heuristic algorithm leads to solutions of unmatched quality up to this date, especially on large-scale benchmark instances.

■ WA-18

Wednesday, 8:30-10:00 - Room: Esther Simpson 2.09

OR Education 1

Stream: OR Education
Invited session
Chair: Nina Kajiji

1 - Applying the Technique of O.R. to School Management
Olabode Adewoye

Education covers a range of sectors, including kindergarten, primary, secondary, and higher institutions. Each of the above sectors is plagued with the daily running of the schools, scheduling of lessons and assignments of teachers to classes, logistics of getting pupils to schools, allocation of resources, examination time tables, maintenance, replacement, staff welfare and management, security, result management, etc. The objective of Operations Research (O.R). in school management is to optimize the effectiveness and efficiency of the school management system. The first problem the work addressed is whether the above-listed problem should be solved as a whole (System Approach) or by applying a pragmatic approach to problem solving. Secondly, diverse problems faced by the management of schools and consumers of education are surveyed and a proposal on how OR techniques can be applied in an effort to improve these operations is provided.

2 - Application of System Dynamics Modelling and Simulation for Promoting Sustainable Development and Access to Education in Rural Tanzania
R. M. Kazakov, Genuine Mwasha, Yavora Rosenova, Penka Petrova

The Roof of Africa Project utilizes system dynamics modelling and scenario simulation to evaluate and refine its interventions. This approach provides a robust framework for understanding and addressing complex, interconnected challenges. Through system dynamics modelling, policymakers can visualize how interventions such as financial incentives, infrastructure development, and societal attitude shifts impact outcomes like school enrolment and community well-being over time. Baseline and intervention scenarios enable policymakers to compare the effectiveness of various initiatives, identifying those with the most significant and sustainable benefits. The modelling process captures feedback loops, such as the relationship between increased primary school enrolment and community support or how improved attitudes toward education reinforce student participation. These insights help optimize policy design. Scenario simulations provide a long term forecast of intervention outcomes, offering critical insights into timing, sustainability, and resource allocation to achieve long-term developmental goals. Adjustable parameters in the simulation model allow for sensitivity testing, identifying leverage points that maximize impact with minimal resources. Scenario simulation results are visually and quantitatively communicated, fostering collaboration among government agencies, NGOs, and local communities to align goals and resources.

3 - A New Perspective on the Human-Machine Interface Design: Transformative Personalized Learning Efficiency in AI-Powered Active Learning Settings
Nina Kajiji, Gordon Dash

This study explores the human-machine interface (HMI) as a transformative mechanism that impacts the use of AI and OR in education. HMI methods crafted in the age of generative AI can leverage personalized and adaptive learning systems, add to efficient classroom management, and support ethical principles. The HMI framework described in this study utilizes WinORS (Winidows Operational Research Software), a computational tool integrating AI and Operations Research, to enhance pedagogy across diverse disciplines. Two case studies are featured, one in computational finance and another in neuroethics. The finance case study demonstrates WinORS' capabilities, such as integrating a multi-target neural network and multiple-objective goal programming to optimize complex investment portfolios. The neuroscience case study details how a neural network mapping of the rodent brain is used to formulate a multiple-goal OR assignment model to seek efficient prosocial outcomes in an urban housing application. The WinORS support for experiential lab solutions and branded digital credentials demonstrates its scalable framework for integrating a unique human-machine interface to effectively incorporate AI and Operations Research principles into modern classroom pedagogy.

4 - Decision and Risk Analysis for public policy problems
Gilberto Montibeller

Public policy problems are rife with conflicting objectives, uncertainties, and multiple stakeholders and societal demands. Decision and Risk Analysis provide robust methodologies to support policymakers in making tough choices and in designing better policy options when considering these challenges. In this presentation, I discuss how these methods can be used in practice to support high-quality public decision-making. I illustrate these guidelines with decision consulting projects that we have conducted over the last two decades for several organizations, such as the World Health Organization, the Food and Agriculture Organization of the United Nations, the UK Department of Environment Food and Rural Affairs, the Malaria Consortium/USAID, the UK Department of Health, among others.

■ WA-20

Wednesday, 8:30-10:00 - Room: Esther Simpson 2.11

Topics in Combinatorial Optimization 3

Stream: Combinatorial Optimization
Invited session
Chair: Jésica de Armas

1 - Heuristics for solving Reentrant Permutation Flow Shop Problems
Itamar Segal, Tal Grinshpoun, Elad Shufan, Hagai Ilani

In a permutation flow shop (PFS), jobs are serially processed on a set of machines, with the same machine order for all jobs (flow shop) and the same job order on each machine (permutation). While the meaning of "permutation" is clear for flow shop, it is ambiguous for a reentrant flow shop (RFS). In RFS, jobs may revisit some machines, leading to multiple interpretations of permutation; different researchers have interpreted the term under varying assumptions. To clarify this inconsistency, we defined four permutation types for a reentrant permutation flow shop (RPFS) with a cyclic pattern. Building on this foundation, we investigate the impact of the four types on both optimization and heuristic performance, focusing on the makespan objective. We first show that the best possible solution can be achieved under each of the four types. We then conduct a statistical evaluation of solution quality on small-scale problem instances. In addition, we extend several well-known PFS heuristics, including NEH, to all four permutation definitions. We conduct computational experiments to evaluate the effectiveness of these heuristics. A direct extension of known heuristics to RPFS results in poor solutions for two permutation types that allow level passing. We propose methods to address this, such as restricting level passing. Beyond their immediate significance, these findings provide insights for developing metaheuristics specifically designed for RPFS problems.

2 - A Metaheuristic to the Twin Rural Postman Problem: Asynchronous case
Marcos José Negreiros, Augusto Wagner Palhano, Nelson Maculan, Claudio B. Cunha

This work proposes a metaheuristic procedure based on GRASP for a new multi-objective problem recently proposed to the arc routing related problems to waste collection, the twin rural postman problem. The twin rural postman problem is a problem where a strongly connected mixed network (i.e. street network) must be covered by two servers, a vehicle and a human. The vehicle departs from a garage and ends its route at a disposal site, while the human starts and ends

its route in any of its required link. The vehicle may not pass by any required link covered by the human, and the human may traverse his assigned required links in such a way that the service (garbage collected) must be disposed in the corners where the vehicle may pass. The work of both servers must be done in such a way that the service is completed by the human before the vehicle passes by one of any corners. When the time the human starts and ends his route is significantly ahead of the vehicle's time, or the constraint of service does not matter, it is called the asynchronous twin mode. The GRASP metaheuristic here proposed considers a previously well succeeded greedy strategy from maximum cover tour problem. We report its results in comparison to a column generation and semi-automatic route design procedures evaluated and implemented in the domiciliary waste collection of Andradina/SP.

3 - Optimizing Caregiver Allocation and Island-Based Distribution in Home Care Services with Changing Demand
Jésica de Armas, *Ana Raquel Pena de Aguiar*

In the field of home care, a pioneering strategy involves partitioning a city into subareas, usually termed islands, to heighten the quality and personalization of cares. Each island is entrusted with a dedicated team of home care services.

The challenge lies in determining the optimal number of caregivers and working schedule (full or part time), considering variable demand for home services across islands and over the planning horizon. We propose a dual caregiver approach for Barcelona home care services: exclusive island caregivers and caregivers with flexibility to work in multiple islands. The latter must be as small as possible, and allows to cushion the variability in demand. Service managers operate within personnel hiring budget, which may lead to unmet demand hours. The primary objective is to optimize caregiver hiring within budget constraints, minimizing unmet service hours. This poses a strategic problem, compounded by potential benefits of merging islands for improved planning.

We present a Mixed-Integer Linear Programming model determining exclusive and floating team size and composition, along with necessary island mergers. This enables fulfilling maximum demand while maintaining fixed team stability. Our model facilitates valuable analyses, exploring factors such as maximum team size impact, budget impact, potential of merging islands or team stability in planning horizons with different kind of scenarios with variable demand.

4 - Job shop scheduling problem with a dual-gripper robot
Wei Wang, *Zhaofang Mao*

Robots are increasingly being deployed as integral material-handling components within automated manufacturing systems. In this paper, we address the scheduling problem in a bufferless job shop environment. The system processes multiple job types, all served by a dual-gripper robot. The dual-gripper robot is capable of holding two jobs simultaneously but can load or unload only one job at a time. We also consider the time required for the robot to switch grippers. The objective is to determine both the robot's transport sequence and the job processing sequence to minimize the makespan. We formulate a mixed-integer linear programming (MILP) model that minimizes the makespan. Due to the complexity of the problem, we develop an improved simulated annealing algorithm (ISA). Extensive computational experiments are conducted to evaluate the performance of both the MILP and ISA, and the results confirm the superiority of the ISA compared to the MILP and other heuristic algorithms.

■ WA-21

Wednesday, 8:30-10:00 - Room: Esther Simpson 2.12

Metaheuristics for Scheduling and Production

Stream: Metaheuristics
Invited session
Chair: *Camil Zarrouk*

1 - Single-machine scheduling with fixed energy recharging times to minimize the number of late jobs and the number of just-in-time jobs: a parameterized complexity analysis
Renjie Yu, *Daniel Oron*

We study single-machine scheduling problems where processing each job requires both processing time and rechargeable energy. Subject to a predefined energy capacity, energy can be recharged after each job during a fixed recharging period. Our focus is on two due date-related scheduling criteria: minimizing the number of late jobs and maximizing the weighted number of jobs completed exactly at their due dates. We analyze the parameterized tractability of the two problems and develop fixed-parameter algorithms with respect to three natural parameters: the number of different due dates, the number of different processing times, and the number of different energy consumptions.

2 - Bi-Objective Multi-Mode Project Scheduling with Time-Dependent Resource Costs and Capacities
Sofía Rodríguez Ballesteros

This study investigates a variant of the Multi-mode Resource-Constrained Project Scheduling Problem (MRCPSP) by introducing a novel methodology designed to address more realistic and complex scenarios. The approach builds on two key components added to the base problem: time-dependent resource costs and capacities. The former indicates that the cost varies depending on both the resource in use and the time it is utilized, while the latter suggests that resource availability is defined for each period within the planning horizon. Additionally, a multi-objective framework is adopted, aiming to minimize both the makespan and the total resource usage cost. A mathematical formulation is provided for this problem, and an attempt is made to solve it using an exact method to determine the Pareto front (PF). However, the inability of exact methods to handle large-scale instances of this challenging problem motivates the development of a metaheuristic to approximate the PF. We propose an innovative multi-objective genetic algorithm that integrates the new elements of the problem to generate high-quality solutions. A thorough computational study is performed on a benchmark set of instances for this novel bi-criteria, multi-mode problem, with results demonstrating the effectiveness of the proposed metaheuristic.

3 - Improvements of a Column Generation Approach for Production Planning in Semiconductor Manufacturing
Camil Zarrouk, *Nabil Absi*, *Stéphane Dauzere-peres*

Semiconductor manufacturing includes the most complex production processes, involving several hundred steps for each product. Additionally, re-entrant flows and congestion must be considered, resulting in a production timeline of approximately 8 to 20 weeks per wafer of chips. This complexity is further exacerbated by the large volume of wafers processed in a single factory with hundreds of heterogeneous machines, as well as the large number of different products in high-mix factories. In this work, we consider an operational production planning problem in semiconductor manufacturing. The column generation approach of Béraudy et al. (2022), that relies on the notion of timed routes where a specific time period is assigned to each production step for a product, has been extended by Anthouard et al. (2023) to consider various industrial constraints. However, to improve the convergence of the column generation approach for industrial instances, it is crucial to start with an appropriate initial set of timed routes. Given that the production process spans several months and that production plans are executed in a rolling horizon, we propose in this work to integrate and adapt previously generated timed routes to enhance the stability of the production plan and to significantly reduce the computational times. Computational results on industrial instances will be presented.

4 - Integrating Flexibility in Nurse Scheduling
Flore Caye, Antoine Legrain

The nurse scheduling problem (NSP) involves assigning nurses to shifts while balancing institutional staffing requirements and individual preferences. Traditional approaches often produce rigid schedules that do not account for unforeseen last-minute constraints faced by nurses. To address this, we introduce flexibility mechanisms: shift flips and nurse swaps. A shift flip allows a nurse to interchange a working day with a day off, provided that the new schedule remains feasible. A nurse swap extends this concept by allowing two nurses to exchange assignments, ensuring mutual benefit without compromising staffing needs. We first solve the NSP without flexibility using a Column Generation algorithm to generate individual rosters. Because swaps have to be mutually beneficial, their pricing cannot be embedded in the Column Generation framework. We formulate a mixed-integer programming model, composed of the column generation restricted master problem to which we add a set of flexibility constraints. The model ensures a minimum level of swap opportunities while optimizing overall scheduling costs and respecting demand constraints. We propose different swap pricing strategies and analyse the balance between flexibility and operational costs. Experimental results demonstrate the possibility of incorporating flexibility without being detrimental to operating costs.

■ WA-23

Wednesday, 8:30-10:00 - Room: Esther Simpson 3.01

Data Analytics for Business Resilience and Sustainability - Measuring SME Performance

Stream: OR for Societal Development
Invited session
Chair: *Helper Zhou*

1 - Mining Hidden Signals: Unstructured Data in SMME Performance Modeling
Helper Zhou, Evelyn Zhou, Gordon Dash, Nina Kajiji, Sharon Mandizha

The use of unstructured data in predicting Small, Medium, and Micro Enterprises (SMMEs) performance has been largely overlooked, with traditional models relying on structured financial and operational metrics. However, emerging studies—mainly in developed economies—suggest that qualitative factors, such as business descriptions and owner motivations, can offer critical insights into business success. This study bridges the gap by analyzing a dataset of 2,200 SMMEs across South Africa, leveraging sentiment analysis to assess how business narratives relate to financial performance. Findings reveal that owners who expressed highly positive sentiments about their businesses tended to be overly diversified and had moderate to low revenue. In contrast, those with more measured, neutral descriptions exhibited significantly higher revenue. This suggests that SMMEs may be influenced by optimism bias, where excessive positivity leads to overexpansion, diluted focus, and weaker financial outcomes. To mitigate this, policymakers should integrate sentiment analysis into SMME assessment frameworks and provide targeted training on strategic focus. Business support programs should incorporate structured self-reflection tools to help entrepreneurs assess their market positioning realistically, fostering more sustainable growth.

2 - Decommmoditised SMEs: The role of big data in driving nuanced innovation among SMEs in South Africa
Sharon Mandizha, Fulufhelo Godfrey Netswera, Helper Zhou

In today's data-driven economy, Small and Medium-sized Enterprises (SMEs) face increasing pressure to escape commodity traps through strategic differentiation. This study investigates how big data analytics enables SMEs to implement nuanced innovation strategies that foster decommoditisation and sustainable competitive advantage. The study utilised mixed methods approach combining systematic literature review with empirical analysis to develop a comprehensive understanding of this phenomenon. The study employed advanced R programming techniques to analyse bibliometric data from major academic databases including Scopus and Web of Science; and performs quantitative analysis of unstructured internet data from SME digital footprints. This research established a new framework that classifies big data applications into four key dimensions: customer insight generation, operational optimisation, product development acceleration, and market positioning refinement. The study found that SMEs leveraging big data analytics demonstrated higher innovation diffusion rates and improved margin retention compared to non-adopters. The study contributes to operational research literature by proposing a decision support model that enables resource-constrained SMEs to prioritise big data investments aligned with specific decommoditisation objectives. This study offers practical implications for SME leaders seeking to leverage data analytics for strategic differentiation.

3 - Unlocking Firm Performance Insights: A Machine Learning vs. Traditional Methods Approach
Trustlord Marecha, Helper Zhou

Research highlights the growing need for SMEs to adopt advanced tools to understand key performance drivers. However, limited studies—especially in developing economies like South Africa—compare traditional and machine learning (ML) techniques, with the former often failing to capture complex insights. This study departs from prior empirical work that relies on linear models for policy recommendations, which have had little impact on SMEs. Using data from 1,490 South African SMEs, a quantitative approach was applied, employing Robust Regression, Generalized Least Squares (GLS), and the Enhanced Radial Basis Artificial Neural Network (K4-RANN) for comparative analysis. Findings reveal key differences: Internet Access positively influences employment in GLS but negatively in the Neural Network, suggesting automation effects. Social Media has a slight negative impact on employment in GLS but a much stronger negative effect in the Neural Network, implying reduced workforce needs. Smartphone Usage negatively impacts employment in GLS but shows a strong positive effect in the Neural Network, suggesting mobile-enabled job creation. These differences highlight how GLS captures linear trends, while the Neural Network uncovers complex, non-linear relationships. The study underscores the importance of multi-model validation in firm performance analysis, particularly for SMEs in developing economies.

4 - Revolutionizing Accounting Systems with AI-Driven Automation and Analytics Tools in Developing Countries
Amos C. Mpofu, Helper Zhou, Gordon Dash, Nina Kajiji

This study explores the integration of AI tools into Accounting Information Systems (AIS) for both small and medium enterprises (SMEs) and corporate entities across the Southern African region. Over a three-month period, ten companies were analyzed to assess the impact of generative AI-driven automation in financial transaction processing and analytics. The study employed Llama and Gemini models, with a comparative focus on Llama, deployed in Python. The system, termed "Smart Quantilytix" or "Smart Qx Ledger," was connected to a WhatsApp interface to facilitate real-time interaction, transaction tracking and data visualization using both audio and text prompts. Results revealed that all transactions conducted in English were accurately captured, while those in indigenous languages—Shona, Zulu, Sotho, and Ndebele—had an error rate of up to 20%. Despite language-based discrepancies, companies utilizing Smart Qx Ledger, the AI-powered analytical tool, exhibited significantly faster transaction processing and analysis compared to the control group. These findings highlight the transformative potential of generative AI in enhancing data processing efficiency and analytical capabilities, contributing to resilient business performance in both SME and corporate environments.

■ WA-24

Wednesday, 8:30-10:00 - Room: Esther Simpson 3.02

Optimization Models for Unit Commitment in Electric Energy Systems

Stream: Tutorials (and Workshops)
Tutorial session
Chair: Sanne Wøhlk

1 - Optimization Models for Unit Commitment in Electric Energy Systems
Miguel Anjos

The unit commitment (UC) problem addresses a fundamental decision that is taken when operating a power system, namely to set the schedule of power production for each generating unit in the system so that the demand for electricity is met at minimum cost. The schedule must also ensure that each unit operates within its technical limits; these typically include ramping constraints and minimum uptime/downtime constraints. Units that are scheduled to produce electricity during a given time period are said to be committed for that period. Various jurisdictions solve UC on a daily basis. In particular, it is the standard tool to clear spot markets, and particularly the day-ahead markets in the USA. In North American jurisdictions without markets, the system operators use UC to determine the day-ahead commitments and dispatches. Starting with an introduction to UC, this tutorial will cover the fundamental mathematical optimization models, concluding with current research challenges. No previous knowledge of unit commitment or electric power systems will be assumed.

■ WA-26

Wednesday, 8:30-10:00 - Room: Maurice Keyworth 1.33

Successful collaborations with academic partners

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: Maurizio Tomasella

1 - Successful collaborations with academic partners
Maurizio Tomasella, Leendert Kok, Enis Kayis

Students are often involved quite heavily in joint work between OR practitioners and academic institutions, in a way that not only helps to enhance their learning experience but also, more importantly to our community of practitioners, so that these collaborations may be more effective and impactful to the so-called 'real world'. Schools and Departments of Operational Research, Management Science, and Decision/Business/Data Analytics have traditionally included their students in external engagement initiatives. The talks in this session will share with the audience some recent examples of knowledge and impact co-creation involving students and institutions across Europe. If you are an OR practitioner and have never worked with universities, this session will give you reasons to try and engage more with them, for your benefit. If you already work with academia, the session may still provide you with a few ideas for revitalizing your existing partnerships!

The session will start with the following three short talks (10 minutes each):

1. A decade of research collaboration in e-commerce: opportunities, challenges, and lessons learned. Speaker: Dr Leendert Kok, Chief Science Architect at ORTEC

2. Turning Theory into Impact: Navigating Industry Partnerships in OR/IE. Speaker: Dr Enis Kayis, Associate Professor at Ozyegin University

3. Involving Students in Effective Knowledge and Impact Co-creation for the UK Airport Industry. Speakers: Gavin Sillitto, Transformation Programme Lead at London Gatwick; Dr Maurizio Tomasella, Reader (Associate Professor) at University of Edinburgh Business School

Following the short talks will be a panel discussion involving the audience.

■ WA-30

Wednesday, 8:30-10:00 - Room: Maurice Keyworth 1.05

Shared Mobility Optimization I

Stream: Shared Mobility Optimization
Invited session
Chair: Christine Currie

1 - Price optimization for demand responsive transport
Christine Currie, Julia Bennell, Richlove Frimpong, Rym M'Hallah

A demand responsive transport (DRT) service operates a fleet of vehicles that are used to transport customers between their individual pick up and drop off locations. Unlike a taxi service, customers may share a vehicle for part of their journey. Similar rideshare services have been introduced across the world as a way of reducing the environmental impact of transport. We implement dynamic pricing in combination with routing and scheduling to improve the financial sustainability of DRT and use this model to investigate how successful DRT is under different scenarios. Within a DRT system, customers first submit a request for service including when they wish to travel and their pickup and drop off points. The system then returns a set of options for them to choose from. We set up the problem of maximising the expected profit as a dynamic program using a choice model to estimate the probabilities that a customer will choose each of the offered. Data from a stated preference survey of Leeds residents is used to fit the choice model while demand data is determined from transport surveys carried out by Leeds City Council. We use approximate dynamic programming techniques combined with routing and scheduling heuristics to estimate the optimal prices to charge for a journey and the routing of the vehicles. The talk will describe the context of the work, the methods we have designed and some preliminary results.

2 - A Maximum Flow-Based Matching Model for Car-sharing Services: Integrating Pricing, Subsidies, and User Choice Behavior
Xin Wang, David Watling

In car-sharing services, the efficiency of matching between renters and vehicle owners is a critical determinant of overall system performance and service quality. Rental owners' decision-making processes are significantly influenced by pricing strategies and subsidies, which, in turn, affect the balance between supply and demand. Conversely, renters' choices, when selecting among multiple available rental options, are shaped not only by price but also by factors such as proximity. Consequently, the development of an effective matching mechanism is essential for optimizing system efficiency. This study introduces a maximum flow-based matching model to optimize the allocation between renters and rental owners while incorporating mathematical modeling to analyze their decision-making behaviors. Specifically, a pricing and subsidy decision model is first formulated to examine how varying pricing and subsidy strategies influence the supply side. Subsequently, a nested logit model is constructed to characterize renters' choice behaviors, accounting for the impact of both price and distance on rental decisions. For matching optimization, we employ the maximum flow algorithm to determine the optimal allocation of rental resources, aiming to maximize overall system utilization. Furthermore, we investigate the effects of different pricing and subsidy strategies on flow distribution and explore optimization schemes designed to enhance system efficiency and user satisfaction.

3 - Probabilistic Services on a Ride-hailing Platform
Di Wu

Motivated by Didi's simultaneous call service option, we study probabilistic pricing on a ride-hailing platform offering high- and low-type services. Riders selecting this option do not know in advance which service they will receive but are charged based on the service they ultimately get. Using a rational expectation framework, we characterize the optimal probabilistic pricing strategy. Our results show that the introduction of probabilistic pricing allows the platform to segment riders more effectively and better balance the supply and demand, mitigating the congestion level in the market. Interestingly, more demand from the low-type riders can be fulfilled, albeit at a higher price for the low-type service. Moreover, the platform's optimal pricing scheme depends on riders' aversion to congestion and the platform's cost of offering the probabilistic service. Remarkably, providing probabilistic service can be a win-win-win policy for riders, drivers, and the platform when riders are not highly averse to congestion and the computational cost of the probabilistic services is not too high. Our findings provide practitioners with valuable guidelines for designing probabilistic services in ride-hailing markets.

4 - Mode choice between metro, bus, and ride-hailing: a trip-by-trip analysis with crowding effects
Raul Pezoa

Public transportation systems are crucial for urban mobility, yet the emergence of ride-hailing services has introduced a significant alternative to traditional transit options. This study investigates how commuters in Santiago, Chile, value travel time, waiting time, cost, and crowding when choosing between ride-hailing, metro, and buses. Using a discrete choice model with revealed preference data from smart cards and ride-hailing transactions, we find that users are willing to pay a substantial premium to avoid crowded public transport, highlighting the critical impact of crowding on mode choice. By integrating real-world data and considering the growing role of ride-hailing, our approach might provide a more accurate assessment of commuter preferences in today's urban environments. Our results have significant policy implications, extending beyond the context of our case study, as underestimating the value of crowding could lead to inadequate public transport capacity planning.

■ WA-31

Wednesday, 8:30-10:00 - Room: Maurice Keyworth 1.06

Solution Algorithms for Optimization under Uncertainty 1

Stream: Stochastic and Robust optimization
Invited session
Chair: *Francesca Maggioni*

1 - Iterative CVaR-Chance-Constrained Optimization for Stochastic Problems
Pablo Diaz-Cachinero, Ricardo Gázquez, Roberto Mínguez

We propose an iterative methodology that merges the practicality of chance constraints with the tractability of Buffered Failure Probability (BFP) to resolve the trade-off between risk precision and computational complexity. While chance-constrained formulations can effectively control probabilistic failures, they are challenging to solve at scale. BFP, though more tractable, can lead to conservative outcomes. In the first approach, we iteratively solve a BFP-based reformulation until the chance constraint is strictly satisfied, ensuring the final solution meets the desired probabilistic target while also minimizing the CVaR (worst cases). The second approach employs a sequential hyperplane generation procedure to focus on tail scenarios, the critical region where breakdowns occur. This narrows attention to the most influential scenarios, reducing problem size and enabling faster convergence without compromising robustness. Numerical results across multiple case studies confirm that these methods provide strict probabilistic guarantees while lowering the overall computational burden relative to conventional techniques. This framework supports large-scale, uncertainty-driven applications, allowing practitioners to balance risk mitigation with solution quality more efficiently.

2 - Inverse optimization in finite-state continuous-time Markov decision processes
Archis Ghate, Nhi Nguyen

Inverse optimization involves finding values of problem parameters that would render given values of decision variables optimal. This is in contrast with the usual forward optimization where decision variables are computed using given values of problem parameters. In the context of finite-state Markov decision processes (MDPs), the inverse optimization literature has focused on imputing two types of inputs that would make a given policy optimal: (i) cost parameters or (ii) transition probabilities. All existing work only considers the case of discrete-time MDPs. We will present an extension to the case of continuous-time MDPs (CTMDPs). We will rely on a technique called uniformization to first convert the CTMDP into a probabilistically equivalent discrete-time MDP. Bellman's equations for this discrete-time MDP will then be utilized to formulate a parametric version of the inverse problem. In this parametric version, estimates of parameters that characterize costs are given. The goal is to find parameters that are as close as possible to these estimates and that render a given policy optimal. We will present a tractable linear or convex formulation of this problem. Applications from batch manufacturing and queue routing will be discussed.

3 - Nonlinear Decision Rules Made Scalable by Nonparametric Liftings
Eojin Han

Sequential decision making often requires dynamic policies, which are computationally not tractable in general. Decision rules provide approximate solutions by restricting decisions to simple functions of uncertainties. In this paper, we consider a nonparametric lifting framework where the uncertainty space is lifted to higher dimensions to obtain nonlinear decision rules. Current lifting-based approaches require predetermined functions and are parametric. We propose two nonparametric liftings, which derive the nonlinear functions by leveraging the uncertainty set structure and problem coefficients. Both methods integrate the benefits from lifting and nonparametric approaches, and hence provide scalable decision rules with performance bounds. More specifically, the set-driven lifting is constructed by finding polyhedrons within uncertainty sets, inducing piecewise-linear decision rules with performance bounds. The dynamics-driven lifting, on the other hand, is constructed by extracting geometric information and accounting for problem coefficients. This is achieved by using linear decision rules of the original problem, also enabling one to quantify lower bounds of objective improvements over linear decision rules. Numerical comparisons with competing methods demonstrate superior computational scalability and comparable performance in objectives. These observations are magnified in multistage problems with extended time horizons.

4 - Sampling the Solution of a Randomly Parametrized Convex Program Using Markov Chain Methods
Jonathan Hornewall, Stephane Gaubert, Vincent Leclere

We present a novel method for sampling the optimal solution of strictly convex optimization problems with random parameters. A motivating application are methods in two-stage stochastic programming, which often rely on sampling optimal dual variables for linear programs with random coefficients.

Conventional methods typically proceed by generating samples of the parameters and then solving the optimization problem for each individual realization. By contrast, our approach directly generates samples of the optimal solution by simulating an appropriately designed Markov Chain, whose steady state is designed to have the same probability distribution as the optimal solution. It is worth noting that our framework can generate these samples without solving the optimization problem even a single realization of the random paramters.

We present numerical results for the case where the random optimization problem is a log-barrier regularized linear program. We show results for two choices of Markov chains, where the first represents a generalization of the conventional Metropolis adjusted Langevin sampling algorithm, and the second generalizes the conventional Hamiltonian Monte Carlo sampling algorithm.

Our framework is very general, and can be applied to a larger class of inverse-type problems with random parameters beyond optimization problems. It is hence of independent sampling theoretic interest.

■ WA-32

Wednesday, 8:30-10:00 - Room: Maurice Keyworth 1.09

Hinterland and container drayage operations

Stream: Maritime and Port Logistics
Invited session
Chair: *Zhaojie Xue*
Chair: *Jintao You*

1 - A stable and fair profit allocation in truck scheduling with trailer swapping
Zhaojie Xue, *Zhe Chen*, *Rui Chen*

This study investigates profit allocation in cooperative truck scheduling under trailer-swapping mode (TSM), an innovative approach aimed at reducing empty load rates, operational costs, and carbon emissions. Although TSM offers significant operational advantages, profit imbalances among carriers can create conflicts, jeopardizing system stability. To address these challenges, we propose a novel profit allocation mechanism grounded in cooperative game theory, ensuring both fairness and stability. By employing a precise row generation method, we calculate fair profit allocations while maintaining system equilibrium. A series of numerical experiments are conducted to validate the model's performance and examine the impact of key parameters on the allocation outcomes. The results demonstrate that our approach provides an effective solution for managing complex cooperative transportation systems, offering valuable managerial insights into fair profit distribution and improving overall operational efficiency.

2 - A branch-and-price algorithm for the trucking problem using trailer-swapping operation mode
Wenxiang Peng, *Zhaojie Xue*, *Xiangsheng Chen*, *Jintao You*

This study investigates the trucking problem using the trailer-swapping operation mode (TP-TSOM), where trucks swap trailers at network nodes during transit and then continue to pull the swapped trailer to its destination. Traditionally, trucking involves transport tasks distributed across the network, completed by trucks pulling trailers directly from origins to destinations. The trailer-swapping operation mode (TSOM), which involves collaboration among trucks, can enhance trucking efficiency. Accordingly, a mixed-integer linear programming model for TP-TSOM is developed to determine the optimal truck trailer-swapping plan, and an integer linear programming model for the two-truck swapping case is also constructed. To solve the TP-TSOM efficiently, a branch-and-price algorithm utilizing a trailer-swapping group-based set partitioning model is designed. The pricing sub-problem is formulated as multiple elementary shortest cycle problems with resource constraints (ESCPRC) based on different subgraphs. By iteratively fixing virtual terminals, a new representation of the ESCPRC is constructed, enabling the ESCPRC to be solved using the labeling algorithm. Extensive numerical experiments are conducted to validate performance. The computational results show that the proposed exact algorithm can solve instances with up to 200 tasks and that TSOM significantly reduces transportation costs, travel time, and empty load rates.

3 - Optimizing Container Drayage with Fractional Loads
Eduardo Lalla-Ruiz, *Marco Luis Ochoa Barnuevo*, *Fabian Akkerman*

Container drayage (i.e., the short-distance transport of containers between ports, depots, and customer sites) accounts for up to 40% of total transport costs despite covering only a minor portion of the journey. Traditional models focus on full-truck pickups and deliveries, overlooking opportunities for shared loads, which leads to excessive empty trips and inefficient resource use. This research explores and introduces the Container Drayage Problem with Fractional Loads (CDPFL), which incorporates multi-trip scheduling, clustered customer demands, and shared container loads. The goal is to optimize the total travel time as well as earliness and on-time delivery to respond to customer preferences

To solve this problem, we propose a constructive heuristic for initial solutions and a metaheuristic refinement approach, enhancing scalability for large-scale drayage operations. Extensive experiments using adapted benchmark instances were used. Results show that integrating shared load strategies with multi-trip routing significantly reduces travel time and empty truck movements. This highlights a new aspect and potential of collaborative logistics in drayage operations and provides insights for improving container flow efficiency.

■ WA-34

Wednesday, 8:30-10:00 - Room: Michael Sadler LG10

Advancements of OR-analytics in statistics, machine learning and data science 6

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: *Roberto Rossi*
Chair: *Soumen Kumar Das*
Chair: *Gerhard-Wilhelm Weber*

1 - Robust Product Recommendations via Graph-Driven Co-Occurrence Analysis and Adaptive User Clustering
Serhat Mirkan Acar, *Atakan Yilmaz*, *Egemen Karabiyik*

We propose a recommendation framework that infers user similarity from implicit interactions—such as views, favorites, and orders—while carefully reducing the skew introduced by highly popular products. Unlike conventional methods that treat every product identically, our approach applies a weighted formula to discount widely popular items, thereby emphasizing more distinctive user interactions. In addition to examining individual products, we build an undirected graph based on product pairs, assigning less influence to product pairs co-interacted by a large number of users. This refined strategy yields a more accurate measure of user alignment, enabling the construction of a user-user graph where edges capture these similarity scores. A label propagation process then groups closely related users into coherent clusters, and personalized recommendations are generated by suggesting items within each cluster that users have not yet encountered. Rigorously evaluated through our effective AB testing system, we comprehensively analyze and discuss the impact of our approach, demonstrating its potential to enhance personalization and enrich the user experience.

2 - Enhanced Behavioral Weighting and Explainable Clustering for Adaptive Recommendation Systems
Atakan Yilmaz, *Serhat Mirkan Acar*, *Egemen Karabiyik*

We propose an advanced recommendation framework that refines user similarity modeling through action-aware graph analysis and explainable clustering. Our method assigns distinct importance to different user actions—such as clicks, basket additions, and orders—in the product co-occurrence graph, preserving fine-grained behavioral data while emphasizing more meaningful interactions. To balance the impact of

highly connected nodes, we introduce a modified label propagation algorithm that dynamically adjusts edge influence, promoting fairer cluster formation. Additionally, we incorporate explainability into the similarity graph, enabling transparent reasoning behind recommendations and clarifying how user behaviors align. Clusters update frequently to accommodate evolving preferences, and recommendation lists are composed of items with high intra-cluster relevance yet unexplored by the target user. Extensive evaluations on large-scale e-commerce environment demonstrate improved engagement and diversity, underscoring the effectiveness of our action-sensitive graph construction, bias-resistant clustering, and explainable user similarity modeling for enhanced recommendation performance.

3 - From Raw Data To Real Impact: Unlocking Efficiencies for Prisoner Rehabilitation with Data Science, ML and OR
Roger Brown

In prisons, keyworkers work closely with offenders, aiding rehabilitation & to reduce reoffending once released. Improving quality of keywork (KW) sessions is crucial for these objectives. National Keywork team manually reads & scores a sample of prisoner KW case notes monthly, aggregating the scores producing prison KW Quality Assessment (QA) metrics. This approach is resource-intensive, difficult to sustain with results only statistically valid for annual accountability. Also, manual scoring introduces subjectivity & potential human error. We've developed a Machine Learning approach to automate QA of these sessions using innovative approaches & advanced Natural Language Processing (NLP) methods - Train Gradient Boosting model - Convert text to Longformer - Use Named Entity Recognition removing names - Investigate Claude AI models as alternate approach. Given the subjective nature of the scoring process, traditional machine learning performance metrics were insufficient. We employed Krippendorff's alpha, a statistical measure of observer agreement, to evaluate model performance. We've significantly scaled number of KW sessions QAd each month. Before, 2,500 sessions were manually scored monthly; new algorithm scores all 80,000+ sessions in fraction of the time & cost, 24 hrs. They're providing more complete & timely information for prison teams to act upon. This algorithm helps prison leaders improve KW quality, crucial for rehabilitation & reducing reoffending.

4 - Alternating Minimization for Least Square Estimation in Additive Semi-parametric Regression with Monotone Constraints
Anand Kumar, Radhenduska Srivastava, K. S. Mallikarjuna Rao

Consider an additive semi-parametric regression model observations are sum of term linear in x and monotone function in z. Each sample point y is observed with noise that are independently and identically distributed Gaussian random variables with mean zero and fixed variance. The monotone components increase with index i.e. z increases strictly with each observation. We note that x is not correlated with z.

In this work, we present an alternating minimization method for least square estimation of the parameters - slope and monotone function. The shape constraint semi-parametric regression models are widely applicable in geological isotopic data, economics, astronomical data etc. We also present proof to the convergence of the proposed alternating minimization method. If sample size n increases in block using a dyadic manner, we also illustrate the rate of convergence of the estimator. A simulation study will be shown to illustrate the finite sample performance and convergence.

■ WA-35

Wednesday, 8:30-10:00 - Room: Michael Sadler LG15

Recent trends in zeroth order and simulation-based optimization: 2

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: Warren Hare
Chair: *Margherita Porcelli*

1 - Inverse Problem in River Hydraulics Solved via Derivative-Free Constrained Optimization
Fabio Fortunato Filho, José Mario Martínez

The study investigates the application of the Augmented Lagrangian method to problems with differential equation constraints using derivative-free methods. In addition to the theoretical foundation, the research focuses on estimating the hydraulic coefficient in river flow modeling, a widely discussed problem in the literature. The channel modeling is based on the Saint-Venant equations, applied to the East Fork River, considering data collected over 31 days. To solve these equations, the finite difference method with artificial diffusion was employed, chosen for its computational efficiency, as the equations need to be solved repeatedly. Error minimization between observed and simulated data was performed using the derivative-free methods Nelder-Mead, PRIMA, and BOBYQA, considering a box-constrained problem. Since the selected quadratic methods are naturally suited for this type of problem, the Nelder-Mead approach included a penalty for out-of-box points. The results show that the proposed strategy is efficient and viable for all tested methods, reducing computational time and providing accurate estimates of the hydraulic coefficient. The study highlights the advantages of optimization over traditional methods and suggests future improvements, including compatibility with the HEC-RAS software, widely used for simulating flow in natural and artificial channels.

2 - Multiobjective optimisation of a multifidelity simulation
Warren Hare

Optical dosimetry uses light to measure radiation dosage. It is a critical step in ensuring radiation therapy is delivered safely and accurately. This talk explores the design of a solid-state tank for fan-beam optical dosimetry. We begin with an overview of optical dosimetry, its applications, and solid-state tank design. We then discuss a novel simulation for solid-state tank design that measures image uniformity and scanning coverage. The simulation is used to power a multiobjective optimisation problem, which we solve using NSGA-II and simple multifidelity soft restart techniques. Combined the research provides several useful results: a new test problem for multifidelity multiobjective optimisation, and an improved solid-state tank design for optical dosimetry.

3 - Structured Finite-Difference Methods for Zeroth-order Optimization
Marco Rando, Cheik Traoré, Cesare Molinari, Lorenzo Rosasco, Silvia Villa

Finite-difference methods are widely used for solving black-box optimization problems by approximating function gradients along selected directions. Recent advancements have shown that imposing structure in these directions improves performance, but existing results are often restricted to specific settings or particular choices of directions. In this work, we extend structured finite-difference methods to a broader range of settings. We begin by proposing and analyzing a structured finite-difference method for stochastic smooth optimization, introducing a new gradient approximation technique. We analyze our approach in smooth convex and PL non-convex settings. We then address non-smooth black-box optimization by developing a structured finite-difference algorithm that leverages a smooth approximation of the target function. Our analysis establishes that this method accurately estimates gradients along a subset of random orthogonal directions and achieves optimal complexity in terms of dimension dependence. Finally, we consider black-box finite-sum optimization and incorporate variance reduction techniques into our framework. We provide theoretical guarantees for our approach in multiple settings and validate our findings through numerical experiments, showing better performance compared to state-of-the-art algorithms.

■ WA-36

Wednesday, 8:30-10:00 - Room: Michael Sadler LG16

Quadratic models in global optimization

Stream: Global and nonconvex optimization
Invited session
Chair: *Syuuji Yamada*

1 - On a Special Class of Non-convex Quadratic Programming Problems in Graph Theory
Samr Kumar Neogy

In this talk, we consider non-convex quadratic programming problems in graph theory involving distances in trees and the resistance distance of a connected graph with n vertices. We study the problem of optimizing non-convex quadratic programs with the only constraint that variables must belong to a simplex. Applications in finance and the Quadratic Assignment problem are just two examples. Besides the graph theory literature, there are at least three other areas where these problems have been considered. These areas are: (i) a generalized notion of the diameter of a finite metric space (ii) maximizing weighted average distance in graphs and (ii) Nash equilibria of symmetric bimatrix games. In recent years, the resistance distance has been extensively studied in mathematical, physical and chemical papers. We show that for the class of simple graphs with resistance distance matrix which is not necessarily a tree, this problem can be reformulated as a strictly convex quadratic programming problem and we may use strongly polynomial algorithms available in the literature to solve strictly convex quadratic programming problems involving resistance distance.

2 - A hierarchy of SOCP-based relaxations for 0-1 integer programs
Jitamitra Desai, Sudheer kumar reddy Boggadi

Several methodologies such as the Reformulation-Linearization Technique (RLT) produce a hierarchy of ever-tightening linear programming (LP) relaxations for constructing the convex hull of an underlying pure 0-1 integer program. In this research, we add to the body of literature on hierarchical approaches by employing second-order cone programming (SOCP)-based relaxations to improve the solvability of 0-1 IPs. As with other techniques, this hierarchical procedure also generates a sequence of increasingly tighter SOCP relaxations that ultimately converge to the convex hull of the underlying 0-1 IP, but it offers many computational advantages as the number of constraints required at the kth step of this procedure is significantly lower as compared to existing methodologies while yet retaining the strength of the underlying lower bound. We prove that this SOCP-based relaxation procedure converges to the convex hull of the 0-1 IP in n steps (where n is the number of original binary variables in the problem) and furthermore, detailed computational experiments on several well-known instances from the literature are used to demonstrate the efficacy of the proposed methodology.

3 - An iterative approximation algorithm for a quadratic reverse convex programming problem
Syuuji Yamada

In this study, we propose an iterative approximation algorithm to address a quadratic reverse convex programming problem (QRC) characterized by a linear objective function, one reverse convex constraint, and multiple convex constraints. It is well-known that many global optimization problems can be reformulated into this type of problem. While iterative solution methods for (QRC) have been explored extensively by previous researchers, these algorithms tend to be inefficient when the variable dimensions become significantly large. One major challenge in solving (QRC) lies in the fact that not all locally optimal solutions necessarily satisfy the Karush-Kuhn-Tucker (KKT) conditions. To address this issue, we introduce a procedure for enumerating the KKT points of a subproblem, which is formulated as a quadratic programming problem within the (QRC) framework. Furthermore, by integrating this procedure with a parametric optimization method and a branch-and-bound procedure, we are able to derive an approximate solution to (QRC).

■ WA-38

Wednesday, 8:30-10:00 - Room: Michael Sadler LG19

Industrial Optimization

Stream: Data Science meets Optimization
Invited session
Chair: *Grzegorz Pawlak*

1 - SAT Information size and its implications for industrial optimization
Maciej Drozdowski

The amount of information in satisfiability problem (SAT) is considered. It is argued that the amount of information in SAT grows at least exponentially with the size of the input instance. This is juxtaposed with the limited information content of the input instances, algorithms and external information sources that can be used at the runtime. It is argued that this available information quantity, in some cases, is insufficient in solving SAT. It is also claimed that combinatorial problems like SAT, are ultimately not learnable. This poses a question of the scalability of, e.g., machine learning methods in solving hard combinatorial problems.

2 - Multi-Objective Optimization Model for Strategic Acquisition of Additive Manufacturing Technologies
Federica Tomelleri, Matteo Brunelli

The rapid evolution of Additive Manufacturing (AM) technologies presents new opportunities to optimize production processes. However, selecting and acquiring suitable AM machines is a complex challenge due to the wide variety of specialized, high-cost equipment available, each designed for different applications such as prototypes, functional components, prosthetics, and tools. Efficiently planning these investments to support large-scale production requires robust decision-making under uncertainty. This paper proposes a stochastic optimization model to guide the acquisition and utilization of AM technologies across multiple planning periods. The model employs a multi-objective approach that balances two key goals: maximizing the probability of meeting uncertain demand forecasts and minimizing acquisition costs. To address computational challenges, chance constraints are reformulated into deterministic equivalents, enabling effective integration of stochastic data with machine capacity and production planning decisions. The solution framework leverages mixed-integer nonlinear programming techniques combined with heuristic optimization, specifically genetic algorithms, to identify Pareto-optimal solutions. By reflecting real-world complexities, this research demonstrates the importance of combinatorial optimization in achieving both cost-efficiency and service-level reliability for strategic investments in AM facilities.

3 - Financial Fraud Detection; Machine Learning; Data Balancing; Explainable AI; Transaction Networks
Victor Chang

The intricacy of money laundering operations is becoming increasingly difficult for financial institutions to handle, making compliance and detection jobs extremely difficult. This study suggests a novel approach that combines resampling approaches, specific network-derived characteristics, and cutting-edge machine learning models for increased detection accuracy. Using the sophisticated, realistic synthetic transaction dataset SAML-D, we assess four cutting-edge machine learning techniques: Artificial Neural Networks (ANN), AdaBoost, XGBoost, and Gradient Boosting (GB). We thoroughly examine data balancing strategies, including SMOTE, ADASYN, Random Undersampling, and NearMiss, considering the significant class imbalance feature of financial fraud data, where fraudulent transactions make up just 0.1% of all occurrences. Furthermore, by adding network centrality measurements, the suggested method expands the feature set and successfully captures structural patterns and transaction interactions. According to

experimental findings, the Gradient Boosting algorithm, in conjunction with SMOTE, performs at its best, achieving an AUROC of 0.88, a sensitivity of 0.81, and a specificity of 0.80. Despite the constantly changing landscape of money laundering tactics, financial companies can retain sufficient and comprehensible fraud detection procedures due to this integrated and flexible framework.

4 - AI-Driven Machine Learning Approach for Accurate Structural Modeling of Organic Light-Emitting Diodes
InnJun Choi, Sung Woo Kang

Designing organic light-emitting diodes (OLEDs) with desired emission colors and efficiencies requires complex optimization of material selection and device structure due to their multilayered architecture. The cavity structure in OLEDs enables a broad range of emission colors and efficiencies by adjusting the thickness and optical constants of the layers, even when using a fixed set of materials. However, conventional approaches for optimizing OLED designs are costly, labor-intensive, and time-consuming due to the vast number of possible combinations in multilayer structures.

To address these challenges, this study introduces a novel rule-based machine learning (ML) algorithm capable of intelligently predicting the ideal OLED structure based on the thickness and refractive index of organic layers. The proposed ML algorithm demonstrates remarkable accuracy, achieving an error margin of less than 0.5% for red, green, and blue OLEDs. These findings highlight the potential of ML-driven optimization as an efficient and precise solution, significantly reducing time and resource expenditures in OLED design.

■ WA-39

Wednesday, 8:30-10:00 - Room: Newlyn LG.01

Assessment Methods for Shaping the Green, Inclusive, and Digital Cities

Stream: Sustainable & Resilient Systems and Infrastructures
Invited session
Chair: Sara Torabi
Chair: *Patrizia Lombardi*

1 - Addressing urban vulnerability through Nature-based Solution: A Spatial Multicriteria Analysis to identify priority intervention area
Giulia Datola, Marta Bottero, Marta DellOvo, Giulia Tarantino, Alessandra Oppio

Nature-Based Solutions (NBS) are recognised as effective strategies for addressing multidimensional challenges and implementing climate change mitigation interventions. NBS are nature-inspired solutions that provide environmental, social, and economic benefits. Their implementation in urban contexts aims at fostering synergies with nature, supporting sustainable and resilient development. However, the operative implementation of NBS in urban contexts remains limited due to the absence of a suitable assessment tool capable of addressing their complexity and multidimensionality. Therefore, an operative Decision Support System (DSS) to assist policymakers in properly integrating NBS into strategic urban planning is required. To address this gap, this contribution proposes the Spatial Multicriteria Analysis (SMCA) integrated with Cost-Benefit Analysis (CBA). SMCA is applied to identify the most urgent intervention areas based on a Vulnerability Index that evaluates environmental, social, and infrastructural aspects. CBA then estimates the costs and benefits of proposed NBS interventions. The framework was tested in the city of Milan by identifying vulnerable brownfield sites where intervention was most needed. The obtained results underline that the proposed DSS effectively supports the NBS integration into strategic urban planning, helping decision-makers to prioritize intervention areas and optimize resource allocation.

2 - Assessing the effectiveness of Nature-based Solutions as Inclusive Climate Actions: a case study from Torino, Italy
Sara Torabi, Virginia Pellerey, Patrizia Lombardi

Nature-based Solutions (NBS) are recognized as strategies for climate change adaptation. While existing assessment frameworks focus on the environmental impacts of NBS, they neglect relevant social and economic implications. Instead, a comprehensive approach reveals the role of NBS as Inclusive Climate Actions (ICAs) promoting inclusivity and justice along with climate adaptation. This study details the implementation of an evaluation framework assessing environmental, social, and economic impacts of NBS in four different projects in the city of Torino (Italy). For each indicator, a specific methodology is defined from existing literature. Methodologies include interviews, questionnaires, spatial analysis, and economic modelling. Results of each indicator are normalized for comparison between different projects. Finally, results are discussed to highlight synergies and trade-offs between impacts. The findings stress the relevance of NBS as ICAs. While detected economic and environmental impacts are minimal due to the small dimensions of the projects, results emphasize the effectiveness of NBS in improving well-being, participation, and environmental education. Moreover, this work validates the comprehensive framework and the proposed methodologies. Finally, results contribute with insights for urban policymakers. This work is part of the European project[U+202F]GREEN-INC: growing effective and equitable nature-based solutions through inclusive climate actions.

3 - Selection of social indicators for S-LCA in the assessment of positive energy social housing neighbourhoods
Belal Neazi, Adriano Bisello

The guidelines for Social Life Cycle Assessment (S-LCA) do not address neighbourhood-scale applications. S-LCA is flexible and can incorporate diverse indicators and subcategories with proper explanation, which helps in providing an opportunity to evaluate social sustainability at different scales. This research aims to identify social indicators that will be used in S-LCA for assessing the impacts of refurbishments in social housing at six different demo sites. These sites are part of the Horizon Europe project. Firstly, the methodology involves a literature review using different databases, along with analyses of case studies, standards and reports to identify potential indicators. These indicators are then refined, keeping them aligned with the study goal. This is followed by validation and weighting by the experts. AHP is used to calculate weights. Preliminary findings indicate that neighbourhood-scale indicators differ from those used for products. Key considerations such as transparency, community cohesion, and usability take prevalence, which reflects the broader social context of neighbourhoods. Inputs from stakeholders across the six demos reveal variations in selected indicators, shaped by local cultural, social, and policy contexts. This research highlights the importance of social indicators to be used with S-LCA at neighbourhood-scale. The resulting indicators will be used in the S-LCA methodology, which will help understand the impacts of the project.

4 - Measuring the Impact of Urban Renewal: A KPI-Based Assessment in Rimini
Isabella Giovanetti, Vanessa Assumma, Claudio Lantieri, Leonardo Cameli, Cecilia Mazzoli, Konstantina Douka, Annarita Ferrante

This research is part of the ongoing European project Re-Value, which aims to promote urban regeneration as a pathway toward climate neutrality by integrating the values of the New European Bauhaus(NEB)—sustainability, inclusivity, and aesthetics. The study analyses the impacts of urban regeneration interventions using the Re-Value Impact Model, a framework designed to assess the social, economic, and environmental effects of such projects on urban quality. This research focuses on one of the project's key cities, Rimini(Italy), specifically the districts of San Giuliano and Parco del Mare 4, comparing conditions before and after intervention using key performance indicators(KPIs) defined within the Impact Model. To achieve this objective, the study employs a composite index evaluation based on the Analytic Hierarchy Process(AHP) to assess the impact of NEB principles. The KPIs are structured hierarchically, and an expert survey is conducted to evaluate their relevance to the district. To further refine

the weighting of indicators, a participatory approach is implemented using a 'domino' card game, engaging both stakeholders and experts to define relationships between KPIs and calculate a correction coefficient. Once the final weights are determined, the AHP model aggregates pre- and post-intervention data to compute the NEB performance index, which quantifies the overall effectiveness of the projects in enhancing sustainability, social cohesion, and urban aesthetics.

■ WA-41

Wednesday, 8:30-10:00 - Room: Newlyn GR.01

Impact of AI on Soft OR

Stream: Soft OR and Problem Structuring Methods
Invited session
Chair: *Leroy White*

1 - Soft OR and generative AI
Leroy White

Studies on OR and AI have a long and intertwined history, with no doubt about OR's contribution to predictive AI—particularly in the field of machine learning. However, when applying OR to complex interventions or to solve previously unexplored problems, it is important to distinguish between predictive AI (where machines often outperform humans in specific tasks) and the emerging generation of AI built on large language models (LLMs), which promotes close collaboration between humans and machines to generate novel insights. At the same time, concerns are growing about the efficacy of generative AI in augmenting human tasks, especially in highly complex or high-risk contexts that demand Soft OR approaches. This presentation argues that by adopting a broader perspective of AI and embracing a responsible approach to integrating generative AI into interventions, OR can resolve these tensions and achieve synergies that benefit both organisations and society. Given the rapid advances and capabilities of novel LLMs, there is a pressing need to deepen our understanding of 'AI-in-the making', moving beyond the polarised debates of hope and fear that currently dominate the headlines.

2 - PRA, PANDA, and the Politics of Participation
Katharina Burger

This presentation revisits Participatory Rural Appraisal (PRA) and Participatory Appraisal of Needs and Development of Action (PANDA), drawing from the work of Ann Taket and Leroy White (1993-2000). Their interventions in Soft OR were not just methodological innovations but deliberate challenges to the politics of expertise and the ethics of participation. Rejecting the notion of a neutral OR analyst, their work foregrounded local empowerment, ethical responsibility, and critical reflection on power. PANDA was never just an alternative method—it was a political stance on who gets to define problems, whose knowledge counts, and what participation truly means. Revisiting PRA and PANDA today is urgent as AI-driven efficiency logics threaten to instrumentalise participation, stripping it of its ethical and political dimensions.

3 - Digital Transformation Chatbot (DTchatbot): Integrating Large Language Model-based Chatbot in Acquiring Digital Transformation Needs
Gorkem Yilmaz, Jiawei Zheng

Digital transformation is a strategic imperative for organisations seeking to enhance operational efficiency, reduce manual efforts, and optimise processes by automation and digital tools. A critical challenge in this transformation lies in accurately capturing organisational needs, which traditionally relies on expert interviews. However, these methods often suffer from scheduling conflicts, recourse constraints, and inconsistency.

To address these issues, we propose a novel approach using a Large Language Model (LLM)-powered chatbot to elicit and understand digital transformation needs. Specifically, the chatbot integrates workflow-based instruction with LLM's planning capabilities, enabling it to function as a virtual expert and ask questions to users in the form of conversation in five key areas: corporate governance, customer and market management, research and development, supply chain, and production management. Moreover, the chatbot captures text and audio input in multiple languages, provides guidance on questions and technologies, and generates a comprehensive interview report.

Exploratory case studies with two Turkish manufacturing SMEs indicate that the chatbot effectively conducts conversational interviews, supports insightful user engagement, and helps initial awareness and identifying organisational needs. However, findings suggest that while it is effective for needs assessment, it needs enhanced analytical capabilities, e.g., suggesting solutions.

■ WA-42

Wednesday, 8:30-10:00 - Room: Newlyn GR.02

Industrial Symbiosis

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: *Gulesin Sena Daş*

1 - Challenges and Opportunities in Cross-Sector Collaboration for Circular Supply Chains
Arvind Upadhyay, Farheen Naz

The current dominant taking, making, and disposing production model is considered a dead-end for an economy because it leads to high costs, volatility, and raw material scarcity. To achieve a sustainable future, economies constantly seek emerging innovative models, approaches, and frameworks. In this regard, the shift to a circular economy might be assisted by comprehending the function of collaboration within or across networks as collaboration within the same sector or across sectors enables circular supply chains to recover value from waste and offer a chance for development. However, adopting a circular supply chain through collaboration will face various barriers and challenges. Therefore, this research aims to identify the challenges and opportunities of collaboration to enable circular supply chains. Based on this research motivation, the following research objectives are established: • To identify the collaboration challenges preventing businesses from transforming from linear supply chains to circular supply chains. • To provide strategic recommendations based on the findings of the study for the collaboration of businesses to transform from a linear supply chain into a circular supply chain. This study was conducted to identify the challenges and opportunities of cross-sector collaboration for circular supply chains. A systematic literature review has been conducted to examine the potential research contribution or directions in this field. In total, by usi

2 - Tactical Production Planning under yield uncertainty in a Two-Factories Industrial Symbiosis Collaboration
Cheshmeh Chamani, El-Houssaine Aghezzaf

As global consumption and population growth accelerate, the efficient use of finite resources has become a significant concern in developing sustainable manufacturing models. Consequently, the circular economy is gaining attention, aiming to extend resource life cycles. Industrial symbiosis (IS) fosters eco-collaboration between at least two participants, where a manufacturer's unavoidable residue flow, known as a byproduct, is revalorized as a substitute raw material for another. As a key circular strategy in manufacturing, IS aims to enhance coordination among collaborators to reduce environmental and supply costs while creating market opportunities and strengthening supply resilience. A notable example of IS application is the Kalundborg Industrial Park in Denmark, where symbiotic exchanges of water, energy,

and materials among various collaborators highlight the potential for cross-industry collaboration. While IS is widely studied at a strategic level, its tactical implementation in production planning remains underexplored, particularly under uncertainty. Byproduct yield variability impacts the byproduct availability, reliability among collaborators, and willingness to engage in the partnership. Our study addresses this challenge by incorporating yield uncertainty into lot-sizing optimization within an IS network, bridging the gap between strategic and tactical level planning.

3 - Dynamic resource flow optimization in industrial symbiosis networks
Jiayun Wang, Haohui Zhang, Alessio Trivella, Daniela Guericke, Devrim Murat Yazan

Industrial symbiosis networks (ISNs) are becoming increasingly important in sustainable resource management. They are clusters of industries interacting in a way that one's waste, e.g., materials and energy, can be used as input of another, potentially after treatment. While most of the extant literature focuses on the design of such networks, this work studies their day-to-day optimal operations under uncertainty in the price, demand, and availability of resources and wastes. Adopting a centralized ISN management perspective, we formulate a Markov decision process (MDP) where a set of interconnected (manufacturing and treatment) plants dynamically decide on production planning, inventory levels, and resource exchanges. As this MDP is intractable to solve optimally due to the exponential growth of state and discrete (combinatorial) action spaces with the network size, we compute heuristic policies based on forecast-based and scenario-based reoptimization, and on adaptations of deep reinforcement learning (DRL) methods. Numerical experiments show that DRL is more effective at capturing uncertainty and can thus be valuable for optimizing ISN operations, while reoptimization policies have an edge in large ISNs where DRL methods are difficult to train. Our results also highlight the value of collaboration and provide insights into production and procurement strategies in relation to the evolution of uncertainties.

4 - The impact of carbon reduction strategies on industrial symbiosis networks: a case study
Gulesin Sena Daş, Murat Yesilkaya, Busra Altinkaynak, Burak Birgoren

With the increasing severity of climate change and global warming, interest in mitigating carbon emissions is growing. Strategies such as carbon tax, carbon cap and cap-and-trade systems have proven effective in reducing emissions. One promising approach to cleaner production is the Industrial Symbiosis (IS) which minimizes environmental impacts by reducing waste and conserving natural resources. IS enables businesses to share resources such as waste heat, water and materials resulting from production with other businesses that can use these outputs as inputs. Essentially, IS networks function as closed-loop supply chains, where waste and by-products are continuously repurposed. Studies have shown that these networks, which focus especially on byproduct and waste sharing, positively affect other environmental and social goals. However, it is unclear how IS networks respond to different carbon reduction strategies of governments. To explore this, we utilize multi-objective models that focus on the objectives of maximizing total profit and minimizing raw material use within the IS network. Our research aims to understand how carbon reduction strategies influence the emissions in the network as well as the material and by-product flows. We believe this research will contribute to a better understanding of IS network dynamics and supports the development of effective management strategies for promoting sustainable production practices.

■ WA-43

Wednesday, 8:30-10:00 - Room: Newlyn GR.07

Modelling languages

Stream: Software for Optimization
Invited session
Chair: *Susanne Heipcke*

1 - Recent improvements to JuMP
Oscar Dowson

JuMP is an open source algebraic modeling language and collection of supporting packages for mathematical optimization in Julia. JuMP makes it easy to formulate and solve a range of problem classes, including linear programs, integer programs, conic programs, semidefinite programs, and constrained nonlinear programs. In this talk we discuss a number of recent improvements to JuMP, including our new nonlinear API, which supports MINLP solvers such as Gurobi and Xpress, and a plug-in framework for the automatic differentiation of nonlinear programs. We also briefly give an overview of new JuMP extensions, such MathOptAI.jl for embedding trained machine learning predictors into a JuMP model, and MultiObjectiveAlgorithms.jl for solving multi-objective optimization problems.

2 - Recent new features of FICO Xpress APIs and Xpress Mosel
Susanne Heipcke

This talk gives an overview of recent updates to the FICO Xpress APIs: a completely new set of object-oriented APIs (C++, C#, Java) has been published that make use of modern programming language features. These APIs work directly with Xpress Solver without any need for keeping intermediate copies of problem data.

The Python API for Xpress has been reworked to align it more closely with the other APIs, in particular by introducing linked objects that directly modify the problem, leading to performance improvements for large problems. Besides NumPy, the Python API now also supports SciPy for the efficient creation of large constraint expressions.

We shall also give a short introduction to the newly published Julia API for Xpress that is provided open-source on Github (see https://github.com/fico-xpress/XpressAPI.jl) and through the official Julia registry.

FICO Xpress Mosel has undergone some restructuring of its distribution and build processes, with significant updates to its open source component 'moseltest' (see https://github.com/fico-xpress/mosel). Other new Mosel features include improvements to data handling functionality and support of new Xpress features.

3 - GAMSPy - A Glue Between High Performance Optimization and Convenience
Muhammet Soyturk

GAMSPy - A Glue Between High Performance Optimization and Convenience Muhammet Abdullah Soyturk

A typical optimization pipeline consists of many tasks such as mathematical modeling, data processing, and data visualization. While GAMS has been providing tools with great performance for mathematical modeling, Python and its giant ecosystem provide packages for data gathering, pre/post-processing of the data, the visualization of the data and developing necessary algorithms by utilizing existing ones. In this talk, we will talk about a "glue" package GAMSPy that aims to combine these two environments to leverage the best of both worlds.

4 - Recent Advances in Flowty
Simon Spoorendonk

Flowty is a solver tailored to structured network optimization problems. By combining graph-based modeling with column generation, it enables scalable formulations for problems involving flows, paths, and resource constraints. Constraints are modeled directly on graph elements and traditional integer variables, allowing for expressive yet compact models. Recent developments have focused on improved strategies for solving various multi-commodity flow network problems—with and without resource-constrained paths—an important core challenge in middle-mile transportation networks, among others. In this talk, we present the latest algorithmic enhancements and share recent benchmark results demonstrating Flowty's performance improvements.

■ WA-44

Wednesday, 8:30-10:00 - Room: Newlyn 1.01

Forecasting methods and electricity markets

Stream: Energy Economics & Management
Invited session
Chair: Ibrahim Abada

1 - A Novel Forecasting Framework for Monthly Energy Consumption: AN Explainable Machine Learning Approach
Hamid Eskandari

This study presents an innovative framework that integrates feature selection (FS) methods with machine learning (ML) models to forecast national energy consumption (EC) across multiple energy sources in the United Kingdom. The proposed framework combines three FS approaches—ensemble filter, wrapper, and a hybrid filter-wrapper—with five interpretable ML models, employing Shapley Additive Explanations (SHAP) to enhance both the accuracy and transparency of EC predictions. By incorporating diverse features such as meteorological data, socioeconomic parameters, and historical consumption patterns, the framework optimizes the selection of relevant features, resulting in a more robust and interpretable forecasting model. Experimental results demonstrate the effectiveness of the ensemble FS approach, which refines the feature set and improves forecasting performance. The findings highlight that different FS methods yield varying feature subsets, which contribute to more precise predictions. This study not only advances the field of energy consumption forecasting by integrating advanced FS techniques with ML but also provides a valuable tool for policymakers and energy analysts, offering both accuracy and interpretability in EC predictions. The framework promises to guide future decision-making in energy resource allocation and policy planning.

2 - Bridging Data-Driven and Fundamental Models: Estimating a Merit Order for Probabilistic Day-Ahead Electricity Price Forecasting
Paul Ghelasi, Florian Ziel

Power prices can be forecasted using data-driven or fundamental models. Data-driven models learn from historical patterns, while fundamental models simulate electricity markets. Traditionally, fundamental models have been too computationally demanding for intrinsic parameter estimation or frequent updates, which are essential for short-term forecasting. We propose a novel data-driven fundamental model that combines both approaches. By estimating the parameters of a fully fundamental merit order model from historical data, similar to data-driven models, we eliminate the need for fixed technical parameters or expert assumptions. This allows direct calibration to observations. The model is efficient enough for rapid parameter estimation and forecast generation. Applied to German day-ahead electricity prices, it outperforms both classical fundamental and purely data-driven models. It captures price volatility and sequential price clusters, which are increasingly important with growing renewables. Additionally, the framework enables probabilistic forecasting by modeling entire distributions of input data. By fitting probability distributions to all input variables and sampling from them, the model generates a range of possible price outcomes, effectively capturing forecast uncertainty.

3 - Mitigating market incompleteness with little market distortions: the case of negative spot prices for electricity
Ibrahim Abada, Andreas Ehrenmann

Risk-mitigation instruments are essential to foster investments in electricity production assets and their role is all the more important in the case of market incompleteness. At the same time, such instruments may induce distortions of competition limiting spot markets' effectiveness. An example of such an effect is the dramatic increase of negative spot prices observed in power markets. Such distortions have been so far overlooked in most quantitative research dedicated to market incompleteness, which, most of the time assumes that agents are perfectly competitive. This paper proposes a framework to integrate market distortions when analyzing incompleteness using a bi-level programming approach. The lower level models the power economy via the now standard equilibrium formulation of the two-stage investment problem under risk aversion. A central planner, acting on behalf of consumers, offers a set of risk-mitigation schemes in the form of Contracts for Difference and price markups to foster investments but these can distort competitive bidding of producers. In the upper level, the central planner best tunes the design of contracts so that social welfare is maximized. We provide an existence result and undertake a thorough numerical simulation inspired by the French power system, which demonstrates the potential of best tuning the risk-mitigation instruments offered to electricity producers to enhance welfare and limit the prevalence of negative prices.

4 - Forward electricity market with nonconvexities
Quentin Lété, Thomas Hübner

Thermal generators must decide whether to produce electricity well in advance, as starting up or shutting down operations require lead time. By participating in forward auctions, like day-ahead or intraday auctions, they can lock in prices, ensuring that they will not make a loss when committing to produce power in the future. Their participation leads to the auction turning nonconvex as thermal generators must communicate indivisible fixed costs associated with start-up and shutdown operations. How to price electricity in such a nonconvex auction is a long-standing debate, but a consensus seems to be emerging towards convex hull pricing. However, most existing literature studies the nonconvex forward market in isolation, ignoring the relationship with the convex real-time market. In this talk, we propose a model to study nonconvex pricing in two-settlement markets, accounting for both day-ahead and real-time markets with financial participants. We show on an illustrative example that, in this case, most of the theoretical properties of convex hull pricing (efficiency and loss opportunity costs minimization) cease to hold. We then present simulation results on a case study calibrated on the PJM market.

■ WA-47

Wednesday, 8:30-10:00 - Room: Parkinson B08

Consumer Demand and Marketing II

Stream: Retail Operations
Invited session
Chair: Winfried Steiner

1 - The impact of users' participation patterns on NPD ideas' attention allocation in online innovation communities
Teng Yixiong

When users write up and post their new product development (NPD) ideas online, they exhibit different linguistic styles that reflect their varying participation patterns, including "Opinion leader","Self-presentation", "Enjoyment" and "Altruism". This study examines the role of users' participation patterns in shaping the NPD ideas' attention allocation of company employees in the context of online innovation communities. we develop a theoretical model positing that online users' participation patterns influence the NPD ideas' attention allocation by company employees and that the effect of users' participation patterns on NPD ideas' attention allocation is contingent on various online community characteristics, including the breadth and depth of online communities. Analyzing more than 200,000 NPD ideas collected from Xiaomi's online innovation community, we find that "Opinion leader" and "Self-presentation" have a positive effect on NPD ideas' attention allocation, while "Enjoyment" and "Altruism" have a negative effect. We also find that the positive effect of "Opinion leader"

and "Self-presentation" on NPD ideas' attention allocation is weakened when the breadth of the online community is high and strengthened when the depth of the online community is high. Additionally, we discuss how users can attract the attention of employees so that the employees will focus on their NPD ideas, and we offer suggestions to managers to realize the potential of their online comunities.

2 - Selling and Subscriptions for Clothing Retailers
Janice Carrillo

Recently, several retailers (such as Rent the Runway and Nuuly) have offered subscription services for clothing enabling consumers to effectively rent items of clothing for a short period of time. Yet many of these retailers were unprofitable and discontinued these subscription services. To illustrate, Rent the Runway initially established itself as a clothing rental company focusing on luxury clothing used for special social or work occasions, procuring inventory mainly from designer clothing retailers. While Rent-the-Runway experienced initial success, its profitability recently dropped. In contrast, Nuuly is a profitable subscription service associated with the Anthropologie group which utilizes inventory similar to that which is sold in its stores, focusing chiefly on everyday clothing options. In this paper, we compare and contrast subscription and traditional selling business models in the clothing retail space to establish key factors for success in the clothing industry. In particular, we analyze a model of clothing subscription focusing on the impact of inventory and scale on ultimate retailer profitability.

3 - Retailer's Optimal Pricing Strategies and Channel Dynamics in Live Streaming Sales
Asmita Mukherjee, Arqum Mateen

The retail platform sector has witnessed the emergence of live stream e-commerce, a novel approach where products are showcased by streamers, and consumers make purchases in real-time during live broadcasts. This trend has gained traction on social media platforms such as YouTube and Facebook. Moreover, platforms like Amazon, Walmart, and Taobao have integrated live streaming capabilities into their e-commerce infrastructure, further expanding the reach of this innovative retail model. This study focuses on the pricing and channel choice problem of a retailer opting to sell goods through live streaming wherein they also have the option of collaborating with social media content creators, popularly known as influencers. We utilise game theory to find the retailer's optimal pricing and sales channel choices by incorporating several variables such as product prices, commission structures and the influencer's effort level towards consumer engagement. We provide several strategic insights for the platform stakeholders to increase their profits which is prone to be influenced by consumer's sensitivity towards the overall quality of live streaming in different channels and also suggest potential future directions.

4 - Influencer's Persuasion for Self-Owned Brand When Endorsing National Brand
Jingxin Zhang

Top influencers can persuade their self-owned brand (IB) to consumers as well as endorsing national brand (NB). This paper investigates the influencer's optimal persuasion mechanism in co-opetitive relationship with supplier. Utilizing a Bayesian Persuasion framework, the influencer makes evaluation effort to improve the precision of information. After trading off the margin-increasing effect and evaluation effort cost, the influencer has more incentives to improve information precision as the evaluation efficiency increases. The optimal information strategy evolves from no disclosure to partial disclosure, and ultimately to full disclosure. Correspondingly, consumers behaviors shift from not searching and directly purchasing NB, to searching for information and follow the influencer's persuasion. Two key system parameters, evaluation efficiency and IB prior perception, have non-monotonic impacts on both supplier and influencer. Specifically, an increasing evaluation efficiency may harm the supplier when it is relatively low but benefit the supplier when it is high. Additionally, a higher IB prior perception may benefit the supplier but harm the influencer. We also investigate the impact of different pricing timings in extension. The influencer under late pricing exerts weakly higher effort in evaluation than under early pricing. Correspondingly, the influencer prefers late pricing, while the supplier's preference varies based on system parameters.

■ WA-48

Wednesday, 8:30-10:00 - Room: Parkinson B09

Fairness and transparency in machine learning and optimization

Stream: Transparent and Fair Decision Making with Mathematical Optimization
Invited session
Chair: *Philipp Baumann*

1 - Balancing cost and fairness in large-scale fair clustering
Claudio Mantuano, Philipp Baumann

Clustering is an unsupervised learning task that consists of finding groups of similar objects. It has a wide range of applications and is increasingly used in sensitive contexts where the objects represent customers, employees, or students, with fairness aspects playing a crucial role. In this work, we consider a fair clustering problem where each object is associated with a category of a sensitive feature such as race or gender. The problem consists of assigning the objects to a predefined number of clusters such that each cluster is fair, meaning each category of the sensitive feature meets a user-defined level of representation. The objective is to minimize the clustering cost, defined as the sum of squared distances between the objects and their respective cluster center. Existing fair clustering approaches offer limited control over the trade-off between clustering cost and fairness. Furthermore, many leading fair clustering algorithms do not scale effectively to large-scale instances. To address these limitations, we propose a new approach for the fair clustering problem described above that offers better control over the cost-fairness trade-off and scales to large-scale instances. Numerical experiments on synthetic data sets and widely used benchmark data sets demonstrate the effectiveness and efficiency of our approach.

2 - Enhancing optimization interpretability through problem simplification
Berta Ruiz-González, Sara Lumbreras, Javier García-González

Although interpretability is gaining traction in Artificial Intelligence and Machine Learning, it remains largely overlooked in Optimization, where black-box models are the standard. We introduce a method to enhance the interpretability of optimization models by focusing on the most influential variables and constraints, effectively reducing complexity with controlled impact on accuracy. Our approach systematically eliminates extraneous variables and redundant constraints using filters inspired by existing presolve techniques. To ensure feasibility, constraints are carefully adjusted while redundant elements are removed. We validated this method on 60 linear problems from the GAMS library and openTEPES, a real-world optimization model for long-term energy system expansion. Sensitivity analysis across different thresholds demonstrated that our approach significantly reduces problem size while preserving optimality and feasibility. While preserving the essential structure of the problem, the analysis of the automatic simplification process makes optimization models more transparent and easier to interpret.

3 - A matheuristic for large-scale shift planning problems in the health care industry
Philipp Baumann, Maude Bersier

The majority of employees in the healthcare industry work in shifts. Shift planning is therefore a critical task that directly affects the working conditions and social lives of healthcare personnel. Modern shift planning has become increasingly complicated, as it must account for operational efficiency, legal requirements, employee preferences, and fairness. In addition, with the consolidation of medical services into larger institutions, the size of typical shift planning problem instances

has increased. We consider here a shift planning problem that consists of assigning shifts to employees subject to various hard and soft constraints related to preferences of employees. The objective is to minimize the total penalties associated with violations of soft constraints. The large size of typical instances of this problem poses a challenge to existing shift planning algorithms in terms of scalability. In this work, we propose a new matheuristic that combines problem decomposition strategies with integer programming to achieve the required scalability. Using benchmark instances from the literature, we demonstrate the effectiveness and efficiency of our approach.

4 - Towards a more equitable AI with combined strategies and innovations in fairness
Sandra Benítez-Peña, Rosa Elvira Lillo Rodríguez, Arturo Pérez-Peralta

The increasing adoption of Artificial Intelligence (AI) and Machine Learning in high-impact decision-making (such as in healthcare, organizational justice, and finance) has raised the demand for fairness in these systems. In this work, we present novel approaches to improving fairness in ML through innovative fairness techniques. First, we explore equitable methods that incorporate constraints based on statistical distances to provide verifiable fairness guarantees. We present theoretical perspectives on the relationship between accuracy and fairness, and validate these findings through empirical implementations. Second, we address the challenge of managing multiple sensitive variables by introducing logical processors and multilevel processors, an innovative approach to combining fairness techniques. Our analysis investigates whether these hybrid methods can work synergistically to improve both fairness and accuracy. We also explore their integration in a multivariate context, showing promising results that validate their effectiveness. By connecting theoretical guarantees with practical applications, our work highlights how combining different fairness strategies can lead to fairer AI systems, with measurable and reliable improvements in fairness.

■ WA-50

Wednesday, 8:30-10:00 - Room: Parkinson B11

Systems Thinking 3

Stream: Systems Thinking
Invited session
Chair: *Richard Beasley*

1 - Dynamic Modeling of Transport and Housing Choices: A Luxembourg Case Study
Negar Rezvany, Tim Hillel, Michel Bierlaire

The urban context is a combination of choices: (i) across time horizons: from daily travel mode decisions to long-term residential and infrastructure planning, and (ii) at different hierarchical levels: from individuals/households to public authorities. Urban areas face challenges like congestion, rising housing prices, and accessibility issues, leading to resident relocation. This highlights the need for forecasting tools to model transport and housing choices dynamically. Traditional transport models treat land use exogenously, neglecting interactions, while Land-use Transport Interaction models explore these links. A key challenge is capturing time lags between urban processes—travel mode choice (fast), residential relocation (medium), and infrastructure development (slow). We make a dynamic multi-year model integrating transport-housing feedbacks while accounting for different time lags and hierarchical levels, based on System Dynamics principles. With a daily time-step, it captures short- (daily), mid- (monthly), and long-term (yearly) decisions. An empirical application to Luxembourg with model specifications and calibration for the case-study is showcased, simulating residents' travel and location choice behavior in Luxembourg region including the cross-border commuters. This computationally efficient decision-support tool enables policymakers to assess short- to long-term urban and transport strategies, guiding sustainable planning and investment decisions.

2 - Desperately Seeking Synthesis: Blending Elements of Systems Thinking, Strategy Design, and Operational Research to Address the Challenges of VUCA
Andrew Firth

For some considerable time, managers in all walks of life have recognised increasing challenge from an environment now recognised to be volatile, uncertain, complex, and ambiguous. Numerous proposals have been made to counter this challenge, but for the large part, they fail for much the same reason; they are little more than a 'silver bullet' approach. All have their merits - and indeed their proponents - in isolation, but to deal with complexity anything other than a synthesised approach is a contradiction in terms and doomed to failure.

This paper argues that an approach that blends selected techniques, methods, and methodologies drawn from and inspired by Systems Thinking, Strategy Design, and OR techniques offers more than the sum of its parts to managers who remain desperately seeking ways to meet the challenge of the VUCA environment. It proposes an approach that synthesises their respective advantages and makes the case for its adoption to address the significant systemic challenges we currently face.

3 - The System(s) needed to create a system
Richard Beasley

Standard Systems Engineering focused on identifying the technical stakeholders and their needs that constrain and drive the development of a solution. These solutions can either be a complicated product system (ship, building, engine) or a complex system, capability or service (such as a city, transport system or health service). This paper will explore how these solutions are created, and especially focus on two important "systems" that interact critically with the technical solution. The first of these is the program / project to develop the solution. This provides significant additional constraint in terms of system development cost, project timescale and resource availability. A technically sound solution that does not meet the program constraints is not viable The second is the organization, and its capabilities - people, technology, knowledge, tools, processes, infrastructure, roles, etc. - if these are either not adequate or not properly used then there is great risk the development will be unsuccessful These system consideration make the development of any engineered solution (complicated or complex) more than a technical challenge - it is a complex socio-technical system situation.

■ WA-51

Wednesday, 8:30-10:00 - Room: Parkinson B22

Advances in multiobjective optimization software

Stream: Multiobjective and vector optimization
Invited session
Chair: *Giovanni Misitano*
Chair: *Kaisa Miettinen*

1 - Visualisation techniques in multi-objective optimization: The Liger software
Joao Duro, Robin Purshouse

Visualisation techniques in multi-objective optimization are essential for supporting decision-maker(s) (DMs) in identifying conflicts and synergies between objectives and for navigating high dimensional problem spaces toward the most promising compromise solutions. In high dimensions, parallel coordinates plots and glyphs are commonly used, but have limitations. Visualisations with dynamic and interactive features are able to better engage the DM in the optimization process. In addition, the use of machine learning in visualisation techniques is gaining traction. For instance, objective reduction methods can be

used to identify a subset of essential objectives, reducing the cognitive load on the DM. This talk will cover a novel integration of machine learning and traditional visualisation techniques, implemented in Liger—an open-source optimization and decision-making workflow software. Liger has been developed in partnership with real-world problem stakeholders, and provides dynamic and interactive visualisations that are driven by the popular D3.js library.

2 - MODA - A new C++/Python library with algorithms and data structures for multiobjective optimization
Andrzej Jaszkiewicz, Jakub Dutkiewicz, Piotr Zielniewicz

Advancements in (evolutionary) multiobjective optimization can be achieved not only by developing new MO methods but also by enhancing the efficiency and/or accuracy of fundamental algorithmic procedures used across different MO techniques. In recent years, we have introduced various data structures and algorithms to address tasks such as: - Efficiently updating the Pareto archive, including verifying whether a new solution is nondominated, adding it to the archive if so, and removing dominated solutions, utilizing the ND-Tree data structure. - Identifying the solution that minimizes or maximizes a (modified) Chebyshev scalarizing function over a finite solution set, also leveraging ND-Tree. - Efficiently estimating hypervolume or R2 (contribution) with the ND-Tree. - Computing hypervolume using the improved quick hypervolume algorithm. - Determining guaranteed bounds for hypervolume (contribution). - Enhancing the accuracy of Monte Carlo-based hypervolume (contribution) estimation. - Identifying the extreme (minimum or maximum) hypervolume contribution/contributor within a solution set. - Hypervolume subset selection using a lazy incremental or decremental greedy approach. - Performing on-the-fly updates of hypervolume values. - Exactly calculating the R2 quality indicator. We present a new MO library called MODA (MultiObjective Data structures and Algorithms) in C++ with Python interface that implements these algorithms and data structures.

3 - moocore: Core Algorithms for Multi-Objective Optimization in C, R and Python
Manuel López-Ibáñez

The moocore project collects fast implementations of core mathematical functions and algorithms for multi-objective optimization and makes them available to different programming languages via similar interfaces. These functions include: identifying and filtering dominated vectors; quality metrics such as (weighted and approximated) hypervolume, epsilon, IGD, and others; and computation of the Empirical Attainment Function, which describes the probabilistic distribution of the outcomes obtained by a stochastic algorithm in the objective space.

Many projects such as BoTorch (Bayesian Optimization in PyTorch), pymoo (Multi-objective Optimization in Python), rmoo (Multi-objective Optimization in R), among others, use their own inefficient implementations of such functions or copy old versions of publicly available implementations, which may have bugs or have not benefited from speed improvements.

The goal of moocore is to provide an implementation of these functions that is efficient, thoroughly tested, well-documented, multi-platform (Windows, Linux, MacOS), multi-language (C, R, and Python, so far), with minimal dependencies and reusable from other libraries and packages, thus providing an easy-to-use and high-performance building block for the research community. The development sources are available at https://github.com/multi-objective/moocore/ (R: https://multi-objective.github.io/moocore/r/ and Python: https://multi-objective.github.io/moocore/python/).

4 - DESDEO 2.0: the new and improved open-source framework for interactive multiobjective optimization
Giovanni Misitano, Bhupinder Singh Saini, Juho Roponen, Juuso Pajasmaa, Giomara Lárraga, Babooshka Shavazipour, Kaisa Miettinen

DESDEO is an open-source Python framework for implementing and applying interactive multiobjective optimization methods. Interactive methods involve the decision maker in the optimization process, allowing them to iteratively provide preferences and explore available solutions. Preferences can be utilized to find the most promising solutions for the decision maker, helping them in tackling the tradeoffs among the conflicting objective functions of the problem being solved.

DESDEO 2.0 is the newest major release of the DESDEO framework. The development of new framework has consisted of a full restructuring. In this process, we have developed a novel way to model and represent a vast array of different multiobjective optimization problem types, including non-linear and data-driven problems. Once a problem is modeled, it can be solved using a variety of interactive methods, ranging from exact mathematical methods to heuristic-based evolutionary optimization. This makes DESDEO applicable to a wide range of domains.

This talk will give an overview of DESDEO 2.0's newest features and how to get started using the framework. The framework is aimed to both practitioners and researchers in multiobjective optimization. DESDEO is very modular, making it suitable for experimenting with new ideas, and allowing the reuse of existing components. Our goal is to make DESDEO a collaborative open-source hub for researching and applying interactive multiobjective optimization.

■ WA-53

Wednesday, 8:30-10:00 - Room: Liberty Moot Court

New Trends in Game Theory VIII

Stream: Game Theory and Mathematical Economics
Invited session
Chair: *Yinlian Zeng*

1 - Compensation strategies in online food delivery platform
Yinlian Zeng

This paper examines compensation strategies in online food delivery platforms to mitigate delivery delays. We focus on two key policies: the time-based policy (T policy) and the time-and-price-based policy (TP policy). Our findings show that the effectiveness of the T policy depends on perceived service value, while the TP policy is influenced by the service fee rate and unit compensation fee. When the promised delivery times is endogenously determined, the T policy may favor shorter times to attract customers to on-time delivery services. In contrast, the TP policy may find either short or long delivery times optimal.We also discuss two special compensation policies independent of delay time, highlighting that policies tied to delay duration generally outperform those not linked to it. Our results provide strategic insights into customer behavior and platform management, emphasizing the need for tailored compensation policies to enhance customer satisfaction and platform profitability.

2 - Strategic adoption of telemedicine in a compeititve healthcare market: Intra- or Inter-hospital Blended Treatment Mode
Yufei Ge, Yanfei Lan

With the evolution of information and data technology, telemedicine enables patients to access healthcare from home. However, due to the complexities involved, patients should combine online consultations with offline examinations, a practice known as blended treatment. Telemedicine can be categorized into two modes: intra-hospital, confined to a single institution, and inter-hospital, requiring collaboration between different healthcare entities. By employing game theory, we analyze how hospitals implement these modes and their impact on competition dynamics. Our findings suggest that implementing telemedicine does not guarantee increased profitability; instead, it depends on the specifics of the telemedicine model. When telemedicine services are introduced, a hospital may refrain from further expanding its telemedicine offerings if the costs are high and the potential for enhancing market accessibility is low, thus resulting in adoption of the intra mode. Due to the advantages of openness, the inter mode is more frequently realized, and the existence of a substantial area allows for

greater benefits to the hospitals providing the service, leading to a win-win situation. Nevertheless, hospitals in a passive position may still be at the mercy of more proactive hospitals. This study deepens our understanding of the strategic implications and economic consequences of various blended care modes, providing valuable insights for healthcare organizations in this evolving landscape.

3 - Random partitions, potential, value, and externalities
Frank Huettner, André Casajus, Yukihiko Funaki

We consider fair and consistent extensions of the Shapley value for games with externalities. Based on the restriction identified by Casajus et al. (2024, Games Econ. Behavior 147, 88-146), we define Balanced Contributions, Sobolev's consistency, and Hart and MasColell's consistency for games with externalities, and we show that these properties lead to characterizations of the generalization of the Shapley value introduced by Macho-Stadler et al. (2007, J. Econ. Theory 135, 339-356), that parallel important characterizations of the Shapley value.

■ WA-54

Wednesday, 8:30-10:00 - Room: Liberty 1.08

Applications in Queueing Theory

Stream: Stochastic modelling
Invited session
Chair: Gabi Hanukov

1 - Optimal and approximate solutions to the backup server selection problem
Vasco Alves, Refael Hassin, Jiesen Wang

Backup servers are often used in service systems when the primary servers are overloaded. Backup servers may have a lower service quality or a slower service rate. We analyze a system with one primary and one backup server and compute the system and individually optimal server-selection strategies. We also compare the optimal strategy with the better of two simpler strategies: using only the primary server or never waiting for the primary server when the backup server is idle. We demonstrate numerically that the better of two simpler strategies is a good approximation, in terms of optimal social welfare. We also compare the decentralized equilibrium strategy to the socially-optimal behavior. We show that the Price of Anarchy can be arbitrarily large. However, the socially-optimal behavior can be induced by charging an admission fee to the system and a price for using the high quality server.

2 - Transient Analysis of a Single-Server Queueing System with Expired Customers and Discouraged Arrivals: Applications in Healthcare Management
Suranga Sampath Miyanawathura Ihala Gamage

This research explores a single-server queueing system that integrates the concept of expired customers and discouraged arrivals. In this system, customer arrivals follow a Poisson process, where the arrival rate depends on the number of customers already present. Service times are assumed to be exponentially distributed, and the remaining lifetime of a critically ill patient entering the queue is also modeled as an exponential distribution. If a patient's service is not completed before their remaining lifetime expires, they are classified as expired customers. This study introduces a novel approach, particularly relevant to healthcare management systems, by analyzing how such a queue operates under these conditions. Using mathematical techniques such as the probability generating function and the Laplace transform, the study derives transient system size probabilities. Additionally, several key performance measures are computed, and numerical results are presented to illustrate the system's behavior in the transient state. The findings provide practical insights into optimizing healthcare queue management, especially in scenarios involving critically ill patients.

3 - Efficient Q-Learning for Constrained Decision-Making
Khushboo Agarwal, Konstantin Avrachenkov

Markov decision processes (MDPs) provide a framework for sequential decision-making in stochastically evolving systems. When the transition dynamics are unknown, reinforcement learning (RL) algorithms, such as Q-learning and actor-critic (AC) methods, are commonly used to obtain optimal policies.

The situation is more involved when there are additional constraints. Most RL literature focuses on inequality constraints and employs Lagrangian-based methods for the analysis. However, equality constraints naturally arise in several real-world applications. For example, in queueing systems, one may seek to minimize the delay while ensuring a desired throughput (equality constraint) and an energy cost lesser than a given value (inequality constraint). Similarly, in wireless communication with mmWave systems, a controller might aim to optimize beam alignment to minimize power consumption while maintaining a fixed transmission rate (equality constraint) and keeping the expected number of realignments within a permissible limit (inequality constraint).

Driven by these practical examples, we study average-cost MDPs with 'equality and inequality' constraints. To address this, we propose and analyze a more efficient 'two-timescale' Q-learning algorithm, in contrast to the previously studied slower 'three-timescale' AC algorithm designed only for inequality-constrained MDPs. We also illustrate the performance of our algorithm for the instances mentioned above.

■ WA-55

Wednesday, 8:30-10:00 - Room: Liberty 1.09

Disaster Response

Stream: Humanitarian Operations
Invited session
Chair: Oscar Rodriguez-Espindola

1 - Optimization of community volunteers' participation in emergency flood management
Fan Chen, Sander De Leeuw, Dobrila Petrovic

The UK is one of the countries with the highest flood risks and occurrences. 1,258 severe flood events occurred in England between 2015 and 2020, impacting over 300,000 residents. Climate change and urbanization have intensified the challenge of flood management. Flood management practitioners have increasingly called for collaborative networks and for integration of community volunteers. We are considering real-world flood management in one of county in England. There are regional imbalances in community volunteer participation in emergency which create differences in emergency efficiency. Recent studies have demonstrated that well-coordinated volunteers' efforts can considerably reduce response times and improve overall crisis management. However, these studies tend to focus on the qualitative aspects of volunteer involvement. This research proposes a novel multi-objective optimisation model that integrates community volunteer resources into the emergency management decision-making process. The model determines optimal number of volunteers in different regions. It considers multiple objectives simultaneously including:1) management costs associated with volunteer recruitment, training, and provision of necessary equipment,2) response time reflecting the speed at which volunteers can be deployed to affected areas, taking into account geographical factors and infrastructural constraints and 3) cost incurred when volunteers are transferred to different communities.

2 - A Location-Routing Framework for Efficient Shelter and Vehicle Allocation in Disaster Relief Operations
Jingtong Ma, Antonio Martinez Sykora, Carlos Lamas-Fernandez

Efficient location-routing planning is critical for disaster relief operations, where timely decisions significantly impact emergency response effectiveness. This study proposes three different models, each building upon the previous one, with the aim of minimizing total costs.

In the first model, a single-objective LRP assigns each affected area to only one shelter and determines the minimum number of vehicles required under a time constraint. The second model extends the first by allowing vehicles to serve multiple affected areas from the same shelter if needed, improving resource utilization and cost efficiency. The third model introduces more realistic conditions, including heterogeneous vehicles and different types of shelters with capacity selection options, reflecting real-world complexities. This framework balances computational efficiency with practical usability, demonstrating its potential to optimize shelter selection and vehicle allocation, thereby improving disaster response efficiency. By addressing real-world constraints and complexities, this study provides a practical decision-support tool for emergency decision-makers.

3 - A Dynamic Resource Allocation Model for Search-Rescue and First Aid Tasks in Disaster Response
Emine Nisa Kapukaya, Sule Itir Satoglu

The size and location of the disaster, as well as the socio-economic level of the affected region, affect the participation of actors in relief operations and the coordination structure.

A model for Search-Rescue and First Aid activities has been developed to address the issue of resource allocation in disaster response. The model prioritizes tasks based on the urgency of saving human lives, focusing on a district of Istanbul in preparation for the expected major Marmara Earthquake. Demand was evaluated based on the expected number of damaged or destroyed buildings and victims, classified according to the NATO triage system.

To meet this demand, rescue units, trained volunteers, and spontaneous volunteers work in coordination and use renewable and non-renewable material resources. The model also takes into account the costs of training volunteers, possible road damages, and interregional resource transfer. Pre-positioning and distribution of resources are planned according to needs.

The goal of the model is to minimize unmet demand, the expected total travel distance between regions, and unmet renewable and non-renewable resources. A three-objective stochastic programming model is formulated. AUGMECON2 method is used to solve the multi-objective model, and the results are analyzed through sensitivity analyses. The study provides administrative information and suggests ideas for resource allocation planning for both human and material resources in disaster response.

4 - Multi-organizational collaboration for evacuation of mobility-impaired people
Oscar Rodriguez-Espindola

The increasing number of people affected by natural hazards underscores the need to develop mechanisms to facilitate the efficient and effective evacuation people. Those mechanisms must cater to evacuees with different characteristics. There are different models in the literature looking at shelter location and allocation, but a common assumption among them is homogeneous demand. Recent records, however, have shown that the experience of mobility-impaired people during evacuations is significantly worsened by that assumption. They require special transportation arrangements, along with the right infrastructure and services in shelters. Although these considerations are crucial, single organizations often lack the capabilities to handle those needs, whether in terms of transportation or services. The collaboration between different organizations can create synergies to offer that support. This article introduces a solution for facility location, allocation and evacuation. It uses multi-objective optimization to plan these activities allowing for collaboration between multiple organizations with different resources. It reduces the maximum distance travelled by the different types of evacuees, enhances facility reliability, and minimizes operational cost. The formulation considers the compatibility between the infrastructure available and the services offered to serve a set of heterogeneous users. The solution is tested in a set of numerical examples to draw conclusions.

■ WA-56

Wednesday, 8:30-10:00 - Room: Liberty 1.11

Real-Life Applications in Routing

Stream: Vehicle Routing and Logistics
Invited session
Chair: *Yunyun Wang*

1 - A New Mathematical Model of Soft Clustered Vehicle Routing Problem for the Waste Collection Process
Yaren Çelik, Kumru Atalay, Berna Dengiz, Tusan Derya, Bahar Yetis Kara

Waste management is a process that involves the collection, transportation, recycling, and disposal of waste to protect the environment and use resources efficiently. In this process, logistics optimization plays a crucial role. The Vehicle Routing Problem (VRP) is a combinatorial optimization problem aimed at planning the most efficient distribution of products or collection of waste from one or more depots to specific locations. VRP is used in many real-world applications, such as school buses, fuel distribution, newspaper and mail delivery, retail product distribution, and waste collection. It is classified as an NP-hard problem. Due to variations that occur in real-world problems, several types of VRP have been developed. The Clustered Vehicle Routing Problem (CluVRP) divides customers or collection points into predetermined clusters and determines the most optimal vehicle routes. The Soft CluVRP, which allows multiple entries and exits for vehicles in the clusters, is a generalized version of the classical CluVRP. This flexibility offers significant benefits, especially in waste collection processes. It reduces operational costs and improves overall efficiency. This study addresses and models a real-life problem of waste collected from specific healthcare institutions and transported to a waste collection center as Soft CluVRP. The solutions of the developed mathematical model are obtained, and sensitivity analyses are conducted to observe parameter changes.

2 - Offshore Wind Turbines Installation Problem as Vehicle Routing Problem
Charles Emeka Onyi, Kerem Akartunali, Mahdi Doostmohammadi

Specifically, this project focuses on deriving integer programming formulations for installing offshore wind turbines as a multi-trip vehicle routing problem. Then, the problem was reformulated as a shortest route problem and solved through a data-driven approach and exact solution methods. However, this formulation is modelled through a shortest path-like problem with guarantee constraints and is shown to be NP-Hard. We proposed a polyhedral analysis of the set of solutions by identifying novel problem-specific valid inequalities required in characterising the convex hull of feasible solutions. We developed an efficient algorithm to generate arbitrary predetermined routes based on existing offshore wind farms and show some computational results.

3 - A Mathematical Model for Optimizing Construction Logistics in Urban Areas
Yunyun Wang, An Caris, Kris Braekers

This study investigates the integration of a Construction Consolidation Center (CCC) into urban construction logistics to enhance efficiency while reducing costs and social burdens. A CCC serves as a consolidation hub, facilitating material bundling and Just-In-Time (JIT) deliveries. We analyze multiple scenarios to assess its benefits for cities, construction companies, and suppliers.

Our problem considers multiple urban construction sites requiring materials from external suppliers. A CCC provides storage and operates a heterogeneous vehicle fleet. Suppliers can choose to deliver materials directly to construction sites or via the CCC.

We develop a mathematical model to optimize daily delivery plans, including vehicle assignment, scheduling, and routing for two delivery

types: (1) supplier-to-site or CCC and (2) CCC-to-site. The objective is to minimize total costs, including transportation, inventory, and loading/unloading costs. A rolling horizon approach is implemented to dynamically adjust plans weekly, addressing uncertainties.

Experiments will evaluate the CCC's impact under various urban policies, such as vehicle restrictions and delivery time windows. Additionally, key parameters will be analyzed to determine under what conditions a CCC is beneficial for cities and private stakeholders.

4 - The Capacitated Arc Routing Problem with Zigzag Options
Rafael Martinelli, Thibaut Vidal

The Capacitated Arc Routing Problem with Zigzag Options (CARP-Z) arises in applications such as postal delivery, waste collection, and snow plowing, where some streets require service on both sides. Some streets need to be serviced only once, while others must be covered twice, either through separate traversals or a single zigzag pass. The goal of CARP-Z is to determine a set of minimum-cost vehicle routes where each route starts and ends at the depot, single-service streets are covered once, and double-service streets are serviced either twice or through a zigzag pass. Additionally, the total demand assigned to any vehicle must not exceed its capacity. CARP-Z is a challenging optimization problem that generalizes the classical capacitated arc routing problem. Despite its practical importance, it has received little attention in the literature. This work presents two solution approaches: a hybrid metaheuristic and an exact branch-cut-and-price algorithm. The metaheuristic extends a state-of-the-art framework by incorporating new modes to represent zigzag services and a dynamic programming approach to evaluate costs. The exact method generates high-quality solutions through a specialized pricing procedure and tailored cutting techniques. Computational experiments on benchmark instances demonstrate the strong performance of both methods and highlight promising directions for future research.

■ WA-58

Wednesday, 8:30-10:00 - Room: Liberty 1.13

Food delivery

Stream: Vehicle Routing and Logistics
Invited session
Chair: Yi-Chun Chen

1 - An LP-based local-search algorithm for the Online Food Delivery Platform Routing Problem
Ye Bin Park, Seyoung Oh, Kyungsik Lee

In this talk, we introduce the Online Food Delivery Platform Routing Problem (ORP), a novel variant of the Vehicle Routing Problem(VRP) with pickup and delivery. The ORP is distinguished by its operational policy requiring routes to first serve all pickup requests before handling deliveries. The problem can be shown to be NP-hard, but it presents significant computational challenges in practice, demanding solutions for large-scale instances with hundreds of orders within strict time constraints. To address this unique challenge, we develop an LP-based local-search algorithm for the ORP. Leveraging the classical result that the subtree packing problem on trees is efficiently solvable, we restrict the solution space of the ORP such that only orders forming a subtree of a certain spanning tree, whose nodes correspond to the given orders, can be routed together. We employ a two-level strategy: the low-level solves a restricted ORP under the given spanning tree, while the high-level iteratively modifies the spanning tree to improve solution quality. Extensive computational experiments on large-scale real-world instances demonstrate that our algorithm consistently produces high-quality solutions within the required time constraints.

2 - The capacitated vehicle routing problem with simultaneous pickup-delivery and time windows in the sustainable food supply chains
Mahdi Farshchi

The aim of our study is transportation planning in perishable food supply chains. We model this problem as the vehicle routing problem with simultaneous pickup and delivery, and soft time windows for perishable products (VRPSPD-STW-P). The objective is to minimize the total costs, consisting of variable transportation, vehicle-related fixed, food quality degradation, and time-window violation costs. We formulate the problem as a mixed-integer linear programming model. Moreover, we propose heuristic and metaheuristic algorithms in the methodology to solve the VRPSPD-STW-P. Our methodology comprises two phases: obtaining initial solutions in the first phase and improving these solutions by a genetic algorithm in the second phase. We first employ a method based on the clustering of nodes for the vehicles and different routing heuristics to generate the best routes for the vehicles; that is, solving the problem as an m-traveling salesperson problem with simultaneous pickup and delivery (m-TSPSPD). Then the solution of the problem m-TSPSPD is checked for feasibility taking into account the vehicle capacities and tour lengths; the feasible routes are then the solutions for the vehicle routing problem with simultaneous pickup and delivery (VRPSPD). Finally, the VRPSPD solution is evaluated considering the time window and quality constraints (VRPSPD-STW-P). Our solution methodology yields promising solutions in much less computational time than the exact solution procedures.

3 - Designing Efficient Distribution Networks for Mixed-Cropping Systems
Tugce Canbilen Suticen, Argyris Kanellopoulos, Sonja Rohmer, Tom van Woensel

The distribution of perishable products poses challenges in supply chain design due to limited shelf lives, sensitivity to storage conditions, and the need for coordinated transportation, storage, and processing. These complexities are intensified in agricultural systems like mixed cropping, where diverse crops are grown side-by-side, requiring specialized handling and storage. This paper presents a multi-commodity, multi-period, multi-echelon network design model for perishable products inspired by the requirements of mixed-cropping systems. Our mixed-integer linear programming model incorporates key supply chain decisions, including sales channel selection, facility location, transportation, inventory management, and processing scheduling, providing a comprehensive tool for optimizing the distribution of diverse, perishable products. This research contributes to the literature by offering a holistic network design model for perishable products, enabling the assessment of new supply chain configurations such as short food supply chains. New constraints inspired by real-world biological limitations are introduced to the problem. We demonstrate the importance of addressing these integrated decisions to achieve efficient food distribution through detailed computational analysis.

4 - An optimal integrated model with a solution algorithm for food delivery service and vehicle routing
Yi-Chun Chen, Ting-Yu Yang

With the rapid development of mobile data and the rise of third-party logistics models, food delivery platforms have become the mainstream method for ordering and delivering food. This service model, which integrates online ordering with offline delivery, provides great convenience to consumers, while also reducing the burden of food delivery on restaurants. Especially after the pandemic, consumers have gradually become accustomed to food delivery service, leading more restaurants to join these platforms. To enhance the efficiency of food delivery, platform operators have developed diverse delivery modes. For example, a courier may deliver multiple orders from a single restaurant to different consumers or pick up meals from multiple restaurants and deliver them to multiple consumers. However, the delivery mode is determined by the platform, which assigns couriers who are willing to accept multiple orders at once. This unsystematic assignment model not only leads to an insufficient number of couriers but also causes unnecessary detours during peak hours, resulting in delayed meal deliveries. In this study, the time-space network is employed to construct

an optimal integrated model aimed at minimizing delivery costs. Additionally, a heuristic algorithm is developed to efficiently solve large-scale problems. A case study is conducted to perform the model and algorithm. The results are good, showing that both the model and the algorithm could be useful references in practice.

■ WA-60

Wednesday, 8:30-10:00 - Room: Western LT

DEA applications in Policy Making and Planning I

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: Xun Zhou

1 - Measuring operational efficiency of residential and domiciliary adult care providers: Evidence from online reviews and Data Envelopment Analysis approach
Sojeong Kwon, Seongsoo Jang, Yuncheol Kang

Research has increasingly focused on adult care services, reflecting the expanding range of living options for elderly individuals. This study assesses the operational efficiency of residential and domiciliary adult care providers in the UK from 2015 to 2023 using window Data Envelopment Analysis (DEA). First, we collect online reviews scraped from 100 residential and 100 domiciliary care service providers and quantify input and output variables using sentiment analysis of review content on a yearly basis. Additionally, we extract historical government-driven inspection data from the Care Quality Commission to examine the influence of government interventions on changes in care operational efficiency. Second, we identify both established and novel input and output variables for residential care providers (covering tangible and intangible attributes) and domiciliary care providers (covering intangible attributes). Finally, we evaluate the efficiency of decision-making units (DMUs) using window DEA, which captures value changes over time by assessing DMUs across multiple periods. As a post-DEA analysis, we employ clustering techniques such as K-means analysis to categorize the results, analyze differences in overall trends and identify key variables that distinguish each group. These findings highlight critical factors driving efficiency in the UK's residential and domiciliary adult care sector, offering valuable insights for improving the quality of care services.

2 - Causal effects of policy interventions on productive performance: integrating synthetic control methods into the nonparametric approach
Xun Zhou

Examining the causal effects of policy interventions on productive performance is critical for policy analysis and managerial decision-making. A typical method in the nonparametric approach is to regress efficiency estimates on policy interventions and contextual variables. However, this method has been criticized for ignoring the correlations between inputs and policy interventions and/or contextual variables and hence subject to endogeneity in the efficiency estimation. To address this issue, this study proposes to integrate synthetic control methods (SCM), a data-driven causal inference technique, into the nonparametric approach. SCM estimates the causal effect by constructing a counterfactual of the treated unit (i.e., synthetic control) using a convex combination of control units, analogous to the rationale in DEA. In the integrated framework, 1) SCM ensures the treated unit and the synthetic control closely match before the treatment, with respect to the input, output, and contextual variables; 2) the nonparametric approach estimates the post-treatment efficiency both for the original sample of units and for the synthetic sample where the treated unit is replaced by the synthetic control while retaining all the control units. The causal impact of the policy intervention is then estimated by comparing the efficiency of the treated unit with that of the synthetic control, that is, the counterfactual efficiency of the treated unit in the absence of the intervention.

3 - Efficiency of local government units in northwestern philippines as to the attainment of the millenium development goals
Milagros Baldemor

This study entitled "Efficiency of Local Government Units in Northwestern Philippines as to the Attainment of the Millennium Development Goals" determined the performance of the four provinces and eight cities in Region I, Philippines, vis-à-vis their efficiency along the eight goals and 21 targets of the Millennium Development Goals (MDGs) for 2021-2024. Furthermore, it determined the peer groups and weights of the DMUs (Decision Making Units - the different provinces and cities), the virtual inputs/outputs or potential improvements of the DMUs to be in the efficient frontier, the input and output slacks (input excesses and output shortfalls) needed in the different indicators and the best practices to be considered by the inefficient and weak efficient DMUs. The "best practice" in the frontier is the basis to calculate the adjustments necessary for the DMUs. Different indicators showed varied performance levels in the different years but there are best practices from the "efficient" DMUs which could be adapted by the "weak efficient" and "inefficient" ones.

4 - Exclusive-Or Multiple Criteria Data Envelopment Analysis and Its Application in Renewable Energy
Tareq Ait Hsain, Noureddine Kouaissah

Exclusive-or (XOR) uncertainty arises when decision makers (DMs) are hesitant to express a choice among multiple competitive actions. Several works have shown that integrating XOR uncertainty into the different existing decision making frameworks leads to better results that stem from the greater flexibility offered to DMs. To this end, we develop XOR Multiple Criteria Data Envelopment Analysis (XOR-MCDEA), a novel approach for investigating the impact of XOR uncertainty on MCDEA models. MCDEA has recently emerged as a valuable tool for efficiency analysis that solves two major issues in DEA: weak discriminating power and unbalanced weight dispersion. We extend existing MCDEA models to accommodate XOR uncertainty, and propose methods for determining optimal model parameters. The usefulness of the proposed methods relative to the standard MCDEA is demonstrated through an illustrative example from the MCDEA literature. Moreover, a case study on renewable energy projects is presented as an illustrative application that demonstrates the effectiveness of the proposed approach in addressing technological uncertainties while preserving the advantages of multi-criteria evaluation. The results indicate that the proposed XOR-MCDEA significantly enhances the robustness of efficiency scores and meaningfully discriminates among decision-making units, thereby contributing to the broader field of uncertainty modeling in DEA.

■ WA-61

Wednesday, 8:30-10:00 - Room: Maurice Keyworth G.31

Behavioural lessons from OR use in the lab and field

Stream: Behavioural OR
Invited session
Chair: Monica Oliveira

1 - The impact of causal loop diagrams on business performance
Martin Kunc

An experimental study was conducted to assess the effect of causal loop diagrams on business performance. The findings indicate that providing decision makers with causal loop diagrams of the business

generates more accurate models of the business leading to improved performance.Causal loop diagrams boost confidence in decision making. Despite the overall positive effects, not all decision makers obtained better performance. Further research is provided.

2 - Rational thinking and learning in small, exciting wicked projects using systems methodologies
Julian de Villez

This paper describes the application of soft systems thinking or Soft OR (Operational Research) when dealing with small but complex, challenging, time and resource constrained, qualitative business and management research studies, when seen in their true light, as "wicked projects". It will demonstrate the power, flexibility and effectiveness of these approaches, and their potential for improved learning, changing mental models and enhancing reasoning capabilities for all involved, enabling greater procedural rationality and procedural justice, and thus outcomes and decision making with greater holistic integrity. It helps answer the research question: Is Soft OR as suitable a research methods approach for inexperienced researchers on smaller scale projects, tackling wicked problems, as it is for fully resourced, experienced researcher-led larger interventions? This paper focuses on a set of thirty-two wide ranging studies undertaken by mostly part-time postgraduate students on professional Business and Management related degrees, who are managers in their full-time roles. Systems methodologies and Soft OR have been employed successfully over a period of 20 years by the author, as a collaborative supervisor. They have proved very suitable methods for structuring the project, gathering data, carrying out rigorous analysis and enabling clear, unbiased and rational thinking. They provide even the inexperienced researcher with a fully informed holistic approach.

3 - Human behavioral aspects in production planning: A systematic review of research frameworks
Anita Onay, *Marcus Brandenburg*, *Christina Stampfer*, *Johannes Siebert*

Human aspects are gaining increasing impact in the ongoing debate on key themes in production planning research, which aligns with the emphasis on the human-centricity of the Industry 5.0 strategy as a facilitator of the European Union Commission's priorities. Despite this growing recognition of humans as an integral part of any production system—whether as operators, designers, planners, or customers—production planning research still often lacks a rigorous human-centric analysis. To address the lack of human-centered research in the field of production planning, behavioral operational research (BOR) and behavioral operations (BeOps) provide fruitful theory, methodology, and research methods. This present study aims to pursue a systematic literature review (SLR) on BOR and BeOps research focusing on production planning problems. The result and synthesis of a content analysis that initially includes 149 papers provide insights into (i) key themes of the research landscape and (ii) human-centered research frameworks. Our findings show that studies incorporating human behavioral aspects in production planning mainly focus on the OR phases of modeling and implementation. In contrast, conceptualization and model-solving phases are less central to the respective research efforts. Thus, this study is a rich body of knowledge for production planning researchers that systematically address human aspects embedded in production systems and interacting with them.

4 - Leveraging novel delphi processes for enabling behavioural OR and collaborative value modelling in health settings
Monica Oliveira, *Rui Infante*, *Edgar Mascarenhas*, *Francisco Viterbo*

Delphi (non-face to face) processes have been widely used to gather expert judgments in multiple contexts, for instance for probability assessment, for scenario building, for indicator selection and for value modelling. Such processes enable gathering and understanding the views of large numbers of individuals, while promoting agreement. Several studies have shown the effectiveness of running Delphi processes to inform model building in Operational Research, particularly within the context of Collaborative Value Modelling in health. Although there are multiple types of Delphi formats, most studies follow traditional and qualitative formats and are far from incorporating model and problem structuring features and from registering the detailed rationales from individuals along the process. Contributing to fill this gap, in this study we present and reflect upon two novel Delphi processes implemented in real health settings: one embedding dialogue mapping within an argumentative Delphi to inform clinical guidelines building in a Haematology Department; and another embedding means-ends networks and value-focused thinking within a Delphi process to define which Entrepreneurship & Innovation competencies and topics should be incorporated in health professionals' training. We discuss how these processes have been highly effective in promoting a large group agreement and enable behavioural research, as well as discuss the use of artificial intelligence to assist such research.

Wednesday, 10:30-12:00

■ WB-01

Wednesday, 10:30-12:00 - Room: Great Hall

Oliver Sinnen

Stream: Keynotes
Keynote session
Chair: *Melanie Reuter-Oppermann*

1 - Scheduling, key to the efficiency of parallel computing
Oliver Sinnen

Computers, in all their forms from smartwatches to supercomputers, are a major enabling technology for remarkable advances in so many domains. Today, most of those computing systems have more than one processor (or core). But what to do with all those processors and how to use them efficiently?

Scheduling of the computing tasks and workloads is key to answer that question. Here scheduling refers to the allocation of tasks and workloads to processors and their ordering for execution, while optimising for performance. In the large majority of the cases, such scheduling is a hard combinatorial optimisation problem. In this talk we look at scheduling problems of parallel computing and the different solution techniques that are employed to solve them. This does not only address the meaningful scheduling of computations, but also the consideration of communication (data transfer) between the processors.

New challenges emerge, for example from the breathtaking advances in machine learning and its seemingly insatiable hunger for computing power. To tame the corresponding huge energy consumption, multi-objective scheduling approaches are necessary that not only minimise execution time, but also look at the optimisation of power and energy consumption.

■ WB-03

Wednesday, 10:30-12:00 - Room: Esther Simpson 1.01

Celebrating 50 Years of EURO (session 2)

Stream: Celebrating 50 Years of EURO
Invited session
Chair: *Marc Sevaux*
Chair: *Anita Schöbel*

1 - The Journey from Subjecting Operations Research Problems, to Connecting Decision-Makers, to Projecting Problems onto Systems, to Protecting the Common Good
Cathal MacSwiney Brugha

We describe the journey through four moments in the history of operations research. World War 2 gave us linear programming. The opening up of governance in the sixties led to accepting multi-criteria. Economic development led to the need for management systems. Climate collapse and environmental destruction is starting a new era, concern for the common good.

The linear programming era was driven by military powers maximising gain, and the need to do operations research into the next day's missions, where the problems were subject to ever-changing constraints such as airplanes, pilots, aviation fuel, targets, and bombs. It draws from mathematics and information technology.

The multicriteria era considered where some decision-makers have conflicting objectives, and the political challenge to connect them, discover compatible goals, that minimize decision-makers' pain. It draws from Personal Construct Theory in Psychology, Grounded Theory in Sociology, Critical Realism in the Philosophy of Science, and Decision Science in Nomology or General Philosophy.

In the systems era possessors of businesses, corporates and administrations seek to minimize blame for making mistakes by projecting their problems onto systems for Routing, Strategy, Management, Natural Computing, and Conflict Resolution.

The common good era is driven by the public concern to minimize shame by protecting the future against war, poverty and environmental destruction.

2 - Five decades of EURO connections and incentives for Central (Eastern) European OR issues: a personal perspective
Lidija Zadnik Stirn

The impact of OR, a new and rapidly developing field, and the established EURO society with several outstanding researchers on our specific environment is considered from two perspectives. These are organizational and research oriented. Some personal observations about the advance of OR in the early seventies in Slovenia, a part of former Yugoslavia, the links with EURO, the establishment of SOR, which became a member of EURO only in 2008, and the cooperation of SOR with EURO (and beyond) are briefly discussed in the context of some reminiscences. From a research perspective, we deal with the so-called Practitioner's OR with the task of model-based decision preparation for the design and control of human-machine-nature systems. The challenges of managing natural resources, environmental systems and landscapes to balance economic, ecological and social goals while ensuring sustainability, biodiversity and resilience are addressed in the frame of moving from deterministic to stochastic approaches, from one goal to multiple goals, from one decision maker to group decisions, from static to dynamic approaches, and combining quantitative and qualitative methods, including the work and merits of Bellman, Saaty, Markov, H. J. Zimmermann and others. The presentation concludes with reflections on the future development of the marvelous EURO family and some new trends in analytics that will be useful for decision support in solving new problems in this global, unpredictable world.

3 - COMPUTING in OR: An Early History and Personal Experience
John Ranyard

Much of OR has always involved data analysis, often on a massive scale. In the early 1950s calculating machines, manual and electric, were used but also some analogue computers, as documented in the first IFORS conference in 1957. However by then, digital computers were becoming available, transforming the speed of computation and were quickly adopted. OR software, particularly for LP and Simulation, was also being developed and made more effective. The use of digital computers in OR from the late 50s to the late 80s, via the experiences of a pioneering UK industrial OR Group in British Coal (established in 1948) will be summarised, covering the following eras: first generation computers (1950s); transistorised main frames (mid 1960s/70s); mini computers (1970s); and the ever more powerful Personal Computers (PCs, 1980s on). This rapidly increasing computing power and software efficiency has undoubtedly benefitted quantitative and statistical OR, leading eventually to the Analytics/Big Data revolution that we are still experiencing today.

■ WB-07

Wednesday, 10:30-12:00 - Room: Clarendon GR.01

Portfolio Management

Stream: Risk Management in Commodities and Financial Markets
Invited session
Chair: *Davide Radi*

1 - Path Dependent Arbitrage Portfolio Strategies
Denise Mirabella, Sergio Ortobelli Lozza, Valentina Piantoni

This paper investigates portfolio strategies aimed at maximizing the expected first passage time of wealth to predefined benchmark levels, assuming returns follow Markov processes modeled through Markov Chains. By examining the momentum characteristics of these strategies, we identify potential arbitrage opportunities. We apply timing-based strategies to the components of the S&P500 index and evaluate their performance. Specifically, we compare the ex-post wealth outcomes of traditional approaches against novel strategies optimized to improve the average first passage time to target benchmarks.

2 - Critical Infrastructure Resilience Assessment Using an Integrated HFACS-FMEA Model
James Liou, Tzu-Yu Lai, Chao-Che Hsu

Critical infrastructure, particularly transit centers, is vital for national socioeconomic stability. Enhancing their resilience against natural and human-made disruptions is crucial. This study analyzes operational risks in transit centers by examining complex systems and their interconnected risk factors using an integrated approach combining Human Factors Analysis and Classification System (HFACS), Failure Mode and Effect Analysis (FMEA) and Multiple Criteria Decision Making (MCDM) concepts. To address assessment uncertainties, the study employs Interval-Valued Fermatean Fuzzy Sets (IVFFS) for evaluation, the Best-Worst Method (BWM) for risk factor weighting, and MARCOS for ranking failure modes. Using Taipei station as a case study, this methodology identifies priority areas for improvement and provides reliable risk management recommendations, offering a framework applicable to other critical infrastructure operations.

3 - A multi-asset pricing model with climate financial risks
Davide Radi

We develop a dynamic asset pricing framework with brown and green assets. Green assets are affected by rare natural disasters linked to climate change by rare macroeconomic events. Brown assets are also affected by transition risk which is assumed to be related to physical risk. The novelty of the work is to assume that natural disasters are generated by a self-excited jump. Using analytical results and simulations we show how these natural disasters impact portfolio composition, risk-free rate, credit spread and asset prices.

■ WB-08

Wednesday, 10:30-12:00 - Room: Clarendon SR 2.08

Decision aiding under uncertainty 2

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Sarah Ben Amor
Chair: *Renata Pelissari*
Chair: *Betania Campello*

1 - Which uncertainty matters most in an environmental decision case: climate change, predictions, or preferences?
Sebastian Schär, Judit Lienert

Climate change imposes challenges on sewer systems due to more frequent and severe extreme weather events. Blue-green infrastructure (BGI), such as vegetated basins, roofs, and ponds, can help address these challenges by retaining water. BGI provides multifunctional benefits, such as heat mitigation and biodiversity facilitation. There are, however, many BGI options with different characteristics, benefits, and costs, which must be evaluated against heterogeneous stakeholder interests. Eliciting preferences under these conditions is usually associated with uncertainty, and predicting outcomes of options depends on assumptions about external conditions, such as climate change. We employ multi-criteria decision analysis (multi-attribute value/utility theory) to assess BGI options in a Swiss municipality under different climate scenarios. To handle uncertainty in preference information and performance predictions, we use the concept of expected expected utility (EEU). EEU samples over probability distributions of modelling parameters and confines overall uncertainty in the utilities to a single number that allows to determine a ranking and identify potential consensus. In stepwise sensitivity analysis, we relax uncertainty modelling and test the influence on the ranking to inform further elicitation efforts. Preliminary results indicate that uncertainty in preference information influences the ranking stronger than uncertainty in performance predictions or climate uncertainty.

2 - A new sorting MCDM methodology with probabilistic prediction and temporal analysis
Caroline Mota, Betania Campello

This study introduces a novel multitemporal and multicriteria decision-making methodology designed to sort alternatives while accounting for uncertainties in their future performance. This approach is particularly relevant for problems where the performance of alternatives is best represented by time series data, with past variations playing a significant role in the decision-making process. The methodology evaluates the temporal performance of alternatives against a set of criteria by employing a probabilistic prediction method that models data behavior and forecasts expected future values within specified confidence intervals. In contexts of high uncertainty, traditional classification methods may lose discriminative power; hence, the proposed model integrates varying levels of uncertainty to generate a valued outranking preference function for categorizing alternatives. Grounded in the principles of the PROMETHEE and FlowSort methods, the sorting procedure accommodates multiple classification scenarios. The methodology was applied to categorize five countries based on their economic and financial performance, utilizing 40 years of data from the International Monetary Fund, and the results demonstrate its efficacy and the added informational value it provides.

3 - A Multi-Stage Resilient Supplier Selection under Stochastic uncertainty
Nitin Sahu, Garima Mittal

Supplier management is one of the critical decision-making processes in the supply chain, and it becomes even more challenging in uncertain environments. The increasing globalization and disruptions in supply chains have highlighted the need for resilience across all its components. The recognition that maintaining supply chain continuity during disruptive events is crucial has shifted companies' focus towards prioritizing the selection of resilient suppliers along with other concerns. To address these challenges, the study proposes a multi-stage stochastic resilient supplier selection and order allocation model that considers operational risks. In the first stage, a supplier resilience score for each supplier is calculated to derive a resilience index for the supplier portfolio based on key resilience criteria. The second stage involves formulating a multi-objective stochastic supplier selection model involving chance constraints that address uncertainties in demand, budget, and other critical parameters. Finally, in the third stage, we solve the proposed stochastic supplier selection model for forming a resilient supplier portfolio. The proposed methodology is demonstrated through a numerical illustration, and sensitivity analysis is performed to assess its robustness. This study presents a comprehensive framework for enhancing supplier selection in supply chain operations by integrating resilience and addressing uncertainties within the supplier portfolio model.

■ WB-09

Wednesday, 10:30-12:00 - Room: Clarendon SR 2.01

Algotrading and Market strategies

Stream: OR in Finance and Insurance
Invited session
Chair: *Mario Maggi*

1 - High-Frequency Trading and Risk Sharing Capacity in Market Making with Asymmetric Information
Katsumasa Nishide

We examine how asymmetric information impacts market liquidity and informational efficiency in a market where some market makers possess high-frequency trading capabilities. Our model includes market makers with varying speeds and informed liquidity traders. We find that the degree of information asymmetry can either enhance or diminish liquidity, depending on the specific market structure. We also demonstrate that an increase in the number of HFT market makers generally improves market liquidity, but can degrade it under certain conditions. Our theoretical findings suggest that the impact of HFT should be carefully assessed, especially in markets with significant information asymmetry.

2 - Measuring variability of nodes in the yield term structure
Ilaria Stefani, Edit Rroji, Lorenzo Mercuri, Andrea Perchiazzo

In this paper, we investigate the yield curve extracted from government bonds. Through a comparative analysis of parsimonious models for yield curve estimation we assess the impact of recent political and market events in the bond market for various countries, including Italy, Germany, France, Denmark, Japan, and United States. Market news is expected to affect the shape of the yield curve. We compute daily the coefficients of the parsimonious models and highlight the most important features observed during important events such as the COVID-19 pandemics, the Russian-Ukraine war, and US election results. We also employ non-parametric measures of variability applied to the series of each node in the term structure. An important contribution of this paper is the introduction of a dependence between policy intervention towards a net zero carbon economy and the nodes in the yield term structure. In particular, we introduce a quantity named time to transition computed as the difference of greenium using german twin bonds for two different maturities. Green bonds provide financial backing for developing low-carbon initiatives and facilitating the transition towards a greener economy. The greenium effect refers to the potential premium bondholders are willing to pay to invest in green securities compared to investments with similar characteristics.In our view, this index provides an intrinsic measure of these instruments and serves as a proxy for the investment risk.

3 - Leveraging RNNs, LSTMs, and Recurrence Quantification for Synchronization in the Indian Stock Market
Charu Sharma, Sanjay Sathish

Stock price synchronization is crucial for market dynamics, risk assessment, and portfolio management. Traditional correlation-based methods often fail to capture complex non-linear dependencies in financial markets. This research introduces a new approach for forecasting the synchronization of stock prices using machine learning and non-linear time-series analysis. To capture the complex non-linear relationships between stock prices, we utilize recurrence plots (RP) and cross-recurrence quantification analysis (CRQA). We utilize Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM) networks to forecast the time series derived from Cross Recurrence Plot (CRP) data. Based on predefined thresholds, we then classify the predicted synchronization values into distinct categories, enabling both regression and classification analyses. We apply this methodology to a dataset of 20 highly capitalized stocks from the Indian market over a 21-year period. The findings reveal that our approach can predict stock price synchronization, with an accuracy of 0.98 and F1 score of 0.83. These results demonstrate that deep learning models trained on recurrence-based features can effectively capture synchronization patterns, offering valuable insights for algorithmic trading, portfolio diversification, and risk management in financial markets. Co-author: Mr Sanjay Sathish (ss219@snu.edu.in)

4 - Reducing Investment Risk through Diversification in Benchmark Investing
Mario Maggi, Pierpaolo Uberti

In finance, it is widely acknowledged that diversifying an investment portfolio can help mitigate risk. This paper presents a novel method for efficiently decomposing a set of financial returns to reduce the risk associated with benchmark portfolios by working on diversification. We introduce "pseudo-principal portfolios," a set of orthogonal portfolios derived from a modified version of principal component analysis (PCA). Our theoretical framework establishes a connection between traditional mean-variance optimization and pseudo-principal portfolios, while also highlighting several key properties that have significant implications for financial decision-making. Furthermore, we propose an approach to constructively blend any given benchmark portfolio with a limited number of pseudo-principal portfolios. Our results are validated through both in-sample and out-of-sample analyses using real-world financial data, illustrating the effectiveness of this novel risk reduction strategy.

■ WB-11

Wednesday, 10:30-12:00 - Room: Clarendon SR 1.03

Home Health Care Routing

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Elise Vandomme*

1 - Allocation-Routing Problem in a Multi Hospital Home Hospitalization system: the case of a healthcare provider in Portugal
Valentina Bonomi, Maria Lopes, Daniel Santos, Renata Mansini, Ana Barbosa-Povoa

Home hospitalization (HH) enhances patient-centered care while reducing the strain on conventional healthcare facilities. Managing specialized nurses and doctors efficiently is crucial due to their shared responsibilities in inpatient and outpatient settings. We formulate the Multi-Hospital Home Hospitalization Allocation-Routing Problem (MH-HHARP) as a Mixed-Integer Linear Programming model with three objectives: minimizing routing costs, balancing nurse workload, and minimizing employed doctors. The model is solved individually for each objective, and trade-offs are explored via bi-objective Pareto frontiers within a multi-objective framework. Benchmark instances derived from HH historical data validate the approach. A single-objective analysis assesses the economic impact of opening new HH units, while bi-objective results aid decision-making by presenting Pareto frontiers. A TOPSIS analysis identifies optimal solutions based on varying objective weights. Managerial insights highlight the effects of prioritizing different objectives and the economic implications of strategic decisions.

2 - Techno-Centric Home Healthcare Scheduling and Routing Plans: a systematic literature review
Arghavan Sharafi, Mahdi Bashiri, Dhananjay Thiruvady, Benny Tjahjono

Home healthcare (HHC) involves delivering both medical and non-medical services to patients in the comfort of their own homes. A key component of an effective HHC system is the HHC Scheduling and Routing Plan (HHCSRP), which organizes and optimizes caregiver schedules and routes. Emerging technologies such as the Internet of Things, big data analytics, cloud computing, and blockchain are transforming traditional HHC. As a result, HHCSRP has evolved

to address new operational research challenges that arise in response to the demands of a techno-centric HHC environment. Additionally, the rise of methods like machine learning offers new opportunities for HHCSRP to achieve better outcomes, either through more accurate parameter predictions or by guiding solution algorithms through learning over successive iterations. This paper systematically reviews existing research on techno-centric HHCSRP, examining which technological innovations are considered in the literature and how their impact on techno-centric home healthcare has been integrated into mathematical optimization models and solution approaches. Additionally, we propose potential research directions by exploring optimization problems that may arise from the use of technologies in HHC that have not yet been fully addressed in the literature.

3 - Multiperiod stochastic optimization with machine learning for dynamic home healthcare routing
Louise Tassin, Véronique François, Elise Vandomme, Yasemin Arda

Home healthcare (HHC) is gaining popularity as a means of alleviating pressure on healthcare systems and improving patient well-being. However, effective HHC operations require optimized resource utilization, a challenge complicated by inherent uncertainty and dynamism. Although deterministic variants of the home healthcare routing and scheduling problem have been extensively studied, this is not the case of stochastic and dynamic versions. Aiming to address this gap, our work analyzes the problem of a home healthcare provider (HHCP) making daily decisions regarding the acceptance of new patient requests that arrive dynamically over the planning horizon. The HHCP also has to assign the first visit of each accepted patient to a day. It is assumed that every patient needs at least one visit and a specific periodicity of care, but the total number of visits that a patient will effectively require is stochastic. However, the HHCP must commit to serving accepted patients for their total number of visits. Moreover, the HHCP creates routes for the available caregivers in order to cover the visits planned for the current day. The problem is modeled as a Markov decision process. We will outline a solution approach that integrates machine learning techniques with traditional combinatorial optimization algorithms. This hybrid approach aims to effectively tackle the stochasticity inherent in the patients arrival process and care duration.

4 - Optimizing Digital Health Services in Primary Care: A Data-Driven Approach to Value Assessment
Mariana Peyroteo, António Grilo, Luís Lapão

Multimorbidity places increasing demands on primary healthcare (PHC), requiring coordinated and patient-centred care. Digital Health Services (DHS) offer promising solutions, yet there is a lack of structured models to estimate their value in real-world PHC settings. This study aimed to develop and apply a decision framework to estimate the value of a DHS in PHC, using the METHIS platform. METHIS supports Goal-Oriented Care by enabling patients and professionals to collaboratively define and monitor individual health goals. The framework combines Design Science Research and Multi-Criteria Decision Analysis (MCDA) to integrate clinical data, Patient-Reported Outcomes, and service utilisation across three value domains: quality, service, and cost. A six-month pilot currently underway in seven PHC units in Lisbon, involving 20 professionals (10 doctors and 10 nurses) and 20 patients, will generate the real-world data required to estimate value. Early feedback indicates improved goal alignment, strengthened communication, and high system usability. This framework provides a structured, participatory approach to value estimation, illustrating how operations research can support the implementation of Value-Based Healthcare through measurable and actionable insights.

■ WB-12

Wednesday, 10:30-12:00 - Room: Clarendon SR 1.02

Workforce scheduling

Stream: Scheduling and Project Management
Invited session
Chair: Johanna Mlekusch

1 - Enhancing Ergonomics by Integrated Shift Design and Rotating Workforce Scheduling
Tristan Becker

In many organizations, human resources are a primary cost driver, making careful scheduling of this resource paramount. Within this context, shift design and scheduling emerge as key planning tasks. The shift design problem devises a set of workable shifts based on the staffing requirements. Then, the shift scheduling problem assembles these shifts to a shift schedule. Traditionally, shift design and scheduling are treated as separate problems. This separation ignores synergies between the shift design and scheduling, leading to inefficiencies when relying on predetermined shift designs. Therefore, we introduce an integrated approach for shift design and rotating workforce scheduling. In addition to the shift design objective function, we model an ergonomics objective function for the quality of the schedule. We solve the integrated problem using a branch-and-cut approach based on a compact formulation and graph representation, ensuring feasibility of shift designs by modeling the schedule as a Eulerian cycle of work and rest sequences. Results show that an integrated shift design and scheduling enables shift schedules with improved ergonomics without deteriorating the shift design objective compared to the sequential planning approach. Further, an analysis of the Pareto-efficient frontiers across the benchmark set indicates that substantial improvements in ergonomics are possible if decision makers are willing to accept a minor reduction in shift design quality.

2 - Logic-Based Benders Decomposition for a labour constrained production scheduling problem
Johanna Mlekusch, Carla Juvin, Christian Artigues, Richard Hartl

In modern project and production management, efficiently allocating limited resources to tasks is a critical challenge. This research is motivated by a production problem in the screen-printing industry, modelled as the Dual-Resource-Constrained Re-entrant Flexible Flow Shop, an extension of the Re-entrant Flow Shop Problem. In addition, the problem involves a heterogeneous, multi-skilled workforce, and machines require skilled workers to operate throughout the processing time. As a result, the schedule must not only adhere to precedence constraints but also account for resource limitations while ensuring that tasks are assigned to workers with the necessary skills. Previous research has proposed a constraint programming model and a hybrid genetic algorithm to tackle large problem instances, yielding feasible solutions within a short time frame. This study introduces a novel exact solution method based on Logic-Based-Benders decomposition. The proposed decomposition method is evaluated against the constraint programming model for the integrated problem on a set of small instances. Preliminary results indicate that the proposed method outperforms the constraint programming approach by proving optimality in more cases and within a shorter time frame while also providing tighter bounds for instances that could not be solved to proven optimality.

3 - Navigating Turbulence: Near Real Time Rescheduling of Crew Rosters in Short-Haul Aviation
Louisa Sober, Ruth Walton, Michael Sutherland

In the aviation industry, any disruptions to crew rosters can cause a cascade of knock-on effects which impact both crew and scheduled flights. In order to navigate the many regulations and operational constraints, highly trained crewing teams are required to rapidly reconfigure the shifts to minimise disruptions. During busy periods the volume

of disruptions can overwhelm crewing teams, potentially resulting in regulatory violations, further delays, cancellations and even fines.

In early 2024 we were tasked with developing and deploying a crew rescheduling tool for a short-haul airline to support the crewing team during the upcoming busy summer period. Within a rapid 5 month timeline, we progressed through a full project pipeline from initial scoping to a fully deployed user interface that updated in near real time and which has been adopted into daily operations.

This talk will look into the metaheuristic approach that formed the core of our solution which facilitated rapid and intelligent roster reconfiguration. We will also discuss the inclusion of an explainability layer which provided the rationale behind these recommendations and enhanced user understanding and adoption.

In addition we will address the essential supporting elements that ensured the adoption of the solution. This includes strong stakeholder engagement, implementation strategies and a cross-functional development team that allowed us to fully leverage cloud computation.

■ WB-15

Wednesday, 10:30-12:00 - Room: Esther Simpson 1.08

Discrete, continuous or stochastic optimization and control in networks, transportation and design 2

Stream: Combinatorial Optimization
Invited session
Chair: Gerhard-Wilhelm Weber

1 - MIP and CP formulations for the maritime search and rescue routing problem
Grigorios Kasapidis, Dimitris Paraskevopoulos, Tolga Bektas

Efficient search and rescue (SAR) operations can be the difference between life and death in maritime emergencies. In such environments, rapidly changing weather conditions can lead to unpredictable movements of individuals, making effective SAR routing increasingly complex. To address this, weather forecasts or simulations of wind, currents, and waves can help estimate the most probable location of an individual at a given time after an incident. In the literature, such SAR scenarios are typically modeled as moving target search problems. However, despite existing research, key operational challenges—such as dynamic weather conditions, the safety of both rescuers and those in distress, and diminishing survival probabilities—remain insufficiently addressed. As a result, developing a mathematical framework to solve large-scale, realistic SAR problems presents significant theoretical challenges. This paper proposes a mixed-integer programming model to tackle this integrated problem and explores Constraint Programming (CP) models, which have proven effective in solving complex discrete optimization problems. Computational experiments conducted on newly designed benchmark instances inspired by real-world scenarios will be presented.

2 - Distributionally robust inventory routing for recycling waste batteries under uncertain quality
Xinyi Zhang, Ada Che

This paper addresses, for the first time, an uncertain inventory routing problem for waste battery recycling, managed by multiple regional collection centers (RCCs) with uncertain waste battery qualities. Given a planning horizon and cascade utilization demands, the problem aims to find the optimal number of waste batteries to be collected from RCCs and the transportation routes to minimize the total cost, including recycling, processing, and the risk measure costs over all uncertain battery qualities defined by an ambiguity set. We first formulate the problem into a two-stage distributionally robust optimization model, where one sub-model is non-linear due to the uncertain waste battery quality and the impact of worst-case scenarios on inventory and shortages. A linearized equivalent reformulation is then derived based on exploring the nonlinear nature of the sub-model's objective function and using McCormick inequalities. Then, a decomposition-based exact algorithm is developed based on this reformulation. To enhance its performance, we implement it within a branch-and-check framework and introduce two families of symmetry-breaking inequalities. Finally, we conduct extensive numerical experiments to validate the effectiveness of the proposed method in both static and dynamic settings, deriving insights into how the presence of uncertain waste battery quality and the sufficiency of recycling information influence corporate costs and decision-making.

3 - Optimizing Multimodal Transport Networks in the Mekong Delta, Vietnam
Truong Xuan Dinh, Vedat Bayram, Maria Paola Scaparra

The Mekong Delta in Vietnam is one of the largest river networks in the world (ranked 10th in total length and 8th in annual flow) and has a complex multimodal transport system. Optimizing the integration of road and inland waterway transport in this region will benefit millions of residents and facilitate regional trade. This research addresses the Multimodal Transport Network Design Problem. It develops an optimization model to enhance infrastructure investment and transport network efficiency. The proposed model minimizes transportation costs and travel times for passengers and goods. It supports regional transportation projects such as strategically locating major transport hubs, improving and expanding river ports and road-waterway connections, and optimizing flow allocation between modes while upgrading road and waterways. Validated with empirical data from the Mekong Delta, the model evaluates scenarios for expanding and upgrading multimodal transport networks. It provides decision support tools to identify sustainable infrastructure projects. These network optimization insights promote cost-effectiveness and provide valuable recommendations for multimodal systems in the Mekong Delta and similar regions.

4 - Simultaneous production scheduling and transportation problem with knapsack constraints in a mobile 3D printer
Enyuan Fu, Zhaofang Mao, Kan Fang, Yida Xu

This paper addresses a simultaneous production scheduling and transportation problem with a mobile 3D printer, which operates as a vehicle installed with a mobile smart factory required for the simultaneous production and transportation of products to be delivered to the customer with the minimization of delivery time. Considering the variability of road transportation conditions, this study explores scenarios where continuous processing of products across nodes is not permitted. To solve this problem, a mixed integer linear programming model is formulated, and an exact algorithm based on Benders decomposition method is proposed, followed by an adaptive large neighborhood algorithm and several accelerating strategies. A comprehensive computational study is conducted to evaluate the effectiveness of the proposed algorithm, yielding managerial insights into route selection and the allocation of products for processing along arcs.

■ WB-16

Wednesday, 10:30-12:00 - Room: Esther Simpson 2.07

Beyond the limits of QUBO formalism

Stream: Quantum OR
Invited session
Chair: Dimitri Papadimitriou
Chair: Amina El Yaagoubi

1 - A summary of quantum genetic algorithms and applications.
Mauricio Solar

There are several variants of the quantum genetic algorithm (QGA). One of them is the reduced quantum GA (RQGA), that removes the use of crossover, but also reduces computational complexity by assessing solutions simultaneously instead of iterating over populations as a QGA might do. RQGA makes extensive use of Grover's algorithm, used primarily when fitness is relatively easy to calculate. A Quantum Inspired GA (QIGA) is inspired by quantum mechanical principles, such as superposition, but does not make use of these principles in its implementation, performing better than a classical solution for a small domain. Hybrid Quantum GA (HQGA) combines classical techniques with the quantum paradigm, by doing crossover into a classical system but leaving the representation in a quantum form. This presentation wants to show the main strengths of an Improved Quantum GA (IQGA) over its classical variant. For example, the superposition allows several genetic combinations to be explored at once. Strategies proposed are the removal of crossover for IQGAs, as well as adding disasters within the genetic codes to re-introduce diversity. The characteristics that are associated with IQGA in the works that use it are: (1) Removing crossover; (2) Introducing population disasters; (3) Non-table based adaptive rotation operation.

2 - Penalty Factor Optimization for Quantum Annealing - A Multiobjective Approach

Pascal Halffmann, Michael Trebing

Quadratic unconstrained binary optimization problems (QUBOs) are the working horses for solving optimization problems on quantum computers. An efficient transformation from other problem formulations to QUBOs requires to model constraints as penalty terms with penalty factors as part of the objective function. While constraints can be incorporated in a quantum circuit on gate-based quantum computers using e.g. constraint-preserving mixers, such a direct approach does not exist for quantum annealing. Picking suitable penalty factor is the key challenge in the transformation. Previous approaches rely on the user's experience or utilize machine learning. We present a novel approach that identifies a QUBO as a weighted sum scalarization of a multiobjective optimization problem with both aggregations of penalty terms and the original objective function as objective functions. Penalty factors serve as weights in the weighted sum problem. We adapt existing methods from multiobjective optimization finding so-called lexicographic optimal solutions by iteratively changing the weights. QUBOs are iteratively solved using quantum annealing, where the penalty factors are adjusted based on the previous outcome. These methods do neither rely on existing data nor on the user's experience on penalty factors, domain knowledge on the problem is sufficient. We compare the methods against each other as well as against the Nelder-Mead method as a standard approach in a computational study.

3 - cVRPTW quantum model

Eric Bourreau

Quantum Operational Research is now a reality. Optimization algorithms exist such as QAOA, Grover or VQA), and machines exist and are starting to compute correctly such as a D-Wave machine (3000 qubits), IBM (127 qubits) or QuEra (256 qubits). It is now time to design models adapted to these machines. We propose to model one of the most well-known problems in Operational Research: the cVRPTW, for exact resolution using Grover's algorithm or an approximate solution with a variational method.

4 - QUBO Enhancement Through Preprocessing Techniques: Application to the Bin Packing Problem

Amina El Yaagoubi, Amélia Durbec, Samuel Deleplanque

This study investigates the application of Quantum Annealing (QA) to solve the Bin Packing Problem (BPP) using a QUBO (Quadratic Unconstrained Binary Optimization) framework. While QA presents a promising approach for tackling complex combinatorial problems, practical implementation faces scalability challenges due to qubit limitations and embedding constraints on current quantum hardware. To address these issues, we introduce two preprocessing techniques: Slack Variable Reduction, which minimizes unnecessary variables, and Symmetry Elimination, which removes redundant configurations. Experiments conducted on D-Wave's Advantage System demonstrate that these strategies effectively reduce qubit consumption, shorten chain lengths, and improve embedding feasibility. While these reductions significantly improve performance, the QUBO formulation's inherent quadratic growth in variables remains a limiting factor for larger instances, posing challenges for embedding on current quantum hardware. Nevertheless, our findings highlight that strategic preprocessing is crucial for extending the range of solvable BPP instances, offering promising insights for advancing quantum optimization in real-world scenarios.

■ WB-17

Wednesday, 10:30-12:00 - Room: Esther Simpson 2.08

Integer Programming

Stream: Combinatorial Optimization
Invited session
Chair: *Monique Guignard-Spielberg*

1 - Search Escalation for Heuristic Combinatorial Optimization

Steven Kimbrough, Kelly Wang

We propose and discuss a concept we call search escalation. It augments heuristic search, as typically conducted by meta-heuristics. Search escalation techniques are methods for broadening and deepening heuristic search undertaken by a given meta-heuristic, such as simulated annealing or evolutionary computation. In a prototypical use case calling for search escalation, (i) running longer or replication of a metaheuristic yields diminishing returns and (ii) the importance of finding better solutions is deemed to be very high. Such is the motivating use case for this work: given a gerrymandered legislative redistricting plan, find multiple plans that are as similar as possible to the source plan but that have attractive properties (e.g., on partisan fairness, respect for administrative boundaries, coherence of communities of interest) from a public interest perspective. We further propose an approach to search escalation that we call PPI (pool of potential incumbents). This is a second-order metaheuristic. Under this approach, promising search paths that appear and are NOT pursued by a first-order meta-heuristic (e.g., tabu search) are retained and potentially used in other, separate first-order meta-heuristic searches. This is a heuristic for examining parts of the global search space that would not otherwise likely be explored by the first-order meta-heuristic. We discuss examples and present computational results.

2 - The value function of a binary integer program

Junlong Zhang

We investigate the value function of a binary integer program, which has received less attention in the literature than that of a general integer program. We find that some basic properties of the value function of a general integer program do not hold for the value function of a binary integer program, e.g., superadditivity and integer programming complementary slackness. Therefore, existing approaches for constructing integer programming value functions are not directly applicable to binary integer programs. In this study, we derive structural properties and propose a column-by-column algorithm and also a merge algorithm to construct the value function of a binary integer program. We demonstrate and compare the performance of the two algorithms through extensive computational experiments. We also extend the proposed approach to solve a type of bilevel binary integer programs.

3 - On strengthening some mixed integer optimization algorithms via additional improving steps

Monique Guignard-Spielberg

Several strengthening tools can be used as intermediate steps for obtaining improved algorithmic performance in the solution of optimization problems in 0-1 variables. This talk will concentrate on a few such tools, based, respectively or simultaneously, on the RLT (i.e., Reformulation Linearization Technique) of Adams and Sherali, Lagrangean relaxation, pioneered by Geoffrion in 1975 in Management Science,

the ILP (Integer Linearization Property) of Geoffrion (1974), Geoffrion and Mc Bride (1978) and Guignard-Spielberg (2003), and, in the case of linear constraints and quadratic objective function, decomposable Lagrangean Relaxation or Decomposition (Guignard 2020). After reviewing these tools, several instances and respective numerical results will be presented, for instances with nonlinear objective function and linear constraints.

4 - A Column Generation Algorithm for Solving the Multi-Model Green Logistics Problem
Akane Seto, Takafumi Chida, Stephen Maher, Yuji Shinano

The logistics industry is focusing on reducing operational time and improving the quality of work for drivers by implementing strategies such as driver switching and container changes. Additionally, there is an effort to reduce carbon emissions by transitioning from petrol-consuming trucks to railways and electric vehicles (EVs). To achieve these goals, we propose the "Multi-Model Green Logistics Problem", which integrates five resources in long-haul transportation—drivers, trailer heads, trucks, containers, and trains—and two resources in local delivery— fixed-battery and replaceable-battery EVs. Given the complexity and scale of this problem, it is difficult to solve using conventional general-purpose solvers. Therefore, we have developed an algorithm that decomposes the problem into long-haul transportation and local delivery, employing column generation for each. The framework first solves the long-haul problem, then uses the solution to address the local delivery routing problem, iteratively refining the results. Our method synchronizes the five resources in long-haul transport by using time-expanded network. Additionally, calculation time is reduced by solving complex constraints such as charging times and amounts within sub-problems. Compared to conventional models using petrol trucks without driver switching and container changes, our approach significantly improves operational efficiency and reduces environmental impact.

■ WB-18

Wednesday, 10:30-12:00 - Room: Esther Simpson 2.09

OR Education

Stream: OR Education
Invited session
Chair: Maria Antónia Carravilla
Chair: *Jeroen Belien*
Chair: *Stefan Creemers*
Chair: *Arne Heinold*

1 - Enhancing Operations Research Learning with an Online Exercise and Assessment System
Rafael Martinelli

This talk presents an online platform designed to improve the teaching and learning of Operations Research by enabling students to solve randomized and configurable exercises with automated step-by-step correction. The system ensures that students apply the correct methodology while studying key topics such as Linear Programming, Integer Programming, Transportation Problems, and Physical Distribution. The platform features two modes: an exercise mode, where students receive immediate feedback as they progress through problems, and an assessment mode, where instructors can create timed exams without feedback or grading visibility. This structure makes the system suitable for both practice and evaluation, allowing students to reinforce their understanding while enabling instructors to manage assessments efficiently. Originally developed to address challenges posed by large class sizes and remote learning, the system has evolved into a comprehensive tool that enhances student engagement through interactive problem-solving. A public version of the platform is available, allowing participants to explore and test a variety of exercises. The system's structured feedback mechanism and controlled assessment environment provide an effective way to reinforce theoretical concepts while allowing students to develop practical problem-solving skills.

2 - Teaching Value Function Approximation: A Tutorial-Based Approach
Arne Heinold

This talk elaborates on my experience with tutorial-based teaching of Value Function Approximation (VFA), a solution class of Approximate Dynamic Programming (ADP). VFA describes a heuristic way for solving sequential decision processes like a Markov Decision Process (MDP). Real-world problems in transportation containing dynamic and stochastic elements might be modeled as such processes, but large-scale instances are intractable to be solved to optimality by enumeration due to the curses of dimensionality. VFA can be a proper method for these cases and this talk describes a tutorial-based teaching of the the method.

3 - Challenge-Based Learning in Operational Research: Games and Interactive Strategies for Teaching Optimization
Pablo González-Brevis

Teaching Operational Research (OR) effectively requires engaging methodologies that connect theory and practice while keeping students motivated. This presentation explores challenge-based learning through games and interactive experiences to teach OR concepts such as optimization concepts, graphical optimization and mathematical modeling. These methods not only enhance learning but also attract students who may develop an interest in optimization through hands-on problem-solving activities.

We present four innovative approaches: (1) LEGO-Based Optimization, where students construct under constraints to grasp resource allocation and fundamental optimization principles; (2) Board Game Optimization, applying network design, minimum spanning tree and shortest-path problems, and strategic decision-making in a competitive setting; (3) Designing a Music Festival, using integer programming to optimize stage allocation, artist selection, and budget distribution while balancing constraints; and (4) Football Team Selection with FIFA Data, a binary optimization exercise that challenges students to build the best possible lineup based on real-world player statistics, constraints, and performance metrics.

These interactive methods boost engagement, improve understanding of OR principles, and inspire students to explore optimization. By integrating games and interactive experiences, this approach fosters a dynamic and applied learning environment, making OR more accessible, engaging, and relevant to students from diverse backgrounds.

4 - Can Generative Artificial Intelligence Improve the Teaching of Linear Programming Modelling?
Jeroen Belien

This paper investigates how Generative Artificial Intelligence (GenAI) can be used to improve the teaching of Linear Programming (LP) modelling in terms of both efficiency and effectiveness. By analyzing the responses of over 200 business engineering students in a qualitative survey, we compare LP modelling exercises created by GenAI with exercises created by human experts on five quality criteria: clarity, complexity, challenge, attractiveness, and relevance for a real-life context. We also investigate to what extent these students are capable of correctly identifying GenAI or the human expert as creator of each exercise.

■ WB-20

Wednesday, 10:30-12:00 - Room: Esther Simpson 2.11

Complexity and Approximation

Stream: Combinatorial Optimization
Invited session
Chair: Martijn van Ee

1 - On the NP-hardness of the degree-constrained network design problem
Brieuc Pierre, Francesco Pisanu, Daniele Catanzaro

Given a connected weighted graph G=(V,E), the k-Network Design Problem (k-NDP) consists of deciding whether there exists a spanning tree in G, whose internal vertices have degree k and such that the shortest path between each pair of leaves is smaller than or equal to a given constant. This problem finds applications both in epidemiology and in the modeling of the evolutionary relationships among species. Here we show that the k-NDP is NP-complete for every every natural k greater or equal to 3.

2 - Policies for the Generalised Capacitated Resupply Problem
Mette Wagenvoort, Paul Bouman, Martijn van Ee, Kerry Malone

We consider the Generalised Capacitated Resupply Problem (GCRP) in which locations with a given capacity and demand rate should be resupplied by vehicles such that they do not run out of stock and the number of vehicles is minimised. Compared to related problems, we consider the scenario where the payload of the vehicles may not suffice to bring the stock level back to full capacity. In addition to the GCRP, we consider three variants of the problem in which the capacities and demand rates and/or the resupply times are homogeneous. We prove that the GCRP is NP-hard, even on one vehicle and with homogeneous capacities, and present policies to solve the different variants of the problem and provide corresponding approximation guarantees.

3 - Precedence-constrained shortest path
Corinna Mathwieser, Christina Büsing

We study a variation of the shortest path problem in which the sequence of visited vertices must satisfy precedence constraints. The problem generalizes Graphic TSP Path, making it APX-hard. We discuss the complexity of finding a feasible precedence-constrained path between two vertices and compare different variants of defining precedence-constraints in shortest paths. We propose a dynamic programming approach and identify specific input classes where the dynamic program provides an optimal solution in polynomial time. Furthermore, we analyse the problem's computational limits by demonstrating that it remains hard even under structural restrictions. Surprisingly, we prove that the problem is NP-hard even when the graph is constrained to spiders.

4 - On the complexity of finding central configurations of the graph-generalized (n2 − 1)-puzzle
Martijn van Ee

In the graph-generalized (n2 −1)-puzzle, we are given a graph and a set of tokens. In a configuration, each token is assigned to a vertex in the graph, and only one token can be placed on a vertex. We can transform a configuration into another by making moves, where in a move we slide a token along an edge to an unoccupied vertex. The distance between two configurations is defined as the length of the shortest sequence of moves to obtain one from the other. We consider the problem of finding central configurations for the graph-generalized (n2 − 1)-puzzle. Here, we are given a set of K configurations, called scenarios. In Median Configuration, the goal is to find a configuration that minimizes the total distance from this configuration to each of the scenarios. In Center Configuration, the goal is to find a configuration that minimizes the maximum distance from this configuration to any of the scenarios. We show that finding the median configuration is NP-hard when K = 3, and that finding the center configuration is NP-hard when K = 2. We observe that the complexity heavily relies on the complexity of computing the shortest transformation between two configurations. Hence, we consider two special cases and a problem variant in which we can compute these shortest transformations in polynomial time. We identify several cases that are polynomially time solvable, and cases that are NP-hard.

■ WB-23

Wednesday, 10:30-12:00 - Room: Esther Simpson 3.01

Optimization Models in Supply Chain and Financial Modeling

Stream: OR for Societal Development
Invited session
Chair: Bruno Kamdem
Chair: *Gerhard-Wilhelm Weber*
Chair: *Gordon Dash*

1 - Stochastic home care transportation with dynamically prioritized patients: An integrated facility location, fleet sizing, and routing approach
Yong-Hong Kuo, Jamal Nasir

We study a home health care (HHC) problem that is characterized by prioritized patients and uncertain demands. To formulate the problem, we propose a multidepot and multi-period chance-constrained optimization model with precedence constraints, assuming that the demand quantities for medical supplies are random variables. Since patients' medical conditions vary in severity, the priority of each patient is translated into a time-dependent potential healthcare cost that changes dynamically over the planning horizon. The solution to the proposed model determines the optimal locations for the base Mobile Health Facilities (MHFs) and the fleet size of HHC vehicles, and generates scheduling and routing plans to visit patients within specified time windows. We propose a unique three-phase solution approach, integrated with stochastic simulation, to address the problem. We then assess the robustness of the proposed model based on a realistic case of HHC service provision in Hong Kong and explore the optimal values for two model parameters, namely the Vehicle Threshold Index and the MHF Threshold Index. The performance evaluation tests show that the proposed solution method is efficient and effective for solving real-world problems.

2 - Optimal Strategic Equilibrium in Transport Corridors with Geopolitical Tensions: A Game Theoretic Approach
Bruno Kamdem

Global supply chain disruptions, particularly in the energy sector, due to geopolitical conflicts have compelled stakeholders to diversify resources by investing in alternative transport corridors. This strategy enhances reliability, builds long-term resilience, and reduces dependency on singular routes. Our study introduces a stochastic differential game-theoretic framework to navigate the complexities of managing transport corridors in conflict-prone areas. By employing Stochastic Differential Game Theory and Optimal Control, we model strategic interactions among key players such as governments, transport companies, and international organizations. This methodology fosters robust strategies to mitigate adversarial actions and geopolitical shifts, incorporating transportation costs and geopolitical risks into a comprehensive resilience strategy. We identify a unique Nash Equilibrium that optimizes taxation and transport mode factors, minimizing disruptions and fostering economic stability in volatile regions. The findings underscore the efficacy of cooperative strategies and the flexibility of dynamic commodity pricing mechanisms responsive to shifts in geopolitical risks. Additionally, we propose dynamic tax policy adjustments, which are calibrated based on commodity prices, transportation efficiency, and geopolitical exposure. Our research advances both theory and practice in transport logistics and geopolitical risk management substantially.

3 - Advancing Logistics Development in Colombia: The CLI Methodology as a Bridge Between Data and Policy Action
Claudia Rave

The Logistics Integration Corridors (CLI) methodology was applied to assess logistics corridors in Colombia, using an indicator-based decision support system (DSS) grounded in Multi-Criteria Analysis (MCA). CLI evaluates maturity (connectivity, integration, governance) and performance (operation, competitiveness, reliability), providing actionable insights for policy-making. Embedded in prospective scenarios and spatially disaggregated, CLI enabled stakeholders to prioritize investments, align regional development with national strategies, and identify critical nodes for integration into the national network. Results demonstrated CLI's ability to inform high-stakes decisions, fostering new productive vocations and regional specialization. However, the OR community often undervalues such approaches, limiting their potential outreach and broader stakeholder engagement. This paper calls for greater recognition of indicator-based DSS as essential tools for policy-making, emphasizing their ability to translate complex data into actionable insights. By fostering a deeper understanding of indicators and their role in decision-making, OR can bridge the gap between science and society, driving equitable and sustainable development.

4 - Super-hedging-pricing formulas for vulnerable claims or death derivatives in models with random horizon
Tahir Choulli, Emmanuel Lepinette

We consider the market model described by the triplet (S, F,T). Here, F is the "public" flow of information which is available to all agents overtime, S is the discounted price process of d-tradable assets, and T is an arbitrary random time which might not be observable via F. As random time can not be observed before it occurrence, the adequate larger flow G -that incorporates F and observes T when it occurs- is the progressive enlargement of F with T. This framework covers the credit risk setting where T represents the default time of a firm/client, the life insurance setting where T is the death time of an insured, and other areas of finance. We first address the existence of the super-hedging price as a price, which is intimately related to the absence of Immediate-Profit arbitrage (IP for short). Then we focus on elaborating explicit super-hedging formulas for various claims. Furthermore, we show how the super-hedging prices' set expands under the stochasticity of T. Finally, we quantify the impact of various risks induced by T on the super-hedging price of any vulnerable claim. This is achieved by decomposing its dynamics and singling out explicitly the various informational risks in the dynamics of the price process. This fact is vital when the insurance securitization process is adopted instead of the classical reinsurance process, towards amortizing the mortality and/or longevity risks . This talk is based on a joint work with Emmanuel Lepinette (Dauphine, France).

■ WB-24

Wednesday, 10:30-12:00 - Room: Esther Simpson 3.02

Tutorial: Does Ancient History Offer a Great**n Grandfather of OR?

Stream: Tutorials (and Workshops)
Tutorial session
Chair: Rita D'Ecclesia

1 - Does Ancient History Offer a Greatn Grandfather of OR?**
David Lane

This session explores a possible originator of OR, a precursor to the people we usually think created OR, and someone from a much earlier time. Sadly, much of the development of 'Operational Research' arose during wartime, specifically the Second World War. At its creation, 'OR' meant the use of analysis to organise equipment, information flows and decision-making. Whilst it could involve technological innovation it was perhaps mostly concerned with getting the most out of what was already available. The canonical example is the work of Patrick Blackett on the air defence of Britain. The deployment of radar and fighter aircraft technologies, and the careful organisation of different information sources were crucial on allowing the Royal Air Force to defend against attacks by Nazi forces during 1940 and so win 'The Battle of Britain'. For this and subsequent work Blackett is known as 'the father of OR'. However, very similar work can be seen in events centuries, in fact millennia, before this. In her 1954 account of the history of OR, Florence Trefethen mentions a 'precursor' to OR drawn from ancient history - but offers a tantalising account of only 19 words! Enough, however, to motivate this presenter to explore quite what she was referring to, what had happened in the third century BCE and what the relationship with modern OR might be. Archaeology, dusty books and an inclination to explore sun-drenched ruins are all necessary to put the story together. The story that emerges has the same features of effective organisation of existing equipment to improve results, combined with the use of some new innovations. It reveals the guiding hand of one brilliant figure. He employed contemporary ideas on siege warfare, city defence, ancient artillery and mathematics. He studied war-related operations and carried out analysis which greatly improved the defence of his home. He brought all this together to use a range of technologies and ideas - some created by him - in innovative ways to strike terror into a Roman attacking force and to hold off their direct assault. Who is this remarkable figure? He is widely considered to be the greatest scientist of antiquity and one of the greatest mathematicians of all time. Come along to learn his identity. Stay to give your view about whether he is, perhaps, the Great**n Grandfather of OR and whether we can draw him into the history of our field to make for an extraordinary story that links OR to the Ancient World and to the very beginning of science.

■ WB-25

Wednesday, 10:30-12:00 - Room: Maurice Keyworth 1.32

Design thinking for Impact in OR

Stream: Making an Impact: The Practitioners' Stream 2
Making an impact session
Chair: Geoff Royston

1 - Design thinking for Impact in OR
Geoff Royston, Christina Phillips

OR/MS practitioners know that clients often want support not only with decision analysis but also with the design of systems or processes. For this a combination of skills of analysis and of synthesis is required - what might be termed 'whole brain' OR. This workshop will introduce design concepts and provide examples of "design thinking" in operational research, and allow participants to try out some design thinking approaches.

Whether you are an experienced practitioner with your own reflections to share on the importance of design concepts and skills in "real world" operational research, or someone at an earlier stage of their career who wants to discover how thinking more like a designer can boost your work performance and professional profile, this workshop has been designed for you!

■ WB-26

Wednesday, 10:30-12:00 - Room: Maurice Keyworth 1.33

Lente Festina (aka not too fast, not too slow): how to "match the pace" with IT, Business and Users in OR-based projects

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: Michele Quattrone

1 - Lente Festina (aka not too fast, not too slow): how to
Making An Impact, Michele Quattrone, Slawomir Pietrasz, Georgios Dikas, Laura Houlley, Jelke van Hoorn

Operations Research projects within large organizations are often deeply intertwined with business processes, an end-user flow and existing IT systems. Achieving and sustaining a well-paced, adaptive development cycle is critical to delivering real impact. It is generally said that Agile principles—quick feedback loops, iterative delivery, and early learning—can help reduce risk and adapt to emerging insights. However, applying these principles in the context of OR is not straightforward. Success depends on effective coordination across users, analysts, OR and non-OR developers, suppliers, and consultants. Striking the right pace is a constant balancing act: too slow, and the project risks losing operational momentum and stakeholder engagement; too fast, and it may overlook key constraints, user needs, or systemic complexity—ultimately undermining long-term value.

This session offers an open discussion with four experienced panelists - Laura Houlley, R&D project manager in supply chain digitalization at Air Liquide,Slawomir Pietrasz, research engineer and project coordinator at ENGIE, Georgios Dikas, head of Data Science at Tesco and Jelke Van Hoorn, Ortec- who have led OR projects across their organizations and will share practical insights on how to "keep the pace" while staying aligned with agile values. Panelist bios and further information are available in the Making an Impact Stream section of the conference website.

■ WB-30

Wednesday, 10:30-12:00 - Room: Maurice Keyworth 1.05

Shared Mobility Optimization III

Stream: Shared Mobility Optimization
Invited session
Chair: Thomas De Munck

1 - A rolling horizon approach to coordinating ride-hailing platforms and public transit systems
Thomas De Munck, Jean-Sébastien Tancrez, Jorge Vera Andreo

This work considers the online dispatching problem of a ride-hailing platform (e.g., Uber) that coordinates with a public transit system. Customers are impatient and make requests randomly over time. For each request, the platform must decide (i) whether to provide door-to-door, first-mile, or last-mile service and (ii) which drivers to dispatch to the resulting service. To address this problem, we propose a rolling horizon approach based on stochastic optimization. The approach includes a route selection procedure, and a Benders decomposition to improve its applicability in realistic settings. In numerical experiments, we first demonstrate the effectiveness of our approach in comparison with rolling-horizon approaches based on deterministic optimization. Then, we provide managerial insights into the benefits of coordinating ride-hailing services with public transit by analyzing various supply-demand patterns and transit network configurations.

2 - Optimal charging infrastructure size and location to support electric taxi fleets using real trajectory data: a case study in a Portuguese city
Ana Loureiro, Beatriz Brito Oliveira, Vera Miguéis, João Neves, Álvaro Costa, Michel Ferreira

Despite the rise of electric mobility, taxi fleets lag behind. Accelerating their transition requires demonstrating the feasibility and cost-effectiveness of electric taxis with adequate charging, while highlighting their environmental benefits. This work addresses this issue by seeking, for a charging infrastructure (CP), both the best location within a taxi stand network and the minimum number of chargers required to maximize the number of taxis transitioning to electric vehicles while keeping the current service level. For this purpose, we formulated a bi-objective optimization model and validated it using real data collected by an entire taxi fleet over 4 weeks of operation. We applied the Epsilon-constraint method to solve the model and obtain the Pareto fronts, allowing to quantify efficient and feasible trade-offs. We determined that the configuration of the CP and the number of electric taxis it could support greatly depended on the activity level. In each week, an average of 20 chargers was consistently allocated to a subgroup of stands. For the whole 4 weeks period, we showed that the operation of nearly a third of the fleet could be perfectly adapted to electric mobility. For this scenario, the deployment of 22 chargers would be needed. We believe that the proposed model can aid authorities and managers in promoting the use of electric vehicles for taxi services, by providing a tool that allows to define a customized CP that meets the needs of the operating fleet.

3 - Risk-Aware Car Sharing: Ensuring Fairness and Service Quality with Substitution
Esra Koca, Beste Basciftci

In today's competitive car-sharing industry, optimizing operations while ensuring high-quality service and fairness is crucial for efficiency, profitability, and market competitiveness. This paper examines a reservation-based car-sharing company offering round-trip and one-way rentals with a mixed fleet. We address strategic fleet positioning, relocation, and operational decisions, including vehicle allocation and routing, under demand uncertainty. Our model incorporates risk-aware constraints to ensure fairness across customer segments and demand points while maintaining customer satisfaction. We introduce a stochastic optimization framework that accounts for uncertain demand realizations and integrates substitution options to improve resource utilization. By considering both risk-aware quality of service and fairness constraints, our approach enhances decision-making under uncertainty. To solve this problem efficiently, we propose a decomposition-based branch-and-cut algorithm using the L-Shaped method. This enables us to handle large-scale instances while maintaining computational efficiency. Our computational study demonstrates the effectiveness of our approach in balancing service quality, fairness, and operational efficiency under market uncertainties, offering valuable insights for decision-makers in car-sharing operations.

■ WB-31

Wednesday, 10:30-12:00 - Room: Maurice Keyworth 1.06

Stochastic Vehicle Routing Problems

Stream: Stochastic and Robust optimization
Invited session
Chair: Francesca Maggioni
Chair: Francesca Vocaturo

1 - Enhancing Two-Echelon Vehicle Routing Problem Solutions with Mobile Satellites: A Stochastic Optimization Approach
Aria Dahimi, Mehrdad Mohammadi, Virginie Lurkin, Tom van Woensel

This study introduces an innovative approach to the stochastic two-echelon vehicle routing problem with mobile satellites (2E-VRP-MS), where synchronization is crucial due to significant impacts from time uncertainties. We present an efficient metaheuristic algorithm, combining a Stochastic Approximated Scheduling with Adaptive Large Neighborhood Search (SAS-ALNS), designed to address uncertain travel and service times in urban logistics. The methodology utilizes log-normal distributions to model these stochastic elements, excluding extreme values to maintain operational realism. Extending the deterministic model to a stochastic framework, we implement recourse

optimization and chance constraint approaches. The results include a sensitivity analysis and comparisons of different approaches and variants of the problem. This research contributes to the literature stochastic 2E-VRP-MS and offers practical insights for logistics companies looking to improve their delivery systems amidst uncertainties.

2 - The Vehicle Routing Problem with Uncertain Accessibility
Meike Reusken, Gilbert Laporte

We introduce a new variant of the vehicle routing problem where customer accessibility is uncertain due to external locational factors such as occupied docking stations, full docking queues, and a lack of nearby parking spaces—challenges observed in a Canadian food bank's collection route. These constraints force vehicles to leave inaccessible customers and revisit them later, but the duration of inaccessibility is stochastic, meaning success in subsequent attempts cannot be guaranteed. For this problem, we present two mathematical formulations: one for an a priori route and another for a reactive response to route failures. We propose a solution procedure that isolates and solves each fundamental component separately, resulting in a compact, tractable optimization problem and heuristic with low computational complexity. Numerical experiments validate the procedure's performance and highlight the benefits of integrating specific data to manage uncertainty effectively.

3 - Vehicle routing with multiple customer-based stochastic components
Ymro Hoogendoorn, Meike Reusken

We introduce and investigate an exact algorithm for a vehicle routing problem with multiple stochastic components. The problem concerns the construction of vehicle routes to serve a set of customers, where demand is stochastic along with one or more components that are related to this demand. For this context, we study the a-priori framework, i.e., we construct routes once before starting the route using probabilistic metrics.

The stochasticities in our problem are modeled using expected recourse terms and chance constraints. We construct a generic model that can handle an arbitrary number of customer-based stochastic components, by either including a recourse penalty term or chance constraint per component. This gives us a model that has a wide range of applications, including any vehicle routing problem where demand is uncertain along with, e.g., service time or workload.

We solve our model to optimality by means of an integer L-shaped method. Furthermore, we introduce lower bounding functionals and valid inequalities to accelerate the solving time. We test the efficacy of our model and solution method in numerical experiments. Preliminary experiments have shown that our algorithm can solve moderate instance sizes efficiently for a handful of stochastic components.

4 - The Stochastic Location-Routing Problem with Synchronised Truck-Drone Tandem for Humanitarian Aid Delivery
Hannan Tureci Isik, Melih Celik

We study the network design problem to strategically locate depots for post-disaster response. Disasters such as earthquakes can damage roads, leading to prolonged travel times or isolated regions. We evaluate the integration of drones operating in tandem with trucks to improve delivery times to beneficiaries. We focus on delivering lightweight humanitarian aid bundles such as communication kits, masks, or flashlights, which drones can transport. Trucks and drones operate synchronously: a drone launches from a truck to deliver a package, and lands back on the truck while it continues deliveries. We consider a flexible synchronisation model, allowing the same or different launch and landing locations, multiple take-offs from one location, and the truck waiting or delivering before rendezvousing with the drone. The location decisions address post-disaster logistics while incorporating disaster-related uncertainty through stochastic travel times. We model this as a two-stage stochastic program and develop a tailored heuristic. Our method has two levels: the outer level uses Iterative Local Search (ILS) for depot location, while the inner level solves the stochastic truck-drone routing problem. For each scenario, we apply Greedy Randomised Adaptive Search Procedure (GRASP) to the routing problem, used across all scenarios to evaluate depot performance. We implement the algorithm in a case study based on the 2011 Van Earthquake in Turkiye, to gain managerial insights.

■ WB-32

Wednesday, 10:30-12:00 - Room: Maurice Keyworth 1.09

Green maritime and port logistics-1

Stream: Maritime and Port Logistics
Invited session
Chair: *Cagatay Iris*

1 - Applications of Predictive Analytics in Container Shipping Supply Chains: A Systematic Review
Nader Alshammari, Dongping Song, Yuanjun Feng, Xinjie Xing

Container Shipping Supply Chains (CSSC) encompass the movement of containerized cargo across global maritime networks. CSSCs represent a significant portion of maritime trade's value, making their resilience and operational efficiency essential to global trade. Predictive Analytics (PA) provide powerful tools to enhance CSSC performance and mitigate disruptions in these complex logistics systems. Despite a rise of PA-focused studies in the CSSC domain, existing research on its applications remains scattered and an overview and synthesis of existing literature is lacking, limiting a comprehensive understanding of the field. To address this, we conducted a systematic literature review (SLR) guided by PRISMA practices, screening 4,652 publications, of which 105 met the eligibility criteria. These publications were classified according to specific CSSC segments, and their implications on logistic performance were analysed by mapping dependent variables to established logistic performance frameworks. PA applications are analysed and discussed in terms of forecasting methodologies, approaches, and validation techniques, highlighting key challenges around data quality, methodological rigor, scalability, and generalizability. By offering a structured assessment of PA applications in CSSC, we hope this SLR can inform academics, practitioners, and policymakers of avenues for future research and practices.

2 - Evaluating the Impact of Chokepoint Disruptions in Maritime Transport Networks
Tao Wen, Yu-wang Chen, Tahir abbas Syed, Arijit De

Maritime transport plays a crucial role in international trade, accounting for over 80% of global transport volume. However, recent disruptions, such as the Ever Given blockage in the Suez Canal and security threats in the Red Sea, have severely impacted global shipping, highlighting the key role of chokepoints. Notably, the 2024 Review of Maritime Transport by the United Nations Trade and Development is titled Navigating Maritime Chokepoints, emphasizing their significance. This work develops an agent-based model to assess the impact of chokepoint disruptions on ship operations and re-routing decisions, thereby demonstrating their effects on global trade. When encountering a chokepoint disruption, ships make independent decisions based on multiple factors, including disruption duration, deviations in estimated disruption duration, and sensitivity to disruption. Our findings reveal that the time required for the maritime network to return to normal does not increase linearly with disruption duration. Instead, beyond a critical threshold, recovery time begins to decrease due to rational re-routing decisions made by ships. Furthermore, we systematically analyze the impact of ship heterogeneity, including estimation deviations and sensitivity to disruptions, across multiple scenarios. These insights provide valuable guidance for ship operators navigating chokepoint disruptions and can help logistics firms design effective contingency plans to mitigate operational risks.

3 - An Iterative Optimization-Simulation Approach for Energy-Efficient Ferry Scheduling with Landside Traffic Considerations
Asefe Forghani, Ying Xie

This study presents an energy-aware ferry scheduling model for Ro-Ro ferries, designed to address both maritime and landside operational challenges under cold ironing constraints. The model incorporates collaboration among ferry operators, commercial considerations, deck space flexibility, fallback strategies for charging electric or hybrid vessels, and inland traffic simulation to optimise scheduling. The ferry operator alliance allows capacity sharing, reducing unnecessary crossings and balancing demand. Commercial considerations ensure that schedules align with service levels, maintaining market share for each ferry operator. The model optimises deck space by reallocating surplus freight capacity to cars, while preventing the reverse due to deck height restrictions. Given the limited availability of cold ironing at berths, the model introduces a fallback strategy that allows ferries to switch to diesel when shore power is insufficient. Beyond berth scheduling, it integrates landside traffic simulation using an iterative optimisation-simulation approach, refining ferry schedules to alleviate inland traffic bottlenecks, especially at passport control. Computational experiments show that the approach enhances efficiency, reduces emissions, and improves port traffic, offering a scalable solution for ports adopting cold ironing technology.

4 - Optimal sizing and hybridization of tidal power plants
Flávia Barbosa, Luciana Yamada, Luis Guimarães, Cagatay Iris

Hybrid renewable energy systems (HRES) are gaining increasing attention due to their potential to provide a stable and efficient energy supply, optimize spatial use, and reduce costs. This work proposes an optimization framework to size a tidal power plant by determining the optimal location of the tidal barrage and the number of turbines required. Additionally, it analyzes the integration of energy generation from the tidal farm with nearby offshore wind farms to determine the most suitable grid connection. We demonstrate the methodology's utility in a real River Mersey, Liverpool, England case study. With its huge tidal range, a tidal power scheme on the Mersey could produce enough clean, green electricity to power every home in the city region for more than a hundred years while creating thousands of jobs. Complementing existing strengths in offshore wind and tidal energy, this predictable and proven energy source could be key to the city region's ambition to be net zero by 2040.

■ WB-34

Wednesday, 10:30-12:00 - Room: Michael Sadler LG10

Theory of Knowledge, Technology, and Innovation

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: *Januj Juneja*
Chair: *A. D. Amar*

1 - Grow Organically or Through Acquisition to Create Value for the Firm
A. D. Amar, Januj Juneja

Our approach assesses growth using total employment or related variables by setting up an SEM system that includes several variables tied to the ability of the firm to grow. The model is applied to the datasets constructed from two samples, one for each mode of growth. For the sample of firms that grow by acquisition, we start by identifying all acquisitions using the SDC database. After computing the return to the acquirer by treating the acquisition date as an event, we form our main variable of interest as a growth factor using the Black-Scholes equation treating the acquisition as an option to expand the operation of the firm. Using WRDS and findings from recent works to determine the ten most critical variables of growth in two stages using OLS by controlling for potential autocorrelation and heteroskedasticity bias. We repeat this for organic growth firm by starting with identifying those firms that did not undergo growth by acquisition over the same sample period and had available returns within a short window of time of the event date. We highlight the advantages of growth through acquisition as a source of value creation relative to organic growth and so of the myriad possible theoretical reasons for this advantage. We focus on the longer time to grow through organic means relative to acquisition and compute that time differential using a recently proposed timing algorithm constructed based upon the Fourier series and conclude with directions for future research.

2 - What Explains the Use of Business Analytics? A Comprehensive Analysis of the Ability, Opportunity, and Motivation of Firms' Use of Business Analytics
Bernd Brandl, Gokce Basbug, Barbara Bechter, Ulrike Leopold-Wildburger

For many firms the use of business analytics and the effective use of the available information and data appears to be a self-evident advantage but comparatively few firms make use of it. Recent literature suggests that there are various firm specific and contextual factors that encourage as well as restrain firms from making use of OR- and Business Analytics but little is known about their role and relevance. On the basis of an up-to-date, large scale, cross-national and cross-sectoral data set on the incidence of use of OR- and Business Analytics in 20,411 firms in all member states of the EU, we investigate the role and relevance of a comprehensive list of factors that potentially explain why some firms make use of business analytics while others refrain from its use. Against the background that the dataset covers firms within a wide range of countries and therefore within different institutional and legal systems which were shown to be decisive for the use of business analytics, we systematically analyse the relevance of firm specific, i.e. organizational, market specific, and country factors on the incidence of business analytics in firms using a multi-level framework. Our findings show that country specific factors matter but market factors appear to be of less importance. Most notably, however, we find that the use of business analytics is explained by firm traditions rather than market and business matters.

3 - Building a RAG pipeline from scratch
Hisham Taj, Alice Saunders

Retrieval augmented generation (RAG) pipelines are a popular method for resolving common shortfalls with large language models (LLMs). Whilst LLMs provide valuable assistance in generating text, summarizing information, and enhancing productivity, they also come with limitations, particularly the risk of hallucinations, where LLMs generate incorrect or misleading information with apparent confidence.

RAG pipelines offer a structured approach to mitigating these issues by retrieving relevant, fact-checked information from trusted sources before generating a response. This reduces the likelihood of hallucinations and improves the accuracy and reliability of the output.

Standard approaches to RAG pipelines typically rely on a wide variety of different libraries in Python that provide support for the creation of Vector stores and retrievers. Outside of Python however, there is limited support for these objects, meaning these structures often have to be created manually. For applications where the use of Python is not possible, this issue acts as a significant barrier to the implementation of RAG.

This talk will give an overview of how to create these structures from scratch, discussing not only the creation, but the optimisation of these structures, in order to give a full description of how RAG pipelines function.

4 - Integration of Support Vector Machines and Mean-Variance Optimization
Roy Kwon

This work introduces a novel methodology for portfolio optimization that is the first to integrate support vector machines (SVMs) with cardinality-constrained mean-variance optimization. We propose augmenting cardinality-constrained mean-variance optimization with a preference for portfolios with the property that a low-dimensional hyperplane can separate assets eligible for investment from those ineligible. We present convex mixed-integer quadratic programming models that jointly select a portfolio and a separating hyperplane. This joint selection optimizes a tradeoff between risk-adjusted returns, hyperplane margin, and classification errors made by the hyperplane. The models are amenable to standard commercial branch-and-bound solvers, requiring no custom implementation. We discuss the properties of the proposed optimization models and draw connections between existing portfolio optimization and SVM approaches. The mathematical programming models and the associated parameter selection strategy are amenable to financial back-testing. The models are evaluated in-sample and out-of-sample on two distinct datasets in a rolling horizon backtesting framework. The portfolios resulting from the proposed approach display improved out-of-sample risk-adjusted returns compared to cardinality-constrained mean-variance optimization.

■ WB-35

Wednesday, 10:30-12:00 - Room: Michael Sadler LG15

MINLP 1

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: *Jan Kronqvist*

1 - Branch-and-Cut for Mixed-Integer Programming Games
Aloïs Duguet, Tobias Harks, Martin Schmidt, Julian Schwarz

Generalized Nash equilibrium problems with mixed-integer variables form an important class of games in which each player solves a mixed-integer optimization problem with respect to her own variables. Those games are hard to solve as they are more general than both purely continuous games and purely integer games. In particular, most methods for those two classes are not applicable to the mixed-integer case. In this work, we introduce the first branch-and-cut algorithm to compute exact pure Nash equilibria for different classes of mixed-integer games with linear constraints. The main idea is to reformulate the problem of finding Nash equilibria as the problem of solving a suitable bilevel problem based on the Nikaido–Isoda function. The proposed branch-and-cut method is applicable to (generalized) Nash equilibrium problems under reasonable assumptions. Depending on the specific setting, we use tailored equilibrium or intersection cuts. The latter are well-known in mixed-integer linear optimization and we adapt them to the game setting. We prove finite termination of the algorithm and present some first numerical results for knapsack games and capacitated flow games.

2 - Rotational relaxations for global optimization of quadratic programs
Yehor Blokhin, Jan Kronqvist

In this talk, we consider the global optimization of non-convex quadratic programs with linear constraints, defining a bounded set. We introduce a family of new relaxation methods, which are derived by reformulating the problem by linearly transforming the vector space using constraints. The preliminary results show that the presented approaches, integrated with the αBB method and McCormick envelopes, can massively increase the quality of the convex relaxation.

3 - Using quadratic cuts to iteratively strengthen convexifications of box quadratic programs
Daniel Porumbel, Amélie Lambert

We consider the exact solution of minimizing a quadratic function f with box-constrained variables. Our idea is to compute convex-quadratic functions that form a piecewise-quadratic convex underestimator. To do so, we generate one by one p quadratic-convex cuts as in a cutting-planes fashion. Then, our underestimator is defined as the maximum of p convex-quadratic functions. We show that when p $\rightarrow \infty$ the optimal solution of this relaxation converges to an optimal solution of the strong "Shor plus RLT" semi-definite relaxation of the initial problem.

The integration of the resulting quadratic convex bound into a spatial branch-and-bound algorithm allows us to solve the initial problem to global optimality. Numerical results show that even a small value of p can often be enough to reduce the branching tree size by half compared to sticking to p = 1. The resulting algorithm is also competitive in terms of CPU time compared to well-established solvers that rely on other techniques. Full paper at cedric.cnam.fr/ porumbed/pconvex.pdf

4 - Cutting plane algorithms for local exploration in black-box optimization: Heuristics for cut generation
David Alejandro Linan Romero, David Ek, Daniel Marjavaara, Anders Forsgren, Jan Kronqvist

This work introduces a black-box (BB) cutting plane (BCP) algorithm and provides a computational and theoretical comparison of cut generation techniques that solely rely on BB function evaluations. BCP differs from standard cutting plane methods in the sense that, instead of evaluating a solution candidate and generating a cut for this candidate at each iteration, BCP samples multiple solution candidates within a neighborhood and uses their objective function information to heuristically generate a cut at each iteration. Different heuristics to approximate cuts are compared, including those based on the simplex gradient and its variants. These strategies are tested against a newly proposed cut generation technique that relies on the solution of an auxiliary linear programming (LP) problem that considers the history of previously evaluated objective function values and offers the option to adaptatively update previously generated cuts. Overall, the results show that the proposed cut generation technique allows BCP to find better objective function values, at the expense of requiring extra computational time for the solution of auxiliary LPs. From a practical perspective, the key novelty of this work is the development of an open-source implementation of BCP that gives the user freedom to experiment with different cut generation heuristics. This is desirable in a purely BB context where the mathematical properties of BB functions (e.g., convexity, smoothness) are unknown.

■ WB-38

Wednesday, 10:30-12:00 - Room: Michael Sadler LG19

Optimization and Machine Learning: Methodological Advances

Stream: Data Science meets Optimization
Invited session
Chair: *Ender Özcan*
Chair: *Michael Römer*

1 - Towards Convexity in Anomaly Detection: A New Formulation of SSLM with Unique Optimal Solutions
Hao Wang

An unsolved issue in widely-used methods such as Support Vector Data Description (SVDD) and Small Sphere and Large Margin SVM (SSLM) for anomaly detection is their nonconvexity, which hampers

the analysis of optimal solutions in a manner similar to SVMs and limits their applicability in large-scale scenarios. In this paper, we introduce a novel convex SSLM formulation which has been demonstrated to revert to a convex quadratic programming problem for hyperparameter values of interest. Leveraging the convexity of our method, we derive numerous results that are unattainable with traditional nonconvex approaches. We conduct a thorough analysis of how hyperparameters influence the optimal solution, pointing out scenarios where optimal solutions can be trivially found and identifying instances of ill-posedness. Most notably, we establish connections between our method and traditional approaches, providing a clear determination of when the optimal solution is unique—a task unachievable with traditional nonconvex methods. We also derive the ν-property to elucidate the interactions between hyperparameters and the fractions of support vectors and margin errors in both positive and negative classes.

2 - Improved intuitionistic fuzzy least square twin support vector machine for class imbalance learning
Yash Arora, S. K. Gupta

In the data mining community, imbalanced datasets pose a persistent challenge that affects the performance of classification problems. Although support vector machine (SVM) is a well-established classification technique, it struggles with imbalanced datasets because it assigns equal importance to all training samples. Several algorithm-level approaches improve the performance of SVM on imbalanced datasets. However, they often face challenges when dealing with noise and outliers. To address these issues, we propose an improved intuitionistic fuzzy least square twin SVM for imbalanced datasets. It introduces a novel membership function that integrates Gaussian and entropy-based score functions with the imbalance ratio. The Gaussian membership reduces the impact of noise in training points and the neighborhood entropy is used to calculate the non-membership to distinguish between support vectors and outliers. The imbalance ratio is incorporated into the membership function to address the skewed distribution of classes. The model's efficiency is enhanced by solving two systems of linear equations to obtain the decision hyperplanes rather than solving a quadratic programming problem. To demonstrate the performance of the proposed method, comprehensive experiments are conducted on synthetic and imbalanced benchmark datasets. The experimental findings reveal that the proposed method outperforms other baseline models, highlighting its effectiveness in addressing realworld problems.

3 - Solving Polynomial Integer Programming with Hypergraph Neural Network
Minshuo Li, Yaoxin Wu, Pavel Troubil, Yingqian Zhang, Wim Nuijten

Complex real-world optimization problems often involve nonlinear relationships (either as constraints or objectives) resulting from physical laws, statistical measures, nonlinear regression, and other factors. While nonlinear programming can model such nonlinear relationships, existing solvers become computationally prohibitive for large-scale problems with numerous variables and constraints. This paper aims to design a hypergraph neural network (HNN)-based framework to accelerate the solvers for general polynomial integer programming (PIP) problems, a critical subclass of nonlinear mathematical problems. Specifically, an HNN is proposed to learn representations of general PIP problems, capturing deep information from polynomial terms. Then the HNN is trained to predict initial solutions that, after feasibility repair, become high-quality solutions for PIP problems. Experimental results on quadratic instances show that the HNN-based framework significantly enhances the solution quality of exact solvers and outperforms another learning-based method. Tests on higher-order polynomial instances are considered for further validation. Moreover, the proposed HNN can be applied to other learning targets with minor adjustments, providing a promising general pathway for addressing a broad spectrum of nonlinear combinatorial optimization problems.

■ WB-39

Wednesday, 10:30-12:00 - Room: Newlyn LG.01

Sustainable Supply Chains I

Stream: Sustainable & Resilient Systems and Infrastructures
Invited session
Chair: Ali Ala

1 - AI-Driven Drug Shortages Mitigation: A Reinforcement Learning and Optimization Framework for Adaptive Supply Chains
Seán McGarraghy, Ali Ala, Abu Shakil Ahmed, Vincent Hargaden

Drug shortages continue to be a significant concern in global healthcare supply chains, resulting in delays to patient care, increased operating costs, and bottlenecks in resource distribution. Conventional machine learning algorithms tend to be used to forecast shortages, but this research proposes that optimization combined with predictive analytics would better model disruptions to these supply chains. Therefore, a hybrid framework is proposed which combines Reinforcement Learning (RL) and Optimization to forecast and mitigate the effects of medicine shortages via adaptive supply chain decision-making. The proposed methodology combines Deep Q-Networks (DQN) with Mixed-Integer Linear Programming (MILP) and metaheuristic optimization models to enhance supply chain robustness. The reinforcement learning agent enhances supplier selection, inventory distribution, and real-time procurement tactics, mitigating cost and scarcity threats. The effectiveness of the model is assessed using critical parameters, including shortage reduction rates, cost savings, and decision-making efficiency. The results indicate that the RL-optimization framework is superior to both RL and conventional supply chain models, offering an AI-driven decision support system for regulators, hospitals, and pharmaceutical distributors.

2 - Changes in the Semiconductor Global Value Chain Amid Shifts in International Relations
Siyeon Lee, Kangbae Lee, Sungho Park, Ham Seunghoon, Jeeseung Han, Jisu Kang, Hyeonji Hwang

The semiconductor industry is a strategically important sector with a complex production structure and a globally dispersed supply chain. Due to its high complexity and broad scope, understanding the global semiconductor value chain is challenging. However, a comprehensive and timely understanding of global semiconductor trade is essential for securing national competitive advantage. This study aims to analyze changes in the global semiconductor value chain from the theoretical perspectives of international relations and global value chain theory. To identify structural changes and shifts among major countries, we examined key global issues and semiconductor trade volumes from 2007 to 2023 using U.N. Comtrade trade data.

The analysis shows a general increase in global semiconductor trade volumes since 2007, with shifts in country rankings. From 2007 to 2023, volumes declined in the West(Europe) while increasing in East Asia, particularly in South Korea, Japan, China, and Taiwan. China's accession to the World Trade Organization(2001) contributed to volume growth, while FTA and SmartPhone adoption drove increases in 2007-2008. The 2018 U.S.-China trade dispute led to a decline in China's semiconductor trade, while trade volumes increased in Taiwan, especially in system semiconductors. This supports the recent shift in international trade paradigms from efficiency-driven offshoring to security-focused friend-shoring in the global semiconductor value chain.

3 - Analysis of Network Centrality Shifts and Supply Chain Stability in the Global Semiconductor Value Chain
Hyeonji Hwang, Sungho Park, Kangbae Lee, Ham Seunghoon, Jisu Kang, Jeeseung Han, Siyeon Lee

This study analyzes the trade network within the global semiconductor value chain (GVC) and examines its structural evolution from 2007 to 2023. Utilizing the CEPII-BACI international trade dataset, we track the bilateral trade flows of semiconductor products(classified by HS codes) and apply network analysis techniques to identify key hub countries and structural linkages. The findings indicate a gradual diversification of semiconductor supply chain centrality, shifting beyond traditional hubs such as the United States, Taiwan, South Korea, and China, with emerging regional players assuming greater roles. Furthermore, by assessing major trade pathways and interdependencies, this study evaluates structural vulnerabilities and supply chain risks within the semiconductor GVC. The insights from this research contribute to a deeper understanding of network dynamics in the semiconductor industry's global restructuring and provide policy implications for supply chain resilience and strategic trade positioning.

4 - Deployment of Sustainable and Efficient Lunar Mining Systems Under Uncertainty: A Distributionally Robust Model Predictive Control Approach
Kosuke Ikeya, Michel-Alexandre Cardin, Jan Cilliers, Stanley Starr, Kathryn Hadler, Antonio del Rio Chanona

To establish long-lasting and sustainable complex engineering systems, some crucial factors in the future, such as changes in demand, need to be considered and incorporated into their designs, deployment, and operations. However, predicting the long-term future over decades, is extremely difficult. To address this challenge, there is an increasing need to develop tools to support decision-makers in optimizing the designs, deployment, and operations of engineering systems under deep uncertainty. Past studies have proposed methods considering a range of uncertain parameters or subsets of plausible values. However, these new methodologies are often complex and require multiple-step implementation. As an alternative and conceptually simpler approach to tackle deep uncertainty, this project employs distributionally robust multi-objective model predictive control (MPC) to solve a sequential decision problem. MPC has been used in various industries, such as chemical processing, for its usefulness. The proposed method considers a set of distributions for uncertain parameters and optimizes sequential decisions given the current state. As a case study, the proposed method is applied to optimize the deployment of an oxygen mining plant on the Moon to minimize the embodied energy and maximize sustainability, considering the lunar oxygen demand uncertainty. The effectiveness of the method is compared with two conventional approaches, the decision rule approach and robust decision-making.

■ WB-40

Wednesday, 10:30-12:00 - Room: Newlyn LG.02

Sports analytics

Stream: Sports and Entertainment
Invited session
Chair: John Trono

1 - The performance evolution of Counter-Strike teams
Jan Rejthar

This study examines the performance of newly assembled Counter-Strike: Global Offensive (CS: GO) teams. The study employs data about 789 professional or semiprofessional CS: GO teams from 7,328 matches between 2012 and 2023. Using semiparametric generalized additive mixed-effects models, the study assesses how team performance evolves over time. The results reveal a significant decline in performance during the first three months of a team's formation, followed by a plateau, suggesting that teams initially overperform. These findings support the presence of a novelty effect in CS: GO and underscore the need for strategies to sustain performance beyond the early success phase.

2 - A Duality-Based Bayesian Framework for Optimizing Lactate Testing in Sports and Medicine
Praowpan Tansitpong

Lactate testing is a cornerstone of performance assessment and metabolic monitoring in sports and medical applications. However, frequent testing can be resource-intensive and invasive. This study introduces a novel optimization framework that combines Bayesian prediction and duality principles to improve the efficiency of lactate testing protocols. The duality problem is formulated to balance testing frequency and predictive accuracy, leveraging Bayesian methods to integrate prior data and real-time observations for precise lactate level prediction. The approach ensures optimal resource allocation by addressing the trade-off between minimizing test invasiveness and maximizing diagnostic reliability. Numerical experiments and real-world data demonstrate the efficacy of the framework in reducing testing frequency while maintaining clinical and performance decision-making accuracy. The results underscore the synergy between duality theory and Bayesian inference, offering a robust solution for adaptive, cost-effective testing protocols in diverse applications.

3 - An Updated Strategy for Surviving an NFL Knock-Out Pool
John Trono

Knock-out pools have gained significant popularity this century. Each week, a different team must be chosen, and they must win their next game, otherwise, that participant is knocked out of the pool. (The participant who outlasts everyone else wins the pool.) Previously, a strategy based solely on a team's probability of winning their games, given each team's current W/L record, was devised and evaluated. A new formula has been created that incorporates the actual game scores and combines them - with the aforementioned estimate of winning - to inform the overall impression regarding predicting each expected victory.

4 - Dynamic Interplay of Sports, Social, and Economic Factors in the English Premier League: A Network DEA Approach
Marios Kremantzis, Yixin He, Siwei Xiao, Aniekan Essien, Umair Tanveer, Ali Emrouznejad, Shamaila Ishaq

This study evaluates the operational and profit efficiency of English Premier League (EPL) clubs from 2016/17 to 2019/20 using a novel Dynamic Network Data Envelopment Analysis (DNDEA) model under the Variable Returns to Scale (VRS) assumption. By integrating dynamic and network structures, the model captures the interplay between economic, sporting, and social factors, addressing limitations of traditional DEA approaches that treat production processes as static "black boxes." Results reveal two distinct clusters: high-performing clubs that achieve competitive outcomes with limited financial inputs through effective resource management, and financial giants that excel in revenue generation but struggle to translate investments into consistent sporting success. Dynamic analysis shows system efficiency peaked in 2016/17 before declining sharply in 2018/19, driven by imbalances between escalating financial investments and stagnating on-field performance. Operational inefficiencies in Stage 1 (resource conversion) were more critical than those in Stage 2 (profit generation), underscoring challenges in aligning short-term investments with long-term sustainability. The study advances sports analytics by providing a holistic framework for evaluating football club efficiency, emphasizing actionable strategies such as optimizing talent acquisition, prioritizing dual-return investments, and leveraging fan engagement.

■ WB-42

Wednesday, 10:30-12:00 - Room: Newlyn GR.02

Sustainable battery supply chains

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: Saeide Jamshidpour Poshtahani

1 - Recycling strategies and cooperation mechanism design for waste power batteries considering recycling regulation
Xinyi Li, Ada Che, Zhaofu Hong

The recycling and reuse of used power batteries not only contribute to resource conservation and environmental protection, but also play a crucial role in to promoting the sustainable development of the electric vehicle industry. This paper investigates the recycling strategies and cooperation mechanism design of waste power batteries considering recycling regulation policy. By using game theory, we construct a dynamic game model between an electric vehicle manufacturer and a dealer to examine the impacts of recycling regulation on the decisions and profits of the electric vehicle supply chain, consumer surplus, environmental performance, and social welfare. The following findings are obtained. (1) When the mandatory recycling rate is low, the recycling regulation benefits electric vehicle supply chain members and system, consumers, and the environment. However, when the mandatory recycling rate is high, recycling regulation is beneficial for improving the profitability of the electric vehicle manufacturers, supply chain systems, and social welfare if the government's per-unit recycling subsidy is high. (2) The electric vehicle manufacturer is more likely to benefit from recycling regulation when the marginal revenue from secondary utilization exceeds the unit cost savings from recycling. (3) Implementing a cost-sharing contract can concurrently enhance the profits of channel members, environmental performance, and social welfare when the mandatory recycling rate is low.

2 - For-profit or for-CSR: decisions of power batteries recovery in the supply chain
Ruxiao Xing, Bo Li

In recent years, the massive consumption of resources has caused severe damage to the global environment, and governments are actively seeking an energy transition to cope with resource depletion and environmental pressures. The transition from traditional fuel vehicles to new energy vehicles (NEVs) will help address this dilemma. However, as the sales of new energy vehicles grow, the recycling of new energy vehicle batteries will be challenging. In this work, we aim to find measures to effectively promote the recovery of used batteries and contribute to environmental protection. This paper discusses the decisions of battery recovery in the supply chain using the Stackelberg game. Specifically, we examine the decision of a system consisting of a supplier and a manufacturer under two decision-making modes: for-profit and for-CSR. We find that if environmental damage is severe, pursuing CSR leads to high retail prices, which is detrimental to NEV sales. Second, although not each member's collection amount improves when they consider CSR, the overall collection effect will be better. Third, we find that both the supplier and the manufacturer have incentives to pursue CSR.

3 - Sustainable Inventory Management for Electric Vehicle Batteries: A Closed-Loop Supply Chain Approach with Buyback Pricing
Saeide Jamshidpour Poshtahani, Brigitte Granville, Guven Demirel, Eun-Seok Kim

In order to realize the significant energy and environmental benefits that come with the widespread adoption of electric vehicles, it is crucial to address the economic and environmental challenges associated with battery production and disposal. One effective solution is building closed-loop supply chain systems for electric vehicle batteries. This study develops an economic production quantity (EPQ) model for the closed-loop supply chain, where used batteries are directed to remanufacturing, recycling, or disposal based on their quality grades. We analyze and compare two setups: a fixed buyback price scenario, as a benchmark, and a variable buyback price scenario, where the buyback price is decided according to quality. Based on our findings, we conclude that incorporating the recycling into the reverse supply chain reduces direct costs and environmental externalities only beyond a critical threshold of recyclable fraction of returned batteries. Furthermore, by differentiating buyback prices based on quality, substantial cost reductions can be achieved, while simultaneously reducing environmental externalities. These findings provide actionable guidance for designing economically viable and environmentally responsible supply chains for electric vehicle batteries.

■ WB-43

Wednesday, 10:30-12:00 - Room: Newlyn GR.07

Parallelize now!

Stream: Software for Optimization
Invited session
Chair: *Yuji Shinano*

1 - State-of-the-art Methods for Pseudo-Boolean Solving with SCIP
Gioni Mexi

The Pseudo-Boolean problem involves linear or polynomial constraints with integer coefficients over Boolean variables. The objective is to optimize a linear objective function, find a feasible solution, or maximize the number of constraints satisfied. In the 2024 Pseudo-Boolean competition, solvers incorporating the SCIP framework won five of the six categories in which they competed. Out of a total of 1,207 instances, SCIP successfully solved 759, while its parallel version, FiberSCIP, solved 776. In this talk, we discuss key modifications and new features implemented in SCIP to enhance its handling of Pseudo-Boolean problems. Moreover, we present the customized racing parallelization strategy used for FiberSCIP. In our post-competition work, we extend SCIP with an infeasibility analysis based on cutting planes, inspired by conflict-driven solvers for Pseudo-Boolean optimization. Phrased in MIP terminology, this type of infeasibility analysis can be understood as a sequence of linear combinations, integer rounding operations, and cut generation. Our experimental results indicate that the new infeasibility analysis algorithm improves SCIP's performance on Pseudo-Boolean problems and on more general mixed-integer programs in terms of running time, number of nodes in the search tree, and the number of instances solved.

2 - A parallelisation framework for solving challenging integrated long-haul and local vehicle routing problems
Stephen Maher, Yuji Shinano, Takafumi Chida, Akane Seto

The integrated long-haul and local vehicle routing problem with an adaptive transportation network is a very challenging optimisation problem. The adaptive nature of the transportation network means that the resulting optimisation problem is extremely large and difficult to solve directly using general purpose solvers. As such, the best approach for finding high quality solutions is to use heuristics combined with a branch-and-bound algorithm. Our research has developed a parallelisation framework that concurrently executes heuristic and exact approached to find high-quality solutions to the integrated long-haul and local vehicle routing problem. Within the parallelisation framework we have attempted to solve the complete problem directly using a MIP solver and by applying Benders' decomposition. The results will show that the use of parallelisation and applying Benders' decomposition increases the scale of problems that can solved and improves the upper and lower bounds that can be achieved.

3 - Current progress in highly parallel ensemble solvers instantiated by UG
Yuji Shinano

The Ubiquity Generator Framework (UG) is a powerful tool to parallelize state-of-the-art solvers that implement the latest algorithms. There are several successful results in solving previously unsolved Mixed Integer programming(MIP) instances, Steiner Tree Problem(STP) instances, Quadratic Assignment Problem(QAP) instances, etc. for the first time by using supercomputers. UG was originally a tool to parallelize branch-and-bound based solvers, but, starting from version 1.0, it was generalized to parallelize any kind of solver that needs to share information among running parallel solvers flexibly. Moreover, the flexibility of UG allows us to parallelize solvers that implement different algorithms as libraries that can run together and

cooperate in parallel. We call it a highly parallel ensemble solver. In this talk, we present the latest status of such highly parallel ensemble solver development.

■ WB-44

Wednesday, 10:30-12:00 - Room: Newlyn 1.01

Network constraints in electricity market design

Stream: Energy Economics & Management
Invited session
Chair: Kenneth Bruninx

1 - Multi-Market Coupling Model: A Residual Demand Approach
Tobias Kargus, Marliese Uhrig-Homburg

The growing share of intermittent renewable infeed calls for further interconnection of electricity markets. The European commission defined one coupled European electricity market as the target model and aims for an expansion of the interconnecting capacities to cover at least 15 % of the electricity produced in each connected country. For Central Western Europe (CWE), we observe that the day-ahead prices are often identical and are influenced by transmission capacities implicitly allocated by the Flow-Based Market Coupling (FBMC) methodology. However, established electricity price models often do not consider market coupling and lack implementable solutions to integrate it. Existent coupling models often assume explicit capacity allocation not following the FBMC and do not account for more than two coupled price zones. Due to the expected growth of interconnecting capacities, an approach using structural information and the FBMC methodology is needed. With our multi-market coupling model we want to fill this gap and answer the following research question: How can we integrate FBMC in a residual demand framework to predict electricity day-ahead prices in a mid-term horizon? Core of the model is the iterative optimization to find the optimal interconnector flows and the corresponding supply functions. Hence, we develop a proxy of the EUPHEMIA coupling algorithm and take the Remaining Available Margins (RAMs) of every interconnector as side restrictions.

2 - On energy distpatch problem with Euphemia Adequacy Patch constraints
Ali Al Zoobi, Jean-Marc Janin

In the context of energy production and distribution, several problems are studied, such as supply-demand equilibrium, grid expansion, and energy distribution optimization. Here, we focus on the electricity dispatch problem, specifically on conserving Euphemia market constraints (Local Matching and Curtailment Sharing) when energy failure occurs.

An electrical network can be represented as a graph where vertices correspond to countries and arcs represent their connections. Two main types of exchange capacity limitations exist: Net Transfer Capacity (NTC), which defines a static upper bound on energy exchanges between regions, and the Flow-Based (FB) model, which dynamically allocates capacity based on real-time grid conditions.

Adequacy Patch is applied as a postprocessing routine by adjusting energy flows after the initial dispatch. However, this approach leads to unusual cases, including an increase in the Energy Not Served (ENS), simultaneous ENS and pumping, and occurrences of ENS alongside Dispatchable Thermal Generation Margins (DTG MRG).

To address these inconsistencies, we propose a local redispatch routine that improves the method by iterating between energy redistribution and dispatch adjustments. This iterative approach ensures a better engagement with Euphemia Adequacy Patch rules while maintaining regulatory constraints.

3 - Assessing Zonal System Inconsistencies on Power Network Security in Real-Time Operations
Jehum Cho, Anthony Papavasiliou

Zonal market systems encounter numerous challenges associated with network congestion. Controlling cross-border power flows at the zonal level further exacerbates issues such as unexpected violations of capacity limits on both intra- and inter-zonal transmission lines. In day-ahead markets, re-dispatch processes can alleviate some of these problems. However, in balancing markets, there is no time to address these inconsistencies. Such discrepancies in real-time operations are directly related to the safety concerns of the network. In this talk, we introduce a method for analyzing the discrepancy between nodal and zonal systems. Nonlinear behaviors of zonal systems, due to the merit order for each zone, are captured using merit-order constraints with binary variables. This allows us to represent the true feasible region of zonal net positions that ensures security in real-time operations. By comparing this feasible region subject to merit-order constraints with the one derived from existing zonal models, one can determine the extent of system distortion in terms of feasibility. We analyze the conditions under which zonal systems can avoid congestion and evaluate the impact and usefulness of the minimum cross-border capacity policy.

4 - Network Constraints in Cross-Border Capacity Market Designs in Europe
Kamaldeen Adekola, Kenneth Bruninx

Capacity markets in Europe have traditionally relied on national mandates with little consideration for the highly interconnected nature of European electricity markets. This approach has been shown to lead to suboptimal outcomes. Leveraging the internal EU electricity market to create a more integrated, Europeanized capacity market could yield efficiency gains and reduce the need for investments. Accordingly, the European Commission mandates that foreign capacity providers be treated on an equal, non-discriminatory basis; however, implementation remains a challenge.

Existing studies of cross-border capacity markets account for network constraints using simplified Available Transfer Capacities (ATC). However, this approach oversimplifies the complex interactions within the network—such as loop flows and unscheduled power flows—which can potentially lead to reliability issues due to the network limitations preventing the delivery of power to zones that depend on contracted capacity from generators located in neighbouring zones.

In this study, we investigate whether leveraging the logic behind flow-based market coupling (FBMC) could yield a unified, European cross-border capacity market for annual capacity contracts. We compare the results of explicitly modelling FBMC constraints with ATC representation on a stylised test network. Finally, we discuss how this set-up creates synergy with long-term capacity contracts issued by Member States.

■ WB-46

Wednesday, 10:30-12:00 - Room: Newlyn 1.07

Nuclear-powered energy systems and new reactor concepts

Stream: Energy Economics & Management
Invited session
Chair: Aldo Bischi

1 - Optimal design and operation of co-generative Micro Nuclear Reactors (MNR)
Aldo Bischi, Mattia Ceccarelli, Andrea Pucciarelli, Andrea Baccioli

Micro Nuclear Reactors (MNR) are a subset of small modular reactors (SMR), designed for scalability, modularity, and eventually flexibility, delivering electrical output from one to tens of megawats. They are often termed "nuclear batteries" to emphasize their compact, distributed, and potentially off-grid capabilities as well as the possibility to re-fuel them every few years, depending on the usage. They look promising, especially for applications that undergo increasing electrification and decarbonization requirements, or the adoption of distributed generation solutions, e.g. temporary worksites or inside ports where boat combustion engines could be substituted with electric cables connected to the shore. MNR can be deployed in a co-generative configuration, generating simultaneously heat and power. This study takes the Westinghouse eVinci as a reference model, which operates with an open-air Brayton cycle, modelled to derive the performance as a function of ambient T and off-design load. The problem has been formulated as a Mixed Integer Linear Program (MILP) to minimize the design and operation cost of the system in a multi-year horizon. Several configurations have been assessed, including CO2 emissions, with the MNR benchmarked vs fully renewable, and electric and gas grid-connected solutions.

2 - SMR integration: a Belgian offgrid study case with Lead-cooled Fast Reactor
Antoine Larbanois

Europe must achieve net-zero emissions by 2050 to attain carbon neutrality. Currently, it remains reliant on energy imports. Alongside this goal, geopolitical tensions are boosting the push for energy independence. Local green energy options are limited and their intermittent natures requires significant investments in grids and storage. Nuclear energy, specifically Small Modular Reactors (SMRs), presents a promising low-carbon alternative. SMRs offer a wide range of capacities, lower initial investments, and quicker deployment compared to traditional reactors. This paper explores a Lead-cooled Fast Reactor (SMR-LFR) in an off-grid, energy-intensive industrial setting. It examines the viability of such a setup and how on-grid sites can size installations to ensure resilience during grid shutdowns. To ensure autonomy, we evaluate flexible storage solutions, such as electric batteries and synthetic molecules (H2, NH3). A comparative analysis of hydrogen production methods (AEC, PEM, SOEC) is also provided. The modelling of these systems is performed using GBOML, with an optimization performed over a cyclic year, using fifteen-minute time steps. Our findings show that integrating flexible storage elements adds only 3% to total costs, mainly for managing seasonal fluctuations. While differences in electrolyzer technology have minimal cost impact, they affect storage requirements. The average costs for electricity and heat are approximately EUR 60/MWh and EUR 25/MWh, respectively.

3 - Modeling hybrid nuclear reactors coupled with district heating networks
Cyrian Hallermeyer, Caroline Bono, Pascal Da Costa, Frederic Lantz

The decarbonization of the space-heating sector is a critical element in the global effort to transition to net-zero. As a proven technology for decarbonized heat and electricity generation, with experience in coupling with district heating (DH) networks, nuclear cogeneration plants (NCP) appear to be a promising technology to contribute to DH decarbonization. However, considering the substantial investment required for this technology and the development of alternative low-carbon sources, its role in DH systems must be critically evaluated. Our paper aims to identify key factors influencing the optimal transition pathways to low-carbon DH systems including NCPs. We seek to understand the benefits of nuclear cogeneration in a local context compared to alternative low-carbon heat production technologies. We conduct a comprehensive study of economic scenarios for optimal decarbonization of DH networks, including heat transport aspects in the modeling and economic evaluation. We develop a multi-period Generation Expansion Planning problem for a local DH system, including a NCP, a heat transmission network, and alternative heat production capacities (e.g, gas boilers, heat pumps). The problem is formulated as a two-phase Mixed-Integer Linear Programming model. The investment phase divides the horizon into 5-year periods, representing short-term system operations with representative weeks. The operation phase optimizes each block's full system operations with an hourly timestep.

■ WB-47

Wednesday, 10:30-12:00 - Room: Parkinson B08

Empirically Driven OR in Retail

Stream: Retail Operations
Invited session
Chair: Heinrich Kuhn

1 - Residual-based Wasserstein Distributionally Robust Optimization for Assortment Planning in E-commerce Services Retail
Yun Long, Xiang Li, Yanzhou Wu, Yanting Jin, Ning Zhu, Jie Chen, Zhu Meng, Yani Ji

This study examines an extension of the assortment problem in E-commerce services retail. Specifically, it focuses on the challenge of deciding what types of products and what quantities to feature within a dedicated promotion section. This decision is challenged by demand uncertainty and multidimensional operational constraints. To address these challenges, this study proposes a residual-based Wasserstein Distributionally Robust Optimization (DRO) framework to model this problem. The model leverages regression analysis to incorporate side information, such as weather and holidays, into the decision-making process. By constructing data-driven ambiguity sets to quantify prediction error distribution deviations, we develop the residual-based Wasserstein DRO model that integrates forecasted demand, product quality, category coverage, and supply capacity constraints. The methodology surpasses the dependence on perfect information assumptions inherent in traditional deterministic optimization, leveraging the Wasserstein metric to characterize high-dimensional uncertainty distributions. The framework ensures robust global decision-making while preserving product quality and diversity. Numerical experiments show that the out-of-sample performance significantly surpasses baseline model, indicating enhanced decision stability in volatile market environments. The proposed approach is extensible to inventory allocation, traffic distribution, and other correlated scenarios.

2 - Automatic Model selection for improving the forecasting accuracy in Manufacturing Demand
Giacomo Gaggero, Pier Giuseppe Giribone

This study explores a rigorous approach to forecasting the future sales volumes for one of the most important Italian companies in the automotive components sector. The methodology investigated in this research is based on analyzing the behavior of historical sales data for over 250 different products, leveraging the classification method proposed by Syntetos and Boylan. This method relies on the Average Demand Interval and the Coefficient of Variation to categorize time series into four classes: lumpy, erratic, intermittent, and smooth. Once the products are classified, the most suitable forecasting model is applied to each time series. For highly intermittent demand patterns—characterized by frequent zeros and unexpected peaks (lumpy)—the Teunter, Syntetos, and Babai (TSB) model is employed, which is a refined version of the well-known Croston method designed specifically for intermittent demand forecasting. For the other categories (erratic, intermittent, and smooth), the SARIMA model is used when the time series is stationary, while a recurrent neural network (RNN) is applied if the series is non-stationary. In this way, we do not apply a generic forecasting method to all products indiscriminately, but rather select the most suitable model for each product, thereby achieving more reliable demand predictions.

3 - Reinforcement Learning-Based Real-Time Inventory Management for Quick Commerce Supply Chains
Rahul Chavhan, Angela Biswas, Pankaj Dutta

The rise of Quick Commerce (Q-Commerce), fueled by post-COVID e-grocery expansion and the demand for ultra-fast delivery, has intensified pressure on retail logistics to ensure seamless product availability. This shift necessitates real-time inventory management, driven by unpredictable demand, stockouts, and perishable goods. Traditional replenishment models struggle to adapt, requiring data-driven solutions. This study collects data through web scraping from a leading Q-Commerce platform over a month, capturing daily fluctuations in inventory levels, pricing, and discount variations. These insights reveal demand patterns, stock volatility, and the impact of dynamic pricing, forming the foundation for robust forecasting and optimization techniques. Time-series models like LSTM and ARIMA enhance demand prediction, while Change Point Detection (CPD) identifies sudden demand shifts. A Soft Actor-Critic (SAC) reinforcement learning framework dynamically adjusts inventory replenishment, optimizing stock levels and reducing wastage. By deploying a real-time reinforcement learning agent across multiple dark stores, this approach outperforms traditional methods, improving fulfillment rates and minimizing holding costs. This research contributes to more sustainable and efficient retail logistics by enabling real-time decision-making, reducing waste, and enhancing operational resilience.

4 - Leveraging Corporate Social Responsibility to Enhance Circular Fashion: Optimization of Charitable Collection Channels for Sustainability
Marjan Olfati, Afshin Mansouri

Fast fashion, while making clothing affordable, shortens product lifecycles, increases used-clothing volumes, and poses a critical environmental challenge. Informed by a systematic literature review and motivated by stakeholder interviews from the post-consumption clothing supply network, we develop a preliminary MINLP model for facility location-allocation focused on charities. The objectives are to maximise collection value and social responsibility while minimising waste sent to incineration. Local councils and retailers partner with the charity to enhance collection, which acts as a supplier to shops, collectors, recyclers, upcyclers, and waste authorities. Key decision variables are pricing to councils per collected item from collection banks, selecting collection banks and shops, investing in corporate social responsibility (CSR) commitments, and exploring CSR's relationship with the circular network. The model supports circular practices such as reuse and recycling, mitigates textile-related environmental impacts, and generates profit to fund charitable activities, creating social value. A small-scale case study using UK charity data demonstrates its applicability. The model, solved using the CPLEX solver with sensitivity analysis, offers insights for charity decision-makers on partnering with retailers and councils to increase profitability, improve collection value, address environmental issues, and enhance CSR while identifying cost-effective collection modes.

■ WB-48

Wednesday, 10:30-12:00 - Room: Parkinson B09

New Approaches in Explainable Optimization

Stream: Transparent and Fair Decision Making with Mathematical Optimization
Invited session
Chair: *Ilker Birbil*

1 - Coherent Local Explanations for Mathematical Optimization
Daan Otto, Jannis Kurtz, Ilker Birbil

The surge of explainable artificial intelligence methods seeks to enhance transparency and explainability in machine learning models. At the same time, there is a growing demand for explaining decisions taken through complex algorithms used in mathematical optimization. However, current explanation methods do not take into account the structure of the underlying optimization problem, leading to unreliable outcomes. In response to this need, we introduce Coherent Local Explanations for Mathematical Optimization (CLEMO). CLEMO provides explanations for multiple components of optimization models, the objective value and decision variables, which are coherent with the underlying model structure. Our sampling-based procedure can provide explanations for the behavior of exact and heuristic solution algorithms. The effectiveness of CLEMO is illustrated by experiments for the shortest path problem, the knapsack problem, and the vehicle routing problem.

2 - HVAC System Management Using an Optimization with Constraint Learning Framework
Donato Maragno, Marco Caserta, Abhinav Pradhan

Heating, Ventilation, and Air Conditioning (HVAC) systems account for a significant portion of energy consumption in buildings, making their optimization crucial for reducing costs and environmental impact. This work presents a novel optimization framework for minimizing energy costs of HVAC systems while maintaining indoor temperature within the comfort zone. We formulate the problem as a mixed-integer optimization (MIO) model to determine optimal temperature setpoints over a daily planning horizon. To overcome the challenge of modeling non-explicit, system-dependent, and highly non-linear functions like power consumption and indoor temperature, we propose an optimization with constraint learning (OCL) approach. Machine learning models are trained on historical data to predict the outcomes of interest and are embedded as constraints and objective functions within the optimization model. The power of ML models such as decision trees, gradient boosting, and neural networks lies in their ability to capture non-linear functions while being themselves MIO-representable. This is why the OCL framework allows us to find globally optimal setpoints efficiently using out-of-shelf MIO solvers. A case study on an Amazon delivery station demonstrates the effectiveness of our approach in reducing energy consumption by 5.2% while maintaining indoor temperatures within comfort bounds.

3 - Counterfactual Explanations for Binary Knapsack Problems
Felix Engelhardt, Jannis Kurtz, Ilker Birbil, Ted Ralphs, Dick den Hertog

Counterfactual explanations (CE) are predominantly used in machine learning. Kurtz, Birbil und den Hertog (2024) extended this notion to linear programming. In this talk, we present the first results on CEs for integer linear programming (ILP).

We show that the notions of weak, strong and relative CEs translate from linear to ILP. Relative CEs for ILP are as hard to compute as the original problem, as long as no special matrix structure (e.g. totally unimodular) is destroyed by the modification.

Weak and strong CEs are generally harder to solve, depending on the mutable parameter space used to compute CEs. For only objective variations, computing CEs is closely linked to existing work on inverse optimization. For, right-hand-side only variations, it suffices to solve a pseudo-polynomial number of instances of the original problem.

Thus, this talk focuses on the most relevant and challenging case, i.e. mutable matrix parameters A. Here, we can show that computing a CE is at least S2P-hard in terms of theoretical complexity, and thus no polynomial time ILP formulation for the CE problem is likely to exist. We then present an enumeration algorithm to solve different types of Knapsack instances. This algorithm is validated through a computational study, results of which are presented as well. Finally, we outline how this method can be extended to problems with multiple constraints or negative parameters.

4 - Computing Counterfactual Explanations for Linear Optimization: A New Class of Bilevel Models and a Tailored Penalty Alternating Direction Method
Henri Lefebvre, Martin Schmidt

Explainable artificial intelligence is one of the most important trends in modern machine-learning research. The idea is to explain the outcome of a model by presenting a certain change in the input of the model so that the outcome changes significantly. In this talk, we study this question for linear optimization problems as an automated decision-making tool. This leads to a new class of linear bilevel optimization problems that have more nonlinearities in their single-level reformulations compared to traditionally studied linear bilevel problems. For this class of problems, we present a tailored penalty alternating direction method and present its convergence theory that mainly ensures that we compute stationary points of the single-level reformulation. Finally, we illustrate the applicability of this method using the example of a real-world energy system model as well as by computing counterfactual explanations for a large set of linear optimization problems from the NETLIB as it has been proposed in the recent literature.

■ WB-50

Wednesday, 10:30-12:00 - Room: Parkinson B11

Systems Thinking 4

Stream: Systems Thinking
Invited session
Chair: Gillian Harrison

1 - Addressing Transport Poverty in Austria: Exploring Coping Strategies, System Dynamics, and Policy Leverage Points
Olivia Gold, Paul Pfaffenbichler, Astrid Gühnemann

Inadequate transport options reduce access to essential services such as employment opportunities, education and healthcare, and increases social exclusion. Long commutes contribute to time poverty, increased stress and challenges in balancing work and social life. Addressing transport poverty is essential to achieving equity by ensuring fair access to opportunities. Transport poverty is characterised by a constellation of interrelated challenges, including the adequate transport options, travel times, safety concerns, and financial burdens. Existing studies lack qualitative insights into the commuting challenges faced by vulnerable groups. Additional data is needed to fill this gap. Therefore, this study combines a qualitative approach with system dynamics to provide actionable insights for reducing transport poverty in Austria. Semi-structured interviews provided qualitative insights into commuting challenges and coping strategies. Vulnerable groups, including migrants with limited language skills, single parents, and those at risk of time poverty due to long commutes, were recruited for this study. The data was analysed using qualitative content analysis and will be examined for themes, key variables, causal relationships, feedback loops and time lags, resulting in a set of CLDs, which will be combined with Meadows' systems thinking framework, to identify feedback loops, causal relationships, and systemic leverage points for policy intervention.

2 - Systemic change: Drama with the Machine
Jose-Rodrigo Cordoba-Pachon, Alberto Paucar-Caceres, Toni Burrowes-Cromwell

Emerging developments in critical systems thinking and practice and complexity place systemic change as an afterword of the use of systems methodologies or methods. Whilst this might be a consequence of encountering machine-like situations where it is difficult to promote joined up thinking, cooperation or mutual learning, there is room to further problematise change and how to deal with it. This paper brings possibilities to help facilitators enact change and survive in the attempt. These possibilities include revisiting what is currently understood by systemic leadership as becoming (Boulton, 2024), and enriching it with insights from drama (Bryant, 2003) and ritual (Córdoba-Pachón 2024). A 'play' in aiming to bring about change after a systemic intervention about food waste in a university campus is written and reflected upon. Insights would suggest that facilitators could go with the flow of events, letting go of their 'ownership' of change and their identity as systems thinkers, whilst critically supporting others who operate within a machine like type of organisation. These insights could contribute to discussions about the value of pragmatism in operational research practice and critical systems thinking.

3 - The Net Zero Systems Tool
Gillian Harrison

The 'Net Zero Systems Tool' (NZST) is an interactive systems thinking tool, which allows users within UK government departments to develop their understanding of interventions related to achieving net zero. The characteristics of the net zero challenge - requiring action by multiple parties across complex sectors, delivery at pace, and management of large uncertainties - underline the need for strong coordination in policy development, as well as a need to take a systems approach to navigate this complexity. Systems thinking has been gradually embedded into civil service practises over the previous few years. The NZST will not only become a standard toolkit component, but also support the further embedding of ST into everyday practises. Based on system dynamics principles of causal loop diagrams, the NZST supports the understanding of interrelationships between variables, allowing users to see how other variables in the system (over five sectors: transport, energy, buildings, industry and land use) are impacted when making policy changes in a particular area, either to gain an appreciation of wider system impacts when developing policies or in the monitoring and evaluation of existing policies. The NZST is not a predictive model, but helps guide knowledge sharing and commission further research and analysis. The tool will empower both cross-government and inter-department collaboration, which enacts policies that brings us to our net zero target.

4 - The Philosophical Foundations of Systems Thinking
Graeme Forbes

Systems thinking has a rich philosophical pedigree. Norbert Wiener, Stafford Beer, Peter Checkland, John Mingers, Mike Jackson, Russell Ackoff and C. West Churchman each brought impressive philosophical literacy to their work in operational research (and/or cybernetics). In this talk I consider the various philosophical currents out of which systems thinking emerges including American Pragmatism, Phenomenology, and the holist and atomist strands of early Analytic Philosophy. The themes that are relevant to systems thinking will include holism, interconnectedness, emergence, feedback, boundaries, complexity and pluralism. This will be addressed in turn. I will conclude by considering developments in contemporary anglophone philosophy which make it ripe for engagement with operational researchers working now, such as interest in 'social ontology', 'formal social epistemology', philosophy of science, philosophy of action and the contemporary revival of virtue ethics.

■ WB-51

Wednesday, 10:30-12:00 - Room: Parkinson B22

Machine learning approaches in multiobjective decision making

Stream: Multiobjective and vector optimization
Invited session
Chair: Tinkle Chugh

1 - Exploring the Impact of Objective Correlations in Multi-objective Optimisation
Tinkle Chugh, Samuel Tebbet, George De Ath

Multi-objective optimisation problems (MOPs) typically involve multiple, often conflicting objectives which can often be computationally expensive to evaluate. Multi-objective optimisers such as multi-objective evolutionary algorithms (MOEAs) provide a computationally feasible way of solving MOPs. Despite the availability of numerous continuous benchmark problems, there is a scarcity of multi-objective optimisation problems that consider the impact of interdependencies

or correlations between objectives. This study explores the influence of these correlations on bi-objective optimisation problems in continuous search space. We investigate the effect of correlations from perfect negative to perfect positive on the performance of multi-objective optimisers, specifically MOEAs. Experiments with two objectives and 2–20 decision variables across three MOEA categories (dominance-, indicator-, and decomposition-based) demonstrate the effects of varying correlations. The analysis and results can provide insights in selecting an optimiser for solving similar real-world problems.

2 - A Diffusion-Driven Generative Framework for Pareto Front Learning
Sedjro Salomon Hotegni, Sebastian Peitz

This work introduces a novel diffusion-driven generative framework for Pareto front learning in multi-objective optimization. By leveraging conditional denoising diffusion probabilistic models (DDPMs), our approach directly generates high-quality Pareto optimal solutions in the decision space. Rather than relying on explicitly labeled training data, we condition the model on objective function values by treating them as upper bounds, thereby encouraging the production of improved candidate solutions during sampling. To further steer the reverse diffusion process toward the Pareto front, we integrate a guidance mechanism based on Multiple Gradient Descent (MGD), which not only mimics a common descent direction for all objectives but also incorporates repulsive interactions to enhance diversity among solutions. Implemented with a diffusion transformer architecture and cross-attention conditioning, our method effectively combines generative modeling with gradient-based optimization principles. Experimental evaluations demonstrate the potential of our framework to efficiently approximate the Pareto front, offering a promising alternative to traditional multi-objective optimization techniques.

3 - A Model for Donor-Beneficiary Assignment at Nonprofit Organizations with Fairness
Ajinkya Tanksale, Jyotirmoy Dalal

Nonprofit organizations (NPOs) play vital role in serving the weaker section of society and ensuring the fulfilment of some basic needs of the needy people. However, most NPOs, typically operating under budgetary, workforce, and various regulatory constraints, face constant challenges arising out of complex interactions among factors like fundraising efforts, inflexible earmarked donation management, and obligations towards maintaining transparency and equity in benefit distribution. To this end, we develop a multi-objective mathematical optimization model to determine an equitable assignment of institutional donations to projects of an NPO. Given a set of donors with limited donation capacities and beneficiaries (projects) with known demand for each period in the planning horizon, the model aims to find the optimal allocation of donors to the projects to minimize the total cost at beneficiaries and maximizing social return on investment for the donors. Our novel 'flexible earmarking' approach aims acting as a middle ground between two extremes of the current system, namely, full- and no-earmarking, and exploiting the 'pooling benefits'. We demonstrate the applicability of our approach with the case of a well-known NPO in India that runs children education and welfare project at pan-India level.

■ WB-54

Wednesday, 10:30-12:00 - Room: Liberty 1.08

Stochastic Models and Optimization I

Stream: Stochastic modelling
Invited session
Chair: *Chesoong Kim*

1 - M/G/1/K machine repair system with general vacation under N-policy
Sudeep Singh Sanga

This study focuses on the modeling and performance of an M/G/1/K machine repair system that incorporates a general vacation feature under the N-policy, along with handling failure recovery and reboot processes. In the system design, the repairman can take a vacation only when no failed machines are in the system. He returns from vacation when the number of failed machines reaches the threshold value of N. In cases where faults in the system are not successfully detected, the system reconfigures itself by initiating a reboot process. To develop the mathematical model for the M/G/1/K machine repair system, supplementary variables corresponding to remaining repair and vacation times are employed to formulate the steady-state equations. These equations are the foundation for deriving explicit formulae for the probability distributions using the Laplace-Stieltjes transform and the recursive method. Various performance measures have also been developed, including the expected system size, machine availability, etc. Furthermore, we construct the cost function and formulate an optimization problem to determine the minimum cost. The objective is to find optimal values for the decision variables, such as the number of operating machines, the threshold parameter, the repair rate, and the vacation rate. Particle swarm optimization (PSO) is employed to solve the optimization problem.

2 - Analysis and Optimization of a Hybrid Queueing System with Dynamic Pricing Strategies Based on Customer Ratings and Queue Length
Chesoong Kim

In this paper, we analyze and optimize a hybrid queueing system where arrival rates and service prices dynamically change based on customer ratings and queue length. The system combines features of multi-server and retrial queueing systems, proposing a pricing strategy that simultaneously considers customer satisfaction and system load. Specifically, higher customer ratings lead to increased arrival rates, while longer queue lengths result in higher service prices. A multi-dimensional Markov chain model is used to analyze the system's stability and calculate performance metrics. In addition, we derive optimal pricing policies to maximize service provider revenue and validates the proposed model's efficiency through numerical experiments under various scenarios. This work can contribute to enhancing the operational efficiency of various service systems where dynamic pricing is crucial, such as taxi networks and online delivery services.

3 - Does Adding a Novel Policy Replication Loop Enhance Approximate Policy Iteration Performance?
Amirreza Pashapour, Dilek Gunnec, Sibel Salman, Eda Yücel

Approximate Dynamic Programming (ADP) has proven effective for solving large-scale stochastic optimization problems by approximating value functions to overcome the curse of dimensionality inherent in Dynamic Programming (DP). An ADP algorithm can utilize Approximate Value Iteration (AVI), Approximate Policy Iteration (API), or Approximate Linear Programming (ALP) regimes to estimate the value functions. Among ADP methods, Approximate Policy Iteration (API) typically employs two nested loops: an outer loop for policy improvement and a middle loop for policy evaluation. State-of-the-art APIs typically apply policy evaluation to each sampled post-state only once. In this study, we introduce novel stochastic modeling to the API algorithm as three nested loops (3API), incorporating an additional inner loop—policy replication—within the policy evaluation process. This third loop repeatedly simulates transitions from every single sampled post-state, which allows for a more accurate estimation of expected value functions in large outcome spaces while maintaining computational efficiency and avoiding overfitting. The proposed 3API framework integrates Least Squares Temporal Differences (LSTD) learning to calibrate the policy vector based on collected data to ensure efficient policy updates. We demonstrate the effectiveness of the 3API approach across several problem contexts to highlight its potential to enhance policy learning and decision quality in stochastic environments.

4 - A Realistic MAP/PH/c Queuing Model for Electric Vehicle Charging Stations: Theoretical Development and Real-World Case Study
Eman Almehdawe

we develop a realistic multi-server queuing model for electric vehicle (EV) charging stations, where multiple identical connectors operate independently. The arrival of EVs follows a Markovian arrival process (MAP), while charging durations follow a phase-type (PH) distribution. This approach addresses the limitations of simpler Poisson-based models, which often do not capture the variability and dynamics of EV arrival patterns and charging durations. We validate the model through numerical examples and a case study using real-world charging session data from Saskatchewan, Canada. By adopting this advanced stochastic framework, we provide practical insights for designing and managing EV charging stations to improve efficiency and user satisfaction. This work contributes to developing a more effective EV infrastructure that can meet the growing adoption of EVs while ensuring a seamless user experience.

■ WB-56

Wednesday, 10:30-12:00 - Room: Liberty 1.11

Heuristics for Vehicle Routing 2

Stream: Vehicle Routing and Logistics
Invited session
Chair: Niels Wouda

1 - The vehicle routing problem with driver scheduling
Razieh Mousavi, Jean-François Côté, Maryam Darvish

This talk addresses the Vehicle Routing Problem with Driver Scheduling, which integrates the Vehicle Routing Problem with Time Windows and Shift Scheduling Problem. The problem becomes more complex when vehicle routing and shift scheduling are solved together, as both aspects need to be optimized simultaneously. We also consider availability for each driver, which further complicates the problem, as the solution must optimize routes while aligning them with driver-specific availability. Considering drivers' availability in vehicle scheduling and routing is essential for improving driver satisfaction and ensuring punctuality in road freight transport. The objective is to minimize total costs, including travel costs, shift costs, and the costs of outsourcing unassigned customers to a Third-Party Logistics (3PL) provider. This talk proposes the mathematical formulation of the problem and a heuristic approach based on the Iterated Local Search (ILS) algorithm to solve this problem.

2 - A collaborative vehicle routing problem for on-demand EV charging service
Seo Yeo Choi, Chungmok Lee

Electric vehicles (EVs) are rapidly replacing internal combustion engine vehicles due to their environmental and economic advantages. However, one of the most significant challenges to widespread EV adoption is the lack of charging infrastructure. Recently, on-demand charging services using mobile batteries have gained attention as they eliminate the need for costly infrastructure investments and offer greater flexibility. This talk introduces a new variant of the vehicle routing problem (VRP) for on-site EV charging services using mobile chargers. Given a set of EV charging requests, mobile chargers can be deployed within designated time windows at customer locations to provide on-demand charging services. These mobile chargers should be transported by vehicles to the requested locations, and after completing the charging service, they can be collected by different vehicles if needed, which requires collaborative operations between vehicles. We first define the problem with unique characteristics of the on-site EV charging and present a mathematical formulation. We then develop a heuristic algorithm based on the adaptive large neighborhood search. Computational study on real-life instances shows that the proposed algorithm outperforms state-of-art MIP solvers.

3 - PyVRP: An improved high-performance VRP solver
Leon Lan, Niels Wouda, Wouter Kool

This abstract presents an improved version of PyVRP, an open-source, vehicle routing problem (VRP) solver. PyVRP is designed to be user-friendly yet performant: performance-critical parts of the algorithm are implemented in C++, whereas all other parts are implemented in Python. The initial release of PyVRP in 2023 supported only the basic capacitated VRP (CVRP) and VRP with time windows (VRPTW). Since then, PyVRP has been extended to support different objectives, heterogeneous fleets, multiple depots, optional clients, simultaneous linehauls and backhauls, routing profiles, client groups and multiple trips. These features can be used to model many problem variants from the literature, as well as their combinations. Inspired by the recent successes of iterated local search (ILS) in solving VRPs, PyVRP has also moved from a hybrid genetic search (HGS) to an ILS algorithm. This shift has significantly improved PyVRP's performance, particularly on large-scale instances with thousands of nodes, while also being conceptually much simpler than HGS. Benchmarks show that PyVRP achieves solutions within 1% of reported results across a wide variety of problem variants. With ongoing development and improvements, PyVRP continues to provide an accessible and high-performance VRP solver for researchers and practitioners in the field.

4 - A priori route planning for attended home delivery with subscription and ad-hoc customers
Niels Wouda, Lucas Veelenturf, Niels Agatz

We consider a setting in which a service provider offers specific (engineering) services at customer locations. The service provider offers these services both on a subscription and ad-hoc basis. Subscription-based customers are known to the provider and can be planned ahead of time. Customers with a subscription need to be offered at least two time slots on different days, from which they are free to choose one. Ad-hoc customers arrive dynamically over time and are offered time slots that are a good-enough fit. We propose a planning model that generates efficient a-priori routes for subscription-based customers by explicitly taking into account random customer choices from the offered time slots. The planning leaves sufficient slack to accommodate ad-hoc customers. We develop an exact method based on branch-and-price for the route planning problem, as well as a fast metaheuristic for practically-sized instances. We compare the performance of both methods on numerical benchmark instances, and also consider a case study using real-world data from an industry partner offering a tyre-changing service.

■ WB-58

Wednesday, 10:30-12:00 - Room: Liberty 1.13

Heuristics for Vehicle Routing 1

Stream: Vehicle Routing and Logistics
Invited session
Chair: Antonio Martinez Sykora

1 - Optimization Methodologies for the Family Capacitated Vehicle Routing Problem
Konstantinos Toulis, Emmanouil Zachariadis

The Family Capacitated Vehicle Routing Problem (F-CVRP) is a new VRP variant, which can be used to effectively model order picking scenarios in warehouses using a scattered storage policy. In the F-CVRP, customers are grouped into families, and an exact number of customers from each family must be served while respecting vehicle capacity constraints. Customers belonging to the same family have equal demands, corresponding to the same ordered items stored in different places within a warehouse. Given a set of orders and a maximum capacity for the pickers, the F-CVRP calls for determining optimal routes within the warehouse for the order picking process. To effectively tackle the F-CVRP we propose a minimum insertion heuristic for initial solution construction, a local search with tabu policies for further refinement, a large neighborhood search with adaptive memory to diversify the solution space exploration as well as exact methodologies to calculate optimal substitutions of customers that are present in the solution. When benchmarked against already published results,

the proposed methodologies manage to match or improve the best-known upper bound in 95.5% of instances, demonstrating the effectiveness of our approach. The research project was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the "2nd Call for H.R.F.I. Research Projects to support Faculty Members & Researchers" (Project Number: 02562).

2 - Multi-Route Optimization in Cyclic Load-Dependent Vehicle Routing: A Two-Strategy Approach
Mahshid Yadegari, Sebastian Urrutia, Andréa Cynthia Santos

This research investigates new strategies for the Multiple Routes Cyclic Vehicle Routing Problem in the context of maritime transportation. The problem is periodically delivering a single product type from a central depot to a set of customer ports via several routes, aiming to optimize the average work performed associated with vehicle load through the routes. All the customer ports dedicated to each route are visited exactly one time when the vehicles return to the depot. By investigating the impact of the load factor on overall transportation costs, we proposed studying the cyclic routing problem by focusing on the direction of the route and evaluating the performance of obtained routes regarding two different approaches: the Unidirectional Multiple Routes Cyclic Load-Dependent Vehicle Routing Problem and the Bidirectional Multiple-Routes Cyclic Load-Dependent Vehicle Routing Problem. In the unidirectional strategy, the route direction remains constant across multiple periods, while in the bidirectional approach, the route direction alternates in each period. To address these problems, we propose two Mixed Integer Linear Programming (MILP) models, which are solved using a commercial solver to obtain optimal values for several benchmark instances. Then, we employ an approximate approach to solve and analyze medium to larger-scale instances. We aim to demonstrate the potential of these strategies for their practical implementation through a precise comparison.

3 - Comparative Analysis of Swarm Intelligence and Predator-Prey Metaheuristics for Solving the Traveling Salesman Problem
Mateusz Turek

The Traveling Salesman Problem (TSP) is a well-known NP-hard combinatorial optimization problem with significant applications in logistics, routing, and manufacturing. Due to its complexity, swarm intelligence-based metaheuristic approaches have been widely explored to find near-optimal solutions efficiently. This study focuses on analyzing the performance of Bee-Inspired Optimization Algorithm (BIA), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO) in solving TSP instances. Additionally, the Predator-Prey and Hunting-Based Algorithm is included for comparative evaluation - Discrete Grey Wolf Optimization (D-GWO). The analysis is conducted based on solution quality, computational efficiency, and convergence behavior on standard benchmark datasets using TSPLIB, a commonly used and widely available Python library for benchmarking TSP-solving algorithms.

4 - A Variable Neighbourhood Search Algorithm for the Truck-Porters Routing Problem
Antonio Martinez Sykora, Chris Potts, Mohammed Alammar, Stefano Coniglio

In the truck-porters routing problem (TPRP), a single truck and a limited number of couriers using bikes, also referred as porters, are available at the main depot. There is a set of customers whose demand is known beforehand. Some customers can be visited only by the truck, others must be served by porters, and there is a third type of customers that can be served either by the truck or by porters. Porters carry a single bag that has a weight limitation, limiting the number of items that can be delivered in one trip. However, a porter can revisit the depot to collect further items for delivery as soon as the working time does not exceed a time limitation. The TPRP problem consists of designing a set of minimum-cost routes, where each route starts and ends at the depot and satisfies capacity and travel time constraints. We propose a VNS algorithm that is able to find the optimal solutions in small size instances as well as best known solutions in larger instances. The VNS is also tested against a problem variant, the Multi-Trip Vehicle Routing Problem, which is a problem that has been explored in the literature, for which the best solution is improved on 5 specific instances, showing a solid behaviour of the algorithm.

■ WB-59

Wednesday, 10:30-12:00 - Room: Liberty 1.14

Transportation network design

Stream: Transportation
Invited session
Chair: *Zijian Wang*

1 - Bus fleet design and route optimization for worker transportation
Cristian E. Cortes, Pablo A. Rey, Francisco Vilches, Jaime Miranda

Many companies offer transport services to their employees from locations near their homes to the company's facilities and vice versa. These services must consider the work shifts together with bus passenger transport problem constraints. The problem of designing routes and schedules for mass transit systems has been widely studied. In this work, we propose a route-based integer programming model to solve a mass transit design problem for a factory with over 800 workers in rotating shifts and nearly 200 administrative employees working weekdays from 9 am to 6 pm. The goal is to minimize total service costs while maintaining worker quality of life. Decision variables include the number of buses, capacities, routes, and stops. A two-step algorithm is proposed: first, generating a pool of routes; then, selecting routes and allocating passengers employing an integer programming model. The current system is compared to two alternative scenarios: an optimized current scenario and a future scenario incorporating an urban train, where buses transport workers to a railway station instead of the factory. Data from June 2023 were used for evaluation. Both alternatives showed cost reductions. Fixed costs remained similar, while variable costs decreased significantly in the future scenario due to shorter routes, though ticket costs offset some savings. The analysis found current routes adequate but highlighted improvements, such as using smaller buses on low-occupancy routes.

2 - A methodology based on the depot selection to identify the non-electrified railway lines to be converted to hydrogen propulsion
Luca D'Acierno, Luca De Matteis, Rosario Stefanelli

Rail and metro systems are essential for sustainable mobility, offering higher passenger capacity with the same energy consumption and lower emissions compared to cars and buses. Railway propulsion currently relies on two main technologies: electric and diesel-powered systems. Electric trains produce no local emissions, though their overall environmental impact depends on the energy mix used for electricity generation. Diesel-powered trains use an internal combustion engine to generate electricity and drive the wheels via an electric motor, resulting in emissions directly linked to diesel combustion. The lack of electrification is often due to an unfavourable cost-benefit analysis, as secondary lines often have insufficient traffic to justify the investment. In this context, to enhance the sustainability of non-electrified railway lines, Italy's National Recovery and Resilience Plan has allocated EUR 300 million to test hydrogen-powered trains, selecting six lines and nine refuelling stations for conversion. Indeed, hydrogen may serve as an intermediate solution to full electrification, enabling a gradual transition from diesel with minimal infrastructure modifications. This paper presents a methodology for grouping railway lines that share refuelling stations to optimise hydrogen production, storage, and distribution costs. The approach is applied to the Italian railway network to evaluate feasibility and support the National Recovery and Resilience Plan objectives.

3 - Choice-Driven Multi-Period Network Design for Advanced Air Mobility
Yuhan Jiang, Xiaohan Zhou, Yu Jiang, Guglielmo Lulli, Shaopeng Zhong

With the development of Advanced Air Mobility (AAM), it provides a novel and competitive alternative for regional travel. This study focuses on the AAM Service Network Design (AAM-SND) problem, aiming to optimise vertiport locations, service frequency and pricing strategies while capturing the interdependencies between passenger travel choices and network expansion to maximise overall profitability over a multiple-period time horizon. To overcome the computational challenges of integrating a choice model into AAM-SND, we propose an exact solution approach that substantially outperforms traditional linearisation approaches in terms of computational efficiency and solution quality. We employ the proposed AAM-SND model to explore two distinct investment paradigms- namely, a centralised investment and a decentralised investment network- to provide a foundation for broader application. The experiments are constructed based on the existing UK railway network, which contains 30 cities. Results reveal a strong interdependence between vertiport and electric vertical takeoff and landing aircraft investments. Moreover, in terms of network outcomes, AAM's advantage is most evident in city pairs that require significantly longer travel times by ground transportation. Lastly, passengers exhibit high sensitivity to pricing strategies, as variations in utility coefficients lead to different network structures and impact overall profit performance.

4 - Pre-Disruption Resilient Transportation Network Design: A Compact Mathematical Programming and a Tailored Branch-and-Price Algorithm
Zijian Wang, Xiangdong Xu, Reza Zanjirani Farahani, Xiangyi Fan, Yonglei Xu

This paper introduces a pre-disruption resilient transportation network design problem. It aims to enhance both network redundancy and robustness by constructing new links, thereby distinguishing itself from prevalent network design problems that alleviate traffic congestion in normal situation. Specifically, the resilient design incorporates two objectives within a unified single-objective model, by minimizing the number of origin-destination pairs with only one behaviorally effective route. This objective explicitly enhances redundancy while implicitly improving robustness, as it induces the model to construct new links that are near and parallel to existing critical links, thereby alleviating disruption consequences of critical links. Mathematically, formulating this problem as a straightforward mathematical programming with an explicit expression is challenging, as the intricate relationship between objective function and decision variables cannot be expressed by a closed-form expression. To overcome this hurdle, we equivalently reformulate this problem as a maximal covering location problem, enabling it to be a mixed integer linear programming. Given that the number of variables in the model grows exponentially with the number of candidate links, we propose a branch-and-price solution algorithm, which reduces the number of variables under consideration and thus ensures computational efficiency. Case studies are conducted in the Winnipeg network to validate our approach.

■ WB-60

Wednesday, 10:30-12:00 - Room: Western LT

DEA applications in Transportation

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: *Young Chun*

1 - Data Envelopment Analysis of Aircraft Reliability and Preventive Maintenance Plan
Young Chun, Seong-Jong Joo

Using the maintenance data of 26 airplanes collected during a 38-month period, we consider various prediction models to estimate the failure rate of military aircraft per flight. Based on the estimated reliability of each aircraft, we then rank the 26 aircraft via the data envelopment analysis (DEA). Specifically, we focus on the failure patterns of a complex electronic and armament system in the military aircraft in the US Air Force. As soon as the system fails, the aircraft aborts a mission and returns to the Air Force base immediately. Under the current reactive or breakdown maintenance plan, the mission-critical system is repaired or replaced only when it fails. In practice, it would be more cost-effective to replace the complex system on a regular basis even before it breaks down. Under the preventive or planned maintenance plan, the system is replaced after a certain number of flights. The number of flights or sorties is a discrete variable, and we propose a discrete-time survival model and analyze the failure patterns of the system. We fit the military aircraft maintenance data and flight records into a discrete-time Weibull model and estimate its two parameter values. The Weibull model is then used to develop a preventive maintenance plan that minimizes the expected total cost per sortie in the renewal-reward process of system failures.

2 - Beyond taskload: Constructing a Multidimensional Cognitive Overload Indicator Using Efficiency Dominance
Ahmed-Youssef Oukassou, Marijn Verschelde

Cognitive workload is a critical determinant of human performance in digital control rooms, yet its measurement remains challenging. Traditional approaches rely on one-dimensional indicators, such as taskload, which fail to capture the complexity of cognitive strain. More advanced methods, including physiological measures like heart rate variability and electroencephalography, offer deeper insights but are costly and impractical for large-scale implementation. This study introduces alpha-efficiency, a multidimensional, data-driven composite indicator that moves beyond simple taskload measures to assess both fatigue accumulation and mental effort. Rather than relying on intrusive physiological monitoring, alpha-efficiency constructs workload indicators from operational data, incorporating active signal clearances, taskload diversity, fatigue accumulation, and workstation unfamiliarity to distinguish between cognitive demands and resources. Using real-world railway digital control room data, we apply nonparametric efficiency analysis to develop a multi-dimensional cognitive overload indicator. Regression results confirm that alpha-efficiency is strongly associated with human error probability, with significant effects observed across different estimation techniques. Interaction effects further highlight that cognitive overload risk is particularly pronounced at both the lower and upper quantiles of cognitive load intensity. These findings demonstrate the effectiveness of alph

3 - Regulator-perspective group performance Luenberger Productivity indicator with decision preference: A generalized approach
Chixiao Lu, Ali Emrouznejad

By integrating the generalized efficiency measure with the Luenberger Productivity Indicator, this paper enhances productivity assessment at the industry level from the regulators' perspective. This is achieved through a modified directional distance function model with constraints regarding regulators' preferences and attitudes. This approach also builds connection between Multiple-Objective Programming and multi-time series productivity analysis. By using the suggested approach and treating the European railway industry in the Year 2021 as the base group, this research also provides insights into whether a more complex railway transportation network indicates greater resilience during long-term disruption, offering implications for regulatory and policy decisions in transportation sectors.

■ WB-61

Wednesday, 10:30-12:00 - Room: Maurice Keyworth G.31

Behavioral studies in cognate domains 1

Stream: Behavioural OR
Invited session
Chair: Martin Kunc

1 - The impact of perceived climate extremes on farmer adaptation decisions to climate change

Oliver Behn, Marlene Kionka, Michael Leyer, Silke Hüttel

Increasing magnitude and frequency of climate extremes pose a major threat to farm productivity and food security. Adaptation trends, however, show gaps, remain incremental (e.g., irrigation) and insufficiently transformative (e.g., agroforestry). These trends could be explained by farmers' risk behavior or low attitudes to changes in the production system. While past studies assume decision-making from description, less is known about how perceived climate extremes shape adaptation behavior through experience. This study applies instance-based learning theory, where individuals form decisions based on past experiences and environmental feedback. We examine how past climate extremes influence farmers' adaptation choices through an experiment using a hypothetical farm. A split-treatment design shows one group a drought-induced field fire, while the control sees no fire. Participants then choose between no adaptation, water storage (no system change), or agroforestry (system change). Results from 176 German agricultural students—54% with farming experience—show those exposed to fire opted more for agroforestry, though timing of implementation was unaffected. Higher past perceived damage due to experiences also increased adaptation likelihood. Findings suggest that adaptation behavior towards climate-mitigating systems like agroforestry can be encouraged by real-world demonstrations of climate impacts. Future research should explore effective communication strategies.

2 - Understanding organisational challenges in secure digital transformation: Baseline analysis of cybersecurity practices in higher education

Waseq Ziaie

Our study uses Behavioural Operational Research (BOR) to develop empirical tools for examining the complex digital transformation processes in Higher Education Institutions (HEIs), focusing on their complex cybersecurity challenges. We will explore the often-neglected organisational dynamics and stakeholder perceptions which critically impact cybersecurity policies and practices. Traditional research has concentrated on technical defences against malware and phishing, often overlooking the crucial interplay between human behaviours and organisational strategies. Our innovative survey-based methodology, anchored in the House of Security framework, integrates aspects such as confidentiality, integrity, availability, and others to capture diverse stakeholder perceptions systematically.This approach addresses existing shortcomings in survey design. It aims to provide a holistic view of cybersecurity issues across various stakeholders, including administrators, IT staff, and academic personnel. The anticipated results will establish a baseline for targeted interventions and refine models for effective cybersecurity governance. Finally, our research enhances understanding of the systemic and behavioural complexities in managing cybersecurity within HEIs, emphasising the need to align technical measures with organisational behaviour to strengthen cyber resilience against evolving threats.

3 - Understanding key predictors of digital health contact-tracing app adoption

Shehani Pigera, Paul van Schaik, Miglena Campbell, Karen Renaud, Petra Manley

Contact tracing is a recognised public health tool to reduce the spread of infectious diseases.Digital contact-tracing(DCT) utilises mobile applications to quickly identify individuals who may have been exposed to an infection and provide appropriate public health advice. The success of the DCT during a pandemic primarily depends on public acceptance. This study examined factors influencing public adoption of DCT, specifically, privacy, perceived benefits, effectiveness,ego and social norms.It also explored how presentation of privacy and benefit information influenced the intention to adopt DCT. Privacy, perceived benefits, effectiveness, ego, descriptive norms and injunctive norms significantly correlated with the intention to adopt DCT. The amount of privacy and benefits information did not make a significant difference, whilst privacy-related images significantly influenced the adoption intention. Additionally, ego and descriptive norms emerged as significant predictors of willingness to adopt DCT. People valued privacy-preserving features of the app and recognised its social and health benefits. However, a lack of confidence in willingness of others to use apps was identified as primary barrier to adoption. The findings highlight the importance of understanding the key predictors and potential barriers to adopting DCT for future pandemic.Behavioural science research could help strengthen the understanding and inform future development of widely-accepted DCT solutions.

Wednesday, 12:30-14:00

■ WC-01

Wednesday, 12:30-14:00 - Room: Great Hall

Sveinung Erland / Eitan Bachmat

Stream: Keynotes
Keynote session
Chair: Florian Jaehn

1 - Project Management and Optics
Sveinung Erland, Eitan Bachmat

We will introduce a family of problems which examine how slow can task durations be, while still completing the entire project before a given deadline. In particular we examine the class of task durations which are Pareto optimal. We make a very basic observation that such task durations have a property that abstractly resembles the concept of a lens in optics. We then show how this rather abstract connection between project management and optics becomes concrete when we examine the family of airplane boarding scenarios on the project side and a family of material designs known as hyperbolic meta-materials. We show how the bridge goes both ways, leading to the design of very high resolution lenses on the optics side, and insights into good airplane boarding policies on the project management side.

The talk will be self contained, however, some experience with boarding airplanes will be useful.

The talk is based on joint work with Andrea Alu, Sveinung Erland, Enrico Renzi, Yves Simone and Diana Strickland (among others).

■ WC-03

Wednesday, 12:30-14:00 - Room: Esther Simpson 1.01

Celebrating 50 Years of EURO (session 3)

Stream: Celebrating 50 Years of EURO
Invited session
Chair: Frits Spieksma
Chair: Anita Schöbel

1 - Reflections on Wonderful OR Experiences at EURO Conferences Over 20 Years
Anna Nagurney

Thank you for the opportunity to reflect and to celebrate 50 years of EURO. In this presentation, I will present highlights of experiences at EURO conferences over 20 years - from Reykjavik in 2006 to Glasgow in 2015, Poznan in 2016, Dublin in 2019, Copenhagen in 2024, and now, in 2025, in Leeds. The breadth and depth of the OR community that EURO has been instrumental in building and supporting are deeply appreciated, as are the lasting memories of such outstanding conferences.

2 - Why the 1970's Was an Important Era in Operational Research, with Personal Reflections
Jyrki Wallenius

Many new areas of Operational Research were born and underwent rapid development during 1970's, including Decision Support Systems, Black-Scholes and Merton model in finance, genetic algorithms, queueing systems that lead to the development of the ARPANET, a predecessor of the INTERNET, Multiple Criteria Decision Making and multi-objective optimization, spreadsheets and OR add-in software, Data Envelopment Analysis, and the work by Tversky and Kahneman on the psychology of human judgment. During the same era, many important societies and journals were founded. After briefly iterating the history of Operational Research, I reflect upon the important developments of Operational Research in the 1970's, coinciding with the founding of the Association of European Operational Research Societies (EURO). It is evident that the concurrent developments in computing technology made the success of Operational Research possible. I also comment on the current state of Operational Research from my personal perspective. I conclude with some personal observations, what it was like being a young academic operational researcher during 1970's, who participated in the first EURO Conference, held in Brussels in January of 1975.

3 - Lessons I learned from EURO
Emilio Carrizosa

EURO has given me a wealth of experiences. It has not only been a meeting point to connect with and learn from colleagues across Europe (and beyond!!!), but also a valuable source of practical insights for academic organizations. I'll focus on the key lessons I've learned from EURO.

4 - Fifty years of Data Envelopment Analysis
Ali Emrouznejad, Anna Mergoni, Kristof De Witte

Data Envelopment Analysis (DEA) has emerged as a powerful analytical tool, revolutionising the field of Operational Research (OR) and contributing to advancements in performance evaluation methodologies. This practical literature review delves into the extensive body of research surrounding DEA, focusing particularly on its evolution within the last 50 years. Drawing upon a comprehensive analysis of publications in top-tier OR journals this literature review paper offers analysis of DEA's development, highlighting key milestones, methodological advancements, and emerging trends. Central to this exploration is the introduction of the COOPER-framework—a structured approach derived from influential papers in the field—that provides a state-of-the-art synthesis of DEA methodologies. Emphasizing nonparametric models and addressing the challenges posed by complex decision-making environments, the COOPER-framework serves as a valuable resource for both experienced scholars and newcomers to the field. By incorporating feedback loops to navigate interconnected decisions, the framework ensures the reliability and robustness of DEA analyses. Through this literature review, we aim to not only refine existing methodologies but also provide a practical tool for researchers, fostering collaboration and driving further innovation in the field of DEA.

■ WC-07

Wednesday, 12:30-14:00 - Room: Clarendon GR.01

Power Trading

Stream: Risk Management in Commodities and Financial Markets
Invited session
Chair: David Wozabal

1 - BESS Optimization and the Value of Intraday Electricity Price Forecasts
Simon Hirsch, David Schaurecker, David Wozabal

Grid-scale battery energy storage is increasingly optimized for commercial success in wholesale electricity markets. The rolling intrinsic (RI) strategy for the continuous intraday market, a widely used and hard-to-beat benchmark, maximizes storage value in a myopic manner. This greedy optimization of the RI is also its major drawback: By failing to anticipate future price changes, it may sacrifice more profitable later trading opportunities in favor of short-term gains. To address this, we extend a recent high-frequency-trading dynamic programming formulation of the RI by integrating price forecast information. This enables the algorithm to trade not only based on immediate market conditions but also by submitting virtual positions against the forecast, allowing it to anticipate future price movements. We demonstrate that

blindly relying on inaccurate forecasts leads to poorer financial outcomes, compared to the myopic RI. However, carefully constructed informed price forecasts, based on public information, can significantly enhance trading yields. Moreover, we argue that improved forecast accuracy, as measured by standard error metrics, does not automatically translate to higher trading profits, and introduce a novel pipeline for measuring the monetary value of intraday price forecast accuracy in grid-scale storage applications.

2 - The Rolling Intrinsic Strategy in High-Frequency Intraday Electricity Trading for a Battery as a Dynamic Program
David Schaurecker, David Wozabal

Maximizing revenue for grid-scale battery energy storage systems in continuous intraday electricity markets requires strategies that are able to seize trading opportunities as soon as new information arrives. This paper introduces and evaluates an automated high-frequency trading strategy for battery energy storage systems trading on the intraday market for power while explicitly considering the dynamics of the limit order book, market rules, and technical parameters. The standard rolling intrinsic strategy is adapted for continuous intraday electricity markets and solved using a dynamic programming approximation that is two to three orders of magnitude faster than an exact mixed-integer linear programming solution. A detailed backtest over a full year of German order book data demonstrates that the proposed dynamic programming formulation does not take worse decisions than the exact solution and enables the policy to react to every relevant order book update, enabling realistic rapid backtesting. Our results show the significant revenue potential of high-frequency trading, where our policy earns 58% more than solving the optimization once every hour and 14% more than solving it once per minute, highlighting that profits critically depends on trading speed. Furthermore, we leverage the speed of our algorithm to train a parametric extension of the rolling intrinsic, increasing yearly revenue by 8.4% out of sample.

3 - Geopolitical Risks, Critical Materials and Energy Transition: Insights from Wavelet Analysis
Ivan De Crescenzo, Loretta Mastroeni, Alessandro Mazzoccoli

This paper investigates the nexus between geopolitical risks and some energy transition-related commodities via a wavelet-based method. The data set includes natural gas, copper, palladium and cobalt, whose time series cover a fourteen-year time span (2010- 2024). Geopolitical risk is measured through the GPR index by Caldara and Iacoviello. Our investigation shows different degrees of correlation between geopolitical risk and the above-mentioned commodities. In an overall perspective, commodities that have a consolidated history of application tend to show a more straightforward connection with geopolitical dynamics, while those recently gaining prominence in the energy transition show weaker and less consistent signals. In this respect, despite its wide use , we infer that GPR index holds some limitations when it is intended to explain dynamics regarding rare and critical elements, which originate from geographical sites that mainstream media are not used to cover on a regular basis. Understanding that the energy transition is producing a change in the paradigm from a geostrategic standpoint requires awareness when such indexes are utilized. At the very same time, it also suggests rethinking the way risk indexes are engineered so to mirror geopolitical phenomena related to the new centers of gravity derived from the energy transitions.

4 - A joint bidding strategy for battery operating on intraday and frequency reserve markets
David Wozabal, Wolfgang Riddinger, Yiming Zhang

This paper proposes a novel approach for optimizing battery energy storage systems (BESS) participation in multiple electricity markets. As renewable energy integration increases grid volatility, BESS presents a viable solution for balancing supply and demand. We develop a joint bidding strategy that combines participation in the primary frequency reserve market with continuous trading in the intraday market, addressing a gap in the extant literature which typically considers these markets in isolation or simplifies the continuous nature of intraday trading. Our approach utilizes a mixed integer linear programming implementation of the rolling intrinsic algorithm for intraday decisions and state of charge recovery, alongside a machine learning classifier that determines optimal capacity allocation between markets based on features available at bidding time.

■ WC-09

Wednesday, 12:30-14:00 - Room: Clarendon SR 2.01

Methods and models in portfolio and risk management

Stream: OR in Finance and Insurance
Invited session
Chair: Marcel Marohn

1 - Portfolio Optimization with Quality Constraints
Marcel Marohn

In recent decades, investors have developed a strong demand for investment funds that select shares according to certain quality criteria, such as sustainability, credit risk, or liquidity. When following this call, fund managers have several options for incorporating quality measures. The question is whether this always comes at the expense of financial performance and, if so, how the damage can be minimized while still satisfying the investors needs. In this paper, we study the effects in a multi-criteria portfolio optimization framework with arbitrary convex risk measures. We characterize and compare the efficient sets resulting from the manager's choice of quality control, and present scalarization methods for finding efficient portfolios that satisfy the desired quality predictions.

2 - Credit Scoring Model of Small Sized Firms Using Default Data during COVID-19 Pandemic
Hiroumi Naganuma, Masaru Iwase, Masahiro Toshiro, Shinsuke Sasaki, Kenzo Ogi, Norio Hibiki

Japanese banks employ credit scoring models with default as the dependent variable to manage their debtors' credit risk. During the COVID-19 pandemic, while the financial condition of firms deteriorated, the government's economic measures reduced the number of corporate bankruptcies. This gives the lower correlation between financial indicators and default occurrence and may reduce the accuracy of models. Therefore, handling data affected by the COVID-19 pandemic is a critical issue to model the credit scoring for Japanese banks. In this paper, we built nine logistic regression models with different learning periods and compared the accuracy ratios (ARs), using Japan Finance Corporation's data on 799 thousand loans from FY 2014 to FY 2021, which include both pandemic and non-pandemic data periods. Our results indicate that incorporating more recent data improves model accuracy, even if including the COVID-19 pandemic period. The model with the highest AR of 58.3% on average is built using the data from FY 2014 to FY 2021. On the other hand, this result is consistent with the previous studies such as Yanagisawa et al. (2007) and Sawaki et al. (2017) who suggest that the accuracy of credit scoring models for Japanese SMEs is affected by the amount of data and learning periods. In addition, our paper can strengthen these studies because we show it even in the case of handling unusual data such as during pandemics.

3 - A simulation approach to robust risk management of derivative products
Bertrand Tavin

This paper considers the problem of assessing and hedging the risk carried by a portfolio of non-standard derivative products managed with a family of parametric models. We first formalize the problem and define the framework in which it can be solved by using a constrained

simulation approach with respect to model parameters. Our approach is suitable for an agent who may be agnostic with respect to a prior model and who may wish to account for expert views on the range of possible model parameters. Instead of breaking them into several sub-problems, the proposed methodology has the important advantage to answer the risk measurement and robust hedging questions in one step. Namely, the agent needs to run the simulation just once to get the desired answers. We present numerical results obtained with recent market data when applying the method to a portfolio of variance swaps and forward-start options valued with models stochastic volatility and jumps. In addition, our method can easily accommodate additional features such as cardinality constraints for the robust hedging strategy or transaction costs.

4 - Optimizing Uncertain Multi-Period Portfolios Under a Conditional Value-at-Risk Measure
Julián Benavides, Anibal Sosa, Andrés Salas

This research develops a multi-period portfolio optimization problem with uncertain share returns (Liu, 2007). Our procedure is novel because we use conditional value-at-risk (CVaR) as a risk measure and develop appropriate expressions for it. CVaR is a more effective risk measure than standard deviation at capturing tail risk and extreme losses. The model includes different constraints, such as bankruptcy, liquidity, diversification, and no short-selling. Importantly, all prior research assumes that the uncertain returns do not affect the self-financing constraint, implicitly considering that trading fees apply to portfolio weights instead of the investment value. Our model improves that perspective by developing a restriction that applies to the investment value. We surveyed ten postgraduate finance students to develop the uncertainty distribution of the portfolio shares. Tests of this approach versus a multiperiod Markowitz model yield interesting insights about weight stability and tail risk.

■ WC-10

Wednesday, 12:30-14:00 - Room: Clarendon SR 1.06

MCDA and urban planning 2

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: *Francesca Abastante*
Chair: *Marta Bottero*
Chair: *Isabella Lami*

1 - Investment Attractiveness of Medium-Sized Italian Cities: A MAVT-Based rating model
Marta DellOvo, Federico Dell'Anna, Francesco Cosentino

Cities have historically played a crucial role in driving regional and national development. Today, urban competitiveness increasingly depends on their ability to attract investments in key sectors. While significant cities dominate global rankings, Italian medium-sized towns are emerging as attractive alternatives due to balanced economic growth, lower real estate saturation, and expanding infrastructure. However, existing urban rankings often lack investment-oriented criteria and structured multi-criteria evaluation methods. This study proposes a Multi-Attribute Value Theory (MAVT) -based rating model to assess the investment attractiveness of medium-sized Italian cities. The research follows a structured methodology: first, selecting relevant indicators validated through expert interviews; second, developing a framework to standardize, weigh, and aggregate data to ensure transparency and replicability. The model is tested on two case studies, Bologna and Catania, comparing their attractiveness based on a composite index. Results highlight the model's potential as a decision-support tool for investors and policymakers, offering a systematic comparison of cities' investment potential. The study has been conducted in collaboration with Gabetti Research Office, integrating academic insights with industry expertise.

2 - Bridging strategy and practice: an innovative problem structuring approach for sustainable urban transformation
Francesca Abastante, Giuliano Poli, Francesco Piras

In sustainable urban planning, monitoring and evaluation systems are crucial for guiding Public Administrations in making informed, responsible decisions. Despite the rise of sustainability guidelines, local implementation remains challenging. The GLOSSA research project (a GLOcal Knowledge-System for the Sustainable Assessment of Urban Projects) addresses this issue by introducing a multi-methodological framework based on operational indicators for urban project assessment. The framework is implemented in a multi-criteria evaluation software called Indicators' Based Tool (IBTool) structured into 4 modules: i) Data Storage to manage a database of indicators; ii) Validation to assess indicators' relevance through the Fuzzy Delphi Method; iii) Weighting to assign weights to the indicators' and identify KPIs via the Best-Worst Method; iv) Performance/Impact Assessment to evaluate urban design alternatives using TOPSIS. This research innovatively integrates qualitative and quantitative evaluation methods into IBTool, bridging the gap between academic research and practical applications. The IBTool was tested in a case study in Italy to assess sustainable development levels.

3 - The design of decision alternatives: experimenting multiple methodologies in an urban decision problem
Alessandra Oppio, Marta Bottero, Alberto Colorni, Chiara D'Alpaos, Alexis Tsoukias, Irene Pluchinotta

Most decision problems start with set of "given" alternatives and the scientific literature mainly focuses on the methods for choosing among them, whereas the process through which the alternatives are defined has been underestimated. The paper aims at exploring the topic of problem formulation and alternatives generation in real world decision problems, reflecting on different OR approaches. Grounding on the results of a pilot workshop where a problem of housing energy retrofitting was examined with 6 OR methods, namely 1) Value Focused Theory, 2) Strategic Choice Approach, 3) Participatory Systems Thinking 4) Decision Tree, and 5) C-K theory, the present study presents a recent advancement of the experimentation for a decision problem related to the reuse of a public abandoned building in Italy. This contribution will illustrate the configuration of a planned workshop with several stakeholders, with specific attention to the organization of the interaction between the experts and the client according to the abovementioned methods.

4 - Unraveling Citizen Acceptance of Wind Energy in Styria, Austria: A Mass Participation Multi-Criteria and Clustering Analysis
River Huang, Salvatore Corrente, Eleftherios Siskos, Peter Burgherr, Russell McKenna

The transition to renewable energy is critical for mitigating climate change and enhancing energy security, with wind power emerging as a key component in regional strategies. In Styria, Austria, where wind energy development is rapidly advancing, public acceptance remains a pivotal element for sustainable growth. This study introduces a novel mass-participation Multi-Criteria Satisfaction Analysis (Mass-MUSA) approach that integrates large-scale community input through a comprehensive questionnaire. By assessing environmental, economic, and social criteria, the analysis not only quantifies overall satisfaction levels but also employs clustering techniques to segment citizens into distinct profiles based on their responses. This clustering reveals nuanced insights into the primary factors driving support or opposition to wind energy initiatives. The findings provide a comprehensive understanding of local attitudes and offer valuable guidance for policymakers and energy developers. Ultimately, the study demonstrates how combining mass participation with advanced multi-criteria decision analysis and clustering can inform more inclusive and effective energy planning strategies for the future development of wind power in Styria.

■ WC-11

Wednesday, 12:30-14:00 - Room: Clarendon SR 1.03

Health systems

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Damjana Drobne*

1 - Design theories and Health Systems, contributions to the Architecture of Health Accounts
Christine C Huttin

Prof C Huttin initiated a review of design theories in health policies (Huttin, EWG-MCDA2024): for Value and Advanced Value Assessment Frameworks; for medical informatics (physicians 'reminder systems, patients 'decision aids) or implementation of decision support systems (e.g. cost sensitivity simulators, Huttin, Orahs, 2018). The structuring of decision-making processes (Soft OR) is also useful for paradigm shifts towards precision medicine. Experimental study designs to analyze medical markets are presented, to discuss how and under which conditions they can be used for policy making (Brunswik meeting, December 2024). They include disease econometrics, choice modeling, and stochastic choice models with random prices.Selection of alternatives for choices mainly relates to medical policy problems (e.g. Huttin and Hausman,2021, Huttin, 2024). They require scaling up for bigger samples and the generation o additional data elements on economic and financial information represent an expansion of the dataspace on prices and costs. Such use of unstructured data elements as well as billing information may require modification of architecture of national or international accounting systems, for instance with the design of ad hoc or satellite health accounts.

2 - The effect of an ageing population on secondary care resource usage in the UK
Alik Vodyanov, Thomas Padgett, Phil McEwan

INTRODUCTION The NHS is under increasing pressures due to an ageing and increasingly comorbid population and is struggling to meet targets for patient waiting times and quality of treatment. The UK population is predicted to continue to age as life expectancy increases, intensifying the problem.

METHODS A system dynamics model was developed to estimate the age- and sex-stratified UK population to 2060. People enter and leave the model through births, migration and death. Secondary care usage was predicted using NHS data.

RESULTS The UK population is predicted to grow from 69.3M in 2025 (mean age of 40.5) to 73.7M by 2060 (mean age of 46.1). Consequently, from 2025 to 2060, annual A&E admissions are predicted to rise from 18.9M to 21.1M (11.6% increase), while annual inpatient bed days are anticipated to rise from 46.6M to 67.3M (44.4% increase). Moreover, annual outpatient procedures are predicted to rise from 13.7M to 16.6M (20.9% increase).

CONCLUSION Population ageing will substantially increase demand for healthcare usage within an already constrained system. Delivery of healthcare must be prioritised to those with the highest need, which often means focusing on older patients. As such, younger, economically active patients are deprioritised, leading to reduced productivity. This fuels a feedback loop whereby resource to deliver healthcare is reduced, leading to further reductions in productivity.

3 - Modeling long-term population health and healthcare demand under baseline, prevention, and efficiency scenarios in BNSSG ICS
Luke Shaw, Richard Wood, Christos Vasilakis

Decisions around medium and long-term allocation of healthcare resources are fraught with challenges and uncertainties. Working for the UK's National Health Service (NHS), our organisation (BNSSG ICS) part a regional NHS apparatus responsible for planning the current and future health needs of the one million resident population. We have developed a Dynamic Population Model (DPM) that combines local primary care and NHS health activity data with Office for National Statistics local population projections, to give projections out to 2043. The model has been developed and coded in R, both as a deterministic set of difference equations and as a microsimulation model at person-level. Both formulations are discrete-time with time-step 1 year. The model allows for different scenarios to be tested, such as prevention efforts in certain cohorts or efficiency measures in different points of delivery like hospital wards. This makes for an effective comparison of cost projections under these scenarios, with not just financial cost but also Years of Life Lost as a human cost, and C02kg-equivalent as an environmental cost. The model highlights through a combination of an ageing population and increasing multimorbidity that healthcare utilisation is projected to grow significantly if we deliver per-person care at the same level as now. Further, it shows this growth is not uniform across the health service, and it quantifies yearly cost-saving effects from different interventions.

4 - Advancing One Planetary Health with Operational Research
Damjana Drobne, Samo Drobne

The planetary health approach addresses the intricate relationships between environmental changes — such as climate change, biodiversity loss and pollution — and their impacts on human, animal, and ecosystem health. This new approach extends beyond human health to include ecosystem health. To effectively address these complex and multidimensional problems, operational research (OR) could provide valuable tools for structuring problems and framing the solutions. Two examples are presented in this paper. The first example summarises studies on the effects of micro- and nanoplastics pollution on human health conducted within the EU PlasticsFatE project (H2020 PlasticsFatE; https://www.plasticsfate.eu/). The second example presents approach to design of safer and sustainable materials in three EU projects: ACCORDs, NOVA and Repoxyble (HORIZON ACCORDs; https://accordsproject.com/, HORIZON NOVA; https://eu-nova.eu/; HORIZON Repoxyble; https://www.repoxyble.eu/ . The first example is based on a top-down approach in which the existing environmental pollution must be mitigated. The second example, on the other hand, is based on the design phase and uses a bottom-up approach that aims to create materials that are as safe and sustainable as possible. The challenge lies in prioritizing problems, integrating diverse knowledge, methods, opportunities, and limitations, and involving stakeholders to ensure One planetary health.

■ WC-12

Wednesday, 12:30-14:00 - Room: Clarendon SR 1.02

Workforce assignment

Stream: Scheduling and Project Management
Invited session
Chair: *Johnson Phosavanh*

1 - Single-machine scheduling with cooperative agents and nondisjoint job sets
Johnson Phosavanh, Daniel Oron

We consider a new class of multi-agent scheduling problems where some jobs are allowed to be completed by more than one agent, each with a different processing time, allowing us to represent workers with different skill sets. This problem can be considered as a multi-stage optimization problem, where the assignment of jobs to agents needs to be decided, followed by the determination of an optimal schedule or vice versa. We show that this class of problems is not strictly easier or harder than the conventional competing or nondisjoint job set scenarios, and we provide an extensive analysis of problems consisting of two agents on a single machine with various scheduling criteria.

2 - Assigning new employees to positions
Leon Jendraszewski, Andreas Wiese

We study the problem of assigning new employees to (partially) vacant positions which arises in the human resources departments of larger public institutions. In particular, our colleagues from the administration of the School of Computation, Information, and Technology (CIT) at the Technical University of Munich need to solve it on a regular basis. When assigning a new employee to position(s), one needs to consider aspects like the pay scale of the new employee, the pay scales of the available positions, which groups of positions they belong to, and other factors. In particular, we may need to partially assign several positions to a new employee, and this assignment may change over time, e.g., because some positions are already assigned during certain time intervals. Therefore, this problem can be seen as a scheduling problem on machines with non-availability periods. We present several MIP-formulations and fast combinatorial algorithms for practically relevant special cases which exploit several insights into the problem that we derive. Those form the backbone of a tool we developed to solve this problem in practice; our tool is now used by our colleagues from the administration of the CIT.

3 - Accelerated convergence in column generation by a modified master problem
Sebastian Van Thienen

We discuss the column generation algorithm in the context of crew scheduling in aviation. This algorithm naturally arises when combining the Dantzig-Wolfe decomposition with the classical simplex algorithm for solving linear programs, and it leverages very fast shortest path algorithms that can be applied to the personalized time-space graph representations of every crew member in parallel. However, this algorithm suffers from degenerate steps, essentially slowing down convergence, leading to the tailing-off effect. In this talk we discuss how we can overcome these convergence challenges by regularizing the master problem, which makes it quadratic instead of linear. We analyze the mathematical structure of this regularized formulation and present specialized algorithms for its efficient solution. Our main contribution lies in explaining how to solve these modified master problems efficiently, and in demonstrating how the new formulation mitigates degeneracy and accelerates convergence of the column generation algorithm.

4 - A Heuristic for Worker Assignment in Multi-stage Production Lines
Xiaowen Zhao, Shao-Chin Sung

We are dealing with a worker assignment problem in multi-stage production lines based on the so-called restricted-cycle model with multiple periods. Given each worker's early probability, expected earliness, and expected tardiness, the objective is to minimize the total expected cost, i.e., the sum of the total expected earliness cost and the total expected tardiness cost incurred at all stages, among all possible worker assignments to stages in the production line. In particular, the expected tardiness cost at each stage depends on the late completions at that stage and the number of consecutive late completions at earlier stages. Previous studies propose branch-and-bound-based algorithms for finding optimal assignments. These algorithms have exponential running times with respect to the number of stages in the production line. To provide a solution method with practical running time, we propose a fast heuristic for finding a near-optimal assignment. The effectiveness of our heuristic is evaluated through numerical experiments.

■ WC-15

Wednesday, 12:30-14:00 - Room: Esther Simpson 1.08

Topics in Combinatorial Optimization 1

Stream: Combinatorial Optimization
Invited session
Chair: *Nikolaos Matsatsinis*
Chair: *Gorkem Yilmaz*

1 - Special implementation of steepest descent algorithm for M-natural-convex function minimization and related problems
Norito Minamikawa

The concept of M-natural-convex function gives a unified framework for discrete optimization problems with nonlinear objective functions, such as the minimum convex cost flow problem and the convex resource allocation problem. We consider M-natural-convex function minimization, one of the most fundamental problems concerning discrete convex analysis, and related problems. In this talk, we present some properties of the steepest descent algorithm for the class of M-natural-convex functions and a more general classes of discrete convex functions called jump M-natural-convex functions and quasi-M-natural-convex-functions. We show that a special implementation of the steepest descent algorithm enjoys the geodesic property. This implies that the trajectory of the solutions generated by the algorithm follows the shortest path to the nearest optimal solution.

2 - Optimizing Multi-Response Experimental Designs under Linear Constraints
Pál Somogyi

Optimal experimental design is a combinatorial optimization problem that seeks to select experimental conditions to maximize the information obtained from an experiment, thereby enabling the estimation of unknown parameters with minimal variance. Since optimal design problems are NP-hard, they are often addressed using heuristics or approximations, such as continuous relaxation, known as approximate optimal design. Harman et al. (J Am Stat Assoc 115:529, 2020) introduced a simple and efficient algorithm, REX, to solve the approximate optimal design problem. However, this algorithm is limited to basic optimality criteria and rank-one elementary information matrices (EIMs). Somogyi et al. (preprint, arXiv:2407.16283, 2024) extended REX for multi-response models (mREX), generalizing it to all Kiefer's optimality criteria and EIMs of any rank. In this contribution, we present the mREX algorithm and we propose a nontrivial extension of this algorithm to handle linear constraints (e.g., on financial resources, materials or time). We present two approaches: (i) transforming the constrained problem into an equivalent problem with EIMs of any rank, and (ii) fully extending the mREX algorithm to directly incorporate linear constraints. Numerical results demonstrate the stability and convergence of the proposed methods.

3 - Simulating pick-and-place operations for optimized robotic operations in reconfigurable manufacturing environments
Konstantinos Giannakos, Dimitrios Tsakoumis, Stathis Plitsos, Gregory Koronakos, Giulio Vivo, Pavlos Eirinakis

Reconfigurable Manufacturing Systems (RMS) require adaptable solutions for dynamic production demands. In robotic pick-and-place tasks, optimizing the picking sequence boosts efficiency. This study models the problem as a Bipartite Traveling Salesman Problem (BTSP), with a robot alternating between two sets: Gravity Racks (GR), storing components, and Kit Holders (KH), receiving assembled kits. We compare three optimization approaches: Heuristic Methods (e.g., Nearest Neighbor, 2-opt), a baseline Linear Method, and an Exact Method using Integer Programming. The Exact Method excels, offering up to 20% improvement over the linear approach. Additionally, we introduce a simulation service extends beyond sequence optimization by testing various GR configurations against multiple KH sequences. By simulating the full sequence of KH setups as a continuous tour, reveals that optimized GR layouts can yield 20-30% efficiency gains beyond sequence optimization alone. The system is modular, processing structured data inputs, enabling rapid evaluation of different layouts and their impact on total picking costs. Experimental results confirm that combining layout optimization with sequence planning enhances performance, reducing operational costs and time. This integrated approach paves the way for intelligent, scalable warehouse automation, with potential in integrating machine learning to predict optimal configurations or enabling multi-agent coordination for multi-robot environments.

4 - Column Generation Enhanced with Machine Learning: Frameworks for Simultaneous Lot-Sizing and Scheduling
Gorkem Yilmaz, Cevdet Utku Şafak, Erinc Albey

Capacitated lot-sizing and scheduling problems (CLSP) are essential challenges in production planning, involving optimising both lot sizes and machine scheduling across multiple periods. The complexity of these problems arises from their combinatorial nature and the interaction between lot-sizing and sequence dependent setup times. Traditional optimisation methods struggle with large-scale instances, leading to high computational costs. Column generation has been widely used to address such problems, but the pricing subproblem can become a bottleneck, significantly affecting efficiency. In this paper, we propose a machine learning-based enhancement for the pricing stage of column generation. Specifically, we integrate multi-layer perceptron (MLP) and recurrent neural network (RNN) models to predict promising regions of the solution space, improving the efficiency of column generation by quickly identifying viable solutions. Our method accelerates the optimization process and outperforms the traditional Gurobi solver on the solution quality and the computational time. Experimental results demonstrate that our approach significantly reduces the computational burden, enabling faster and more effective solutions for large-scale CLSP instances. This work highlights the potential of machine learning techniques to improve optimization efficiency in complex, real-world problems, offering a novel approach for solving large-scale capacitated lot-sizing and scheduling problems.

■ WC-16

Wednesday, 12:30-14:00 - Room: Esther Simpson 2.07

Quantum Computing for Optimization

Stream: Quantum OR
Invited session
Chair: *Philippe Lacomme*
Chair: *Marc Sevaux*
Chair: *Philippe Lacomme*

1 - Comparative Analysis of four Quantum Optimization workflows for Telecommunication Networks
Ali Abbassi, Yann Dujardin, Eric Gourdin, Philippe Lacomme, Caroline Prodhon

Quantum computing is emerging as a promising approach for solving combinatorial optimization problems. This study considers a use case of interest for the the telecomunication industry. We compare the performance of four quantum computing platforms—D-Wave, Pasqal, IBM, and Quandela—on solving the minimum edge multicut problem. Each platform follows a different computational paradigm: D-Wave employs Quantum Annealing, Pasqal and IBM could be used with the Quantum Approximate Optimization Algorithm (QAOA) and Quantum Adiabatic Algorithm (QAA), while Quandela applies a variational quantum circuit method. We modeled our telecom problem according to (respectively) every QC computational paradigm and conduct numerical experiments to analyse solution quality, computational efficiency, and workflow complexity of the different techonologies and associated instance scaling challenges. Each quantum system presents distinct bottlenecks: D-Wave requires careful QUBO formulation and embedding, Pasqal is limited by atom distance constraints, IBM faces decoherence and gate noise in QAOA, and Quandela must optimize variational circuit depth and parameters. By assessing these challenges, we provide insights into the strengths and limitations of current quantum optimization techniques using real and simulated QPU, highlighting their potential impact on real-world applications.

2 - Speeding up Grover's algorithm
Stefan Creemers

To find one of the M target entries in an unstructured database that has N entries, Grover's algorithm performs $\pi/4(N/M)(1/2)$ iterations. In each iteration, a function is called that evaluates whether an entry is a target entry. Compared to a classical procedure that requires N/M evaluations, Grover's algorithm achieves a quadratic speedup. This quadratic speedup, combined with its general applicability, has made Grover's algorithms one of the most important algorithms in existence today. We investigate two strategies to speed up Grover's algorithm: (1) reducing the number of iterations performed in each run and (2) partitioning the database. For each of these strategies, we not only execute Grover's algorithm in parallel, but also execute Grover's algorithm in series on a single Quantum Processing Unit (QPU) as well as on multiple QPUs. For each combination of execution mode (serial, parallel, and serial/parallel) and speedup strategy, we show how to obtain optimal policies using closed-form expressions and a gradient-descent procedure. For a single QPU we obtain a speedup factor of 1.1382 when compared to a textbook implementation of Grover's algorithm. If multiple QPUs are at our disposal, we obtain a speedup factor of at most 1.1382 Q(1/2), where Q denotes the number of QPUs. In addition, we show that the dominant policies that minimize the expected number of Grover iterations also minimize the expected number of iterations that are performed per qubit.

3 - A Hybrid Column Generation-Based Heuristic for Solving the Parallel Machine Scheduling Problem with Sequence-Dependent Setup Times
Luis Perez, Samuel Deleplanque, Riad Aggoune, Stefan Creemers

This study explores the application of a hybrid quantum-classical algorithm for solving the parallel machine scheduling problem with sequence-dependent setup times, a pivotal scheduling problem that has applications in multiple industries. Using a column generation-based approach, we propose a heuristic that combines a classical linear relaxation for the master problem with quantum annealing for solving the pricing sub-problem. Whereas the pricing sub-problem generates columns (i.e., a sequence of jobs that are assigned to a machine), the master problem selects which columns to use in order to minimize the makespan of the schedule. To generate columns, the pricing sub-problem solves a traveling salesman problem that is formulated as a quadratic unconstrained binary optimization problem. The big advantage thereof is that subtours can be eliminated by use of quadratic terms in the objective function. In addition, our approach also leverages the quantum annealer's capability to generate many high-quality solutions (i.e., columns) in a very short time. To assess the performance of our hybrid column generation-based heuristic, we perform a computational experiment. The results of this experiment demonstrate the synergy of hybrid methods for tackling complex decision making problems, achieving competitive high-quality solutions and computational advantages when compared to classical solution methods.

4 - Quantum Optimization for Supply Chain: QUBO Formulations and QAOA Solutions for Facility Location and Load Balancing
Luis A. Moncayo-Martínez

Quantum Bridge Analytics integrates classical and quantum computing to solve binary models by transforming mathematical programs into QUBO formulations. While tutorials exist on this process, key supply chain problems -facility location (FL) and load balancing (LB)- remain unaddressed. This work is among the first to apply QAOA to FL and LB, demonstrating its feasibility for real-world supply chain optimisation. We developed a PennyLane Lightning-GPU-based application that takes FL and LB data as input. It converts these problems into QUBO, transforms them into an Ising model, and solves them via QAOA. For unbalanced penalisation, the objective function and constraints are modelled in DOcplex before transformation into an Ising model. We tested the application on three instances of each problem. For FL, geodata from southwest England was used to determine optimal facility locations across nearby counties. For LB, real production line instances were solved, ensuring tasks were assigned to workstations while maintaining balanced workloads. An analytics report is generated for each instance. Results indicate that the optimal solution is found using a variational approach to optimise circuit parameters. Increasing the number of shots enhances solution accuracy,

closely matching results obtained via classical methods. The largest instance, a 30-qubit problem, is solved in approximately 20 seconds, demonstrating the potential of quantum computing for supply chain applications.

■ WC-17

Wednesday, 12:30-14:00 - Room: Esther Simpson 2.08

Combinatorial Optimization and Data Processing

Stream: Combinatorial Optimization
Invited session
Chair: Lorena Pradenas

1 - Incorporating Uncertainty in the Maritime Inventory Routing Problem: A Sample Average Approximation Approach for Antarctic Logistics
Dagoberto Cifuentes-Lobos, Lorena Pradenas, Víctor Parada

Maritime logistics in Antarctica are critical for sustaining scientific research, yet they face significant challenges due to uncertainties in weather conditions, supply availability, and demand fluctuations. These uncertainties complicate inventory and routing decisions, making the Maritime Inventory Routing Problem (MIRP) particularly complex. Existing optimization models either adopt deterministic formulations—ignoring uncertainty—or focus on short time horizons, limiting their applicability to real-world Antarctic logistics. To address this gap, we propose a stochastic optimization formulation for MIRP using the Sample Average Approximation (SAA) method, extending a previously developed deterministic Mixed-Integer Linear Programming (MILP) model. We apply the SAA-based model to instances constructed from real-world data of Chilean Antarctic scientific bases and compare the solutions against those obtained from the deterministic counterpart, which has previously delivered optimal results for small-scale instances. Our analysis evaluates computational performance, scalability, and the impact of incorporating uncertainty on solution quality and robustness. The results contribute valuable insights into combinatorial optimization techniques for inventory routing under uncertainty, with potential applications extending beyond Antarctic logistics.

2 - A subgradient method for the Cubic Facility Layout Problem
Thi Thuy An Tran, Mourad Baiou, Rafael Colares, Hector Gatt

This paper addresses a combinatorial optimization problem in automated workshops, where facility arrangements minimize product travel distances. It generalizes the Quadratic Assignment Problem (QAP) introduced by Koopmans and Beckmann (1957). The QAP involves a one-to-one assignment of facilities to locations to minimize flow-distance costs. Despite its simple definition, it is NP-hard, with instances of 32 locations still unsolved, while the largest optimally solved case has 128 locations. Our problem extends QAP by introducing unknown flows between facilities. In workshops with replica machines, total flow between machine groups is known, but individual routing decisions add complexity. When all facilities are distinct, it reduces to QAP; otherwise, the objective becomes cubic, defining the Cubic Facility Layout Problem (CFLP). CFLP groups facilities by type, with capacity constraints and group flows dictating total movement. We solve it using a linearization approach, converting the cubic model into an LP for useful lower bounds. Additionally, we develop a two-stage heuristic that iteratively optimizes layout and flow. Both approaches require solving QAP or CFLP, so we employ the Volume Algorithm, an approximate subgradient method. Since the Volume Algorithm supports parallelization, it can be scaled efficiently for large instances.

3 - Data-Driven Prediction of Sewer Blockages: A Spatiotemporal Analysis and Machine Learning Approach
Lorena Pradenas, Iván Veloso, Mauricio Vega-Hidalgo, Víctor Parada

This study researches the occurrence of blockages in urban sewer networks due to the accumulation of fats, oils, and grease (FOG), along with solid waste. A data-driven methodology was employed to conduct a spatiotemporal analysis of blockage events and develop predictive binary classification models. The study area was represented as a directed graph, integrating hydraulic and infrastructural attributes. Three predictive models were implemented: logistic regression, random forests, and neural networks, each evaluated using standard classification metrics. Logistic regression demonstrated an optimal trade-off between sensitivity (84%) and practical applicability, whereas more complex models exhibited superior performance in capturing nonlinear patterns. The findings underscore the significance of data-driven strategies in enhancing preventive maintenance protocols, particularly in high-risk zones, thereby improving the resilience and efficiency of sewer management systems.

■ WC-18

Wednesday, 12:30-14:00 - Room: Esther Simpson 2.09

OR Education 3

Stream: OR Education
Invited session
Chair: Milagros Baldemor
Chair: Kathryn E. Stecke

1 - Gamification in Advanced Operations Research: An Innovative Assessment Approach for Engineering Education
Sadia Samar Ali

This study introduces an innovative gamification approach for assessing students' understanding of advanced operations research concepts in engineering classes. The assessment, named "Case Discussion Analysis & Activity," incorporates game-like elements such as points, leader-boards, quiz board, movie settings to create an engaging and interactive learning experience. The approach evaluates students' problem-solving skills, decision-making abilities, and analytical thinking in a dynamic environment that simulates complex operations research situations. The assessment criteria include student preparedness, conceptual comprehension, logical reasoning abilities, and critical analysis skills. The methodology involves a team-based approach to present their case analysis using gamification elements. The integration of gamification promotes adaptive learning, as the difficulty and complexity of challenges can be adjusted based on individual student performance. Furthermore, the approach incorporates data analytics tools to track student progress, identify areas of difficulty, and provide targeted interventions. The primary objective of this assessment method is to create a more engaging evaluation process while simultaneously assessing students' comprehension and application of operations research concepts, ultimately preparing them for future professional challenges in an increasingly technology-driven world.

2 - Enhancing Business Analytics Education through Active Learning: The Controlling Analytics Challenge
Alexander Baumeister

The increasing digitalisation of business processes and models has significantly altered skill requirements in the labour market for business administration graduates. Employers now demand proficiency in data analysis, statistical reasoning, optimisation, and programming - skills that are difficult to develop through traditional lecture-based instruction. To address this problem, the Controlling Analytics Challenge (CAnChall) at Saarland University introduces an innovative, action-oriented teaching framework that integrates blended learning, student

peer review, and competitive elements. The program combines theoretical instruction with practical, real-world case studies, engaging students in collaborative data analysis tasks using R for statistical computing. The course emphasises classification and regression techniques, applying them to business analytics problems, such as using decision trees for cancellation forecasting to optimise hotel occupancy rates or logistic regression to predict credit card customer payment defaults. This initiative fosters deeper learning across procedural and metacognitive domains, aligning with Bloom's revised taxonomy. This paper presents the design and implementation of CAnChall, highlighting its potential as a scalable and transferable model applicable across various Operations Research (OR) domains and disciplines in higher education.

3 - The 7E's Instructional Model and its Longitudinal Impact on the Mathematics Achievement of Tertiary Students
Milagros Baldemor

This study aimed to determine the effectiveness of utilizing the 7E's Instructional Model on the Mathematics achievement in Calculus of tertiary students of the Don Mariano Marcos Memorial State University, Philippines in comparison with the traditional teaching method. The study sample consisted of sixty students who were divided into two groups: the experimental group of thirty students, who studied Calculus by using the 7E's Instructional Model - Elicit, Engage, Explore, Explain, Elaborate, Evaluate and Extend; and the control group of thirty students, who studied the same concepts using the conventional teaching method. ANCOVA results of the students' scores in the mathematics achievement tests indicated that the 7E's Instructional Model is more effective than the traditional teaching method. Furthermore, the paired-sample t-test findings revealed that the model had a significant positive longitudinal effect on the retention among the students.

4 - Using Generative Artificial Intelligence to Design Operations Modules
Eliseo Vilalta-Perdomo, David Salinas-Navarro, Rosario Michel-Villarreal

This presentation work summarises what has been learnt in this process and provides a series of insights on the use a Generative Artificial Intelligence (GenAI) tool, specifically ChatGPT3.5, for this purpose. According to Lim et al. (2023), GenAI is a technology that makes use of deep learning models to generate human-like content from complex and varied prompts. It is the case that conversations in academia about the use of Generative Artificial Intelligence (GenAI) tools have been centred on plagiarism and the impact on student learning (Chinonso et al., 2023; Eke, 2023; Stokel-Walker & Van Noorden, 2023; Zhai, 2022). This deserves to continue being studied, but other areas of opportunity have not been explored, for instance, the role that GenAI tools can play in supporting academics in the design of effective OR/OM modules.[U+202F]This presentation aims at presenting the progress that CoRSEL has done on the use of ChatGPT3.5 for this purpose; the rationale behind this selections is its open access and its capability to support academics in teaching and learning activities (Michel-Villarreal et al., 2023; Salinas-Navarro et al., 2024a; Salinas-Navarro et al., 2024b). The work aims to showcase the value of GenAI tools in designing engaging educational experiences while acknowledging the need for human expertise in refining and validating the generated proposals.[U+202F]

■ WC-20

Wednesday, 12:30-14:00 - Room: Esther Simpson 2.11

Topics in Combinatorial Optimization 2

Stream: Combinatorial Optimization
Invited session
Chair: Maria João Alves

1 - The McNugget-Knapsack Connection Revisited: Evaluating the Sharpness and Structural Limitations of Frobenius Number Bounds with Operational Research Applications
Aled Williams

We study classical bounds on the Frobenius number, which is the largest integer not expressible as a nonnegative integral combination of given relatively prime positive integers. The Frobenius problem, known in literature by names including the money-changing problem, the coin problem, the chicken McNugget problem and the Diophantine problem of Frobenius, is pivotal in operational research due to its connection with integer infeasibility in knapsack problems. From a geometric perspective, the Frobenius number represents the maximal right-hand side for which the corresponding knapsack problem remains integer infeasible. Computing the Frobenius number is NP-hard in general, motivating research into developing upper bounds.

We present a comparative analysis of existing upper bounds on the Frobenius number, evaluating their relative tightness through both theoretical and simulation-based methods. A key contribution is the proof of a fundamental limitation on upper bounds. Specifically, we show that no general upper bound with a worst-case exponent strictly less than quadratic is possible without imposing stronger conditions than coprimality.

These findings offer deeper insights into the structural constraints on Frobenius number bounds and provide guidance for future refinements.

2 - Real-time crew rescheduling for disruption management in railway systems
Manuel Schlenkrich, Valentina Cacchiani, Vera Hemmelmayr

A well-functioning transport system is the backbone of economic activity. Disruptions due to extreme weather conditions or technical failures happen frequently and reduce the efficiency of the railway system. Since it is mostly impossible to avoid disruptions, a fast and adequate response is necessary. Therefore, advanced decision support systems with the potential to increase the efficiency of the railway system are required. In this work we focus on real-time railway crew rescheduling. The goal is to quickly find a new crew schedule that does not differ too much from the original crew schedule and avoids trip cancellations as much as possible, while still being feasible according to the labor rules and operational constraints. We consider railway crew rescheduling for freight trains along multiple days in real-time, which limits the computation time to only a few minutes. We develop a metaheuristic method, namely a Variable Neighborhood Search, to quickly generate high quality crew plans to recover from a disruption. We propose several neighborhood structures and investigate different types of disruptions regarding their duration and severeness. We test the algorithm on real-world data from Rail Cargo Austria to support the railway operator's decision making.

3 - On Generalizations of Partial Scenario Set Cover
Shai Dimant

In the Partial Scenario Set Cover problem (PSSC), given a finite ground set Q, a collection S of subsets of Q with associated nonnegative costs, and a second collection U of subsets of Q, the goal is to select a minimum-cost sub-collection of S that covers at least l sets from U. PSSC is motivated by an application for locating emergency doctors, which is driven by robust optimization, where the collection U corresponds to an uncertainty set and its elements to scenarios. Here, the aim is to cover at least a certain number l of scenarios by a minimum cost choice of locations.

Here, we consider the following natural generalization of PSSC, called Partial PSSC (PPSSC). Each scenario has a demand that specifies the number of elements that must be covered. The task is to find a minimum-cost sub-collection of S that satisfies the demand of at least l scenarios. PSSC and PPSSC are at least as hard to approximate as the Minimum k-Union problem, which is believed not to admit a sub-polynomial approximation ratio. Our contributions include an approximation algorithm for general instances of PPSSC and polynomial-time algorithms for interesting graph-theoretic versions of the problem.

4 - Bilevel Optimization for aggregation of demand-side flexibility: a hybrid metaheuristic-exact approach
Maria João Alves, Carlos Henggeler Antunes, Inês Soares, Ana Soares

Flexibility is key to managing power systems aimed to encourage modulation of electricity consumption in the face of the increasing share of variable renewable generation. Aggregators play a growing role by collecting flexibility from consumers and prosumers to sell it to the grid/market operator, creating economic and operational benefits for all stakeholders. The aggregator-consumer interaction can be modeled as a bilevel multi-follower mixed-integer program, where the aggregator sets financial incentives at the upper level, while consumers optimize their energy use in response to rewards, electricity prices, and comfort preferences at the lower level. To solve this problem efficiently, we propose a hybrid approach that combines particle swarm optimization for the upper-level problem with an exact mixed-integer linear programming solver for the lower-level problem. Computational experiments have been performed under a computational budget for a real data setting that includes typical residential appliances, an electric vehicle, stationary batteries, microgeneration, and grid interactions.

■ WC-23

Wednesday, 12:30-14:00 - Room: Esther Simpson 3.01

Complex Societal Problems in Development

Stream: OR for Societal Development
Invited session
Chair: *Sadiye Eylul Sadanoglu*
Chair: *Nina Kajiji*

1 - Systems Ideas in Community Operational Research: The Resonance and extension of Soft Systems and Critical Systems
Rebecca Herron, Eliseo Vilalta-Perdomo

This paper looks at the use of systems ideas in Community Operational Research. In particular, it focusses on the resonance and possibilities for extension of ideas from Soft Systems and Critical Systems research. The paper looks at how systems ideas have been used in practice in various contexts and some of the key ideas that transfer across different methodologies. It looks both at Management Systems ideas and more widely at developments in Systems Science in other disciplines and asks the question how these perspectives can help support activities at a community or third sector level. This work is seen as part of a combined research agenda to support the articulation and development of Systems Research and Community O.R. in the UK and internationally.

2 - What makes a 'good' policy simulation model? Findings of a systematic literature review
Lisa Garnham, Clemmie Hill OConnor, Gerry McCartney, Kat Smith

Computational modelling is an established form of analysis is increasingly being used to inform policy decisions in real-world settings. Despite the potential strengths of modelling, however, a significant body of critical literature has emerged, which questions the quality and application of models in policy decision-making. Working in an applied context, with policymaking organisations at national, devolved and local authority level, our research explores the use of modelling in a variety of policy domains. We report on the findings of a systematic review that asked the question: what makes a 'good' model when the aim is to support policy decision-making? We synthesise the findings of this diverse literature to describe what authors propose as the core qualities of a 'good' model and the development processes that enable these qualities. We conclude that, while there is broad consensus on what makes a 'good' policy simulation model for real-world policy applications, there is less critical reflection on the trade-offs between these qualities. The relative lack of perspectives from model users across this literature makes it difficult to determine what these trade-offs are and how they might be assessed to improve the quality and usability of simulation models for policy audiences. We reflect on our findings in the wider context of our current research engagement with organisations with direct or indirect roles in developing policy and our future research.

3 - Formalising an Assessment-Based Roadmap for Circular Economy Transitions: A Longitudinal and Policy-Driven Approach: An Embedded Case Study of London, UK
Sadiye Eylul Sadanoglu

The transition to a circular economy (CE) is widely recognised as a key driver of urban sustainability, yet its integration into local governance structures remains inconsistent. Effective CE adoption depends not only on financial and technological capacity but also on strategic policy coordination and multi-stakeholder engagement (Petit-Boix & Leipold, 2018). This study builds on a longitudinal analysis (2012-2015) that assessed the sustainability performance of 32 London boroughs, revealing that while boroughs prioritised economic and environmental concerns, social sustainability remained marginal (Bellozoni et al., 2022). The findings also indicated that financial constraints and fragmented governance structures limited long-term CE adoption.

This research formalises an assessment-based roadmap, linking longitudinal sustainability evaluations with contemporary policy interventions. It offers an evidence-based strategy for improving CE governance, ensuring financial sustainability, and fostering inclusive urban transitions through multi-level stakeholder collaboration. The findings contribute to broader policy frameworks, providing a scalable model for urban CE integration.

■ WC-24

Wednesday, 12:30-14:00 - Room: Esther Simpson 3.02

Tutorial: Methods for Mixed Integer Non Linear Optimization

Stream: Tutorials (and Workshops)
Tutorial session
Chair: *Sanne Wøhlk*

1 - Methods for Mixed Integer Non Linear Optimization
Claudia D'Ambrosio

In this tutorial, we provide an overview of the fundamentals of theoretical and practical aspects of mixed-integer nonlinear optimization (MINLO). MINLO problems are highly challenging from both a theoretical and practical perspective. They represent one of the largest classes of mathematical optimization problems for which general-purpose solvers exist. Thus, they are generic enough to represent a vast range of real-world applications, arising from finance to chemical engineering, energy systems, hydraulic engineering, transportation, just to mention a few. We begin by introducing several motivational applications. Next, we explore methods for MINLO problems with convex objective functions and continuous relaxation feasible set. We then move on to global optimization techniques, designed to find globally optimal solutions of general MINLOs. Finally, we discuss practical tools for solving MINLO problems and highlight recent trends in the literature.

■ WC-26

Wednesday, 12:30-14:00 - Room: Maurice Keyworth 1.33

Getting to do the things we do: persuading leaders to invest in OR projects

Stream: Making an Impact: The Practitioners' Stream 1
Making an impact session
Chair: Ruth Kaufman

1 - Getting to do the things we do: persuading leaders to invest in OR projects
Making An Impact, Rubén Ruiz, Gueorgui Mihaylov, Ruth Kaufman, Tetyana Mykhaylyk

How do we convince our management and/or customer managers to kickstart and invest in new OR projects and products? What works well, what doesn't? This round table discussion brings together 3 experienced leaders to explore how we can get top management to accept the disruption, change and risk that come with any major OR project.

Panel members: Gueorgui Mihaylov is Principal Data Scientist (AI Director) at Haleon plc, and also has a visiting position at Kings College London.

Tetyana Mykhaylyk is Director of Information, Data and Analysis at the UK Government's Valuation Office Agency.

Rubén Ruiz is currently Principal Applied Scientist within EC2 at Amazon Web Services. He mainly does large-scale optimization in bin packing and balancing problems. Prior to that, he was full professor of statistics and OR at the Polytechnical University of Valencia, Spain, where he did optimization consulting for many companies for more than 20 years.

The panel will be chaired by Ruth Kaufman, a past president of the UK's OR Society, whose career has included leading OR teams, being a senior manager commissioning OR projects, and chairing the Government OR Service, the EURO Practitioners Forum, and the UK's Pro Bono OR scheme.

■ WC-30

Wednesday, 12:30-14:00 - Room: Maurice Keyworth 1.05

Shared Mobility Optimization II

Stream: Shared Mobility Optimization
Invited session
Chair: Reza Atefi

1 - Designing Service Regions for Bike Sharing Systems: Integration with Public Transport Networks
Zhenyu Wu, Shadi Sharif Azadeh, Luce Brotcorne

Designing effective service regions for bike-sharing systems (BSS) is critical for enhancing urban mobility and ensuring seamless integration with public transport (PT) networks. Existing studies on bike station siting and operational optimization often overlook the integration of BSS with PT networks. In this study, we explicitly consider multimodal travel patterns and multiple path possibilities for each origin-destination (OD) pair. By incorporating k-order shortest paths, we propose an integer programming optimization model to define optimal service regions that maximize demand coverage under the constraints of construction and operational budgets. Our approach prioritizes optimal paths for users while strategically allowing slightly suboptimal paths to enhance coverage and reduce operational costs (e.g., rebalancing). To solve the model, we employ a mathematical solver, Gurobi, and conduct initial tests on synthesized data. Our preliminary results indicate that, compared to a baseline approach (where only the first-order shortest paths are allowed), our method can enhance demand coverage and improve operational efficiency. We will further validate our model using TPG data and real-world trip data from Geneva's bike-sharing system. These findings highlight the potential of our approach in designing efficient, multimodal-integrated BSS service regions while optimizing resource allocation within real-world multimodal networks.

2 - A robust optimization approach for strategic planning and inventory management in bike-sharing systems under government supervision
Qingxin Chen, Ning Zhu

Bike-sharing systems offer an efficient and accessible option for short-distance transportation. However, the boom of bike-sharing systems also introduced challenges to urban transportation systems, such as congestion due to oversupplying bikes and low service quality caused by malfunctioning bikes. To address these challenges, government supervision has been conducted in various cities to improve operational standards in bike-sharing systems. Therefore, bike-sharing system operators should incorporate the influence of government supervision when formulating strategic and operational decisions. This study introduces an optimization model that simultaneously addresses depot location, inventory management, and bike rebalancing decisions under government supervision. Moreover, to address the uncertainty of travel demand and government supervision strategy, a distributionally robust optimization (DRO) model which incorporates both moment-based and sample-based information is developed and reformulated. The numerical results imply that the DRO model surpasses benchmark models. Furthermore, a series of effect analyses are conducted, providing valuable managerial insights for bike-sharing system operators and government supervisors. Additionally, we perform sensitivity analyses to verify that government supervision effectively addresses bike oversupply and enhances operational order in bike-sharing markets.

3 - On Robust Inventory Management in Bike Sharing
Haoxiang Wang, Dimitrios Letsios

We aim to enhance the service level of a bike-sharing system, measured by total unmet demand, by developing a robust optimization-based inventory model to decide the robust initial bike allocation at each station. Although deterministic optimization models effectively evaluate past planning decisions with known demand, they struggle to perform well for future bike allocations due to inevitable demand prediction errors. In the robust optimization framework, we address this uncertainty by assuming that demand fluctuations are bounded within a specified uncertainty set. We first formulate a deterministic optimization model, define the uncertainty set, and develop its robust counterpart as a bi-level optimization problem. We focus on the inner problem of this robust counterpart—the adversarial formulation—to study the impact of demand uncertainty. Unlike previous robust inventory control studies that rely on dualization techniques to solve the bi-level problem, we propose a heuristic algorithm to address the robust counterpart and use its solutions as a benchmark. We then design a novel algorithm, inspired by the cutting plane method, to achieve a global (near-)robust solution. The computational results validate the effectiveness and robustness of our approach.

■ WC-31

Wednesday, 12:30-14:00 - Room: Maurice Keyworth 1.06

Solution Algorithms for Optimization under Uncertainty 2

Stream: Stochastic and Robust optimization
Invited session
Chair: Bismark Singh

1 - Two notions of regret in problems with uncertainties in objective function and feasibility space
Dimitri Hubans, Laurent Houssin, Sonia Cafieri

In a robust optimization framework, the goal is to find a solution that is robust to uncertainty in the sense that it is feasible and of good quality in all scenarios. In the literature, many problems consider uncertainty only in the objective function. In such cases, optimization is performed either through optimizing the worst case or optimizing the regret. However, when uncertainties lie both in the objective function and the constraints, another notion of regret appears. As far as we know, this alternative notion of regret has not been addressed in the literature. This second notion of regret compares solutions computed under uncertainties to solutions that are only robust to the uncertainties on the feasible space while considering a deterministic objective function. The two notions of regret may appear similar at a first glance but yield different properties. In particular we can find rather simple problems in which optimizing one or the other regret gives different solutions. In this presentation we rigorously define the two notions of regret. We use a classical problem as an example: the knapsack problem. We address the problem under uncertainty, where uncertainties are in both the weight and the profit of each item. We show on some instances of this problem that the optimization of the two different regrets gives different solutions. We also discuss some differences arising in the solution methods for the two versions of the problem.

2 - Adapting the coordinate-descent method for probability maximization problems
Edit Csizmás, Rajmund Drenyovszki, Csaba Fabian

For probabilistic problems, computing or estimating gradients requires a considerable effort. We build an approximate model, using a random coordinate-descent method to find new test points. We show that better results are obtained when we compute a Lipschitz constant for a region near the optimal solution.

3 - Statistical Performance of Subgradient Step-Size Update Rules in Lagrangian Relaxations of Chance-Constrained Optimization Models
Bismark Singh

Lagrangian relaxation schemes, coupled with a subgradient procedure, are frequently employed to solve chance-constrained optimization models. Subgradient procedures typically rely on step-size update rules. Although there is extensive research on the properties of these step-size update rules, there is little consensus on which rules are most suitable practically; especially, when the underlying model is a computationally challenging instance of a chance-constrained program. To close this gap, we seek to determine whether a single step-size rule can be statistically guaranteed to perform better than others. We couple the Lagrangian procedure with three strategies to identify lower bounds for two-stage chance-constrained programs. We consider two instances of such models that differ in the presence of binary variables in the second-stage. With a series of computational experiments, we demonstrate—in marked contrast to existing theoretical results—that no significant statistical differences in terms of optimality gaps is detected between six well-known step-size update rules. Despite this, our results demonstrate that a Lagrangian procedure provides computational benefit over a naive solution method—regardless of the underlying step-size update rule.

This work is published here: https://doi.org/10.1007/978-3-031-47859-8_26.

■ WC-32

Wednesday, 12:30-14:00 - Room: Maurice Keyworth 1.09

Green maritime and port logistics-2

Stream: Maritime and Port Logistics
Invited session
Chair: *Cagatay Iris*

1 - Prepare for the worst, hope for the best: Robust design of an efficient and fair liner alliance
Yadong Wang, Huming Zhang

As competition in shipping market intensifies, liner shipping companies are increasingly forming alliances to boost profitability in tough market environment through resources sharing among partners. However, it is important to ensure fairness among alliance members, which is critical to maintaining a stable and productive collaboration. Moreover, the international shipping market is highly dynamic with fluctuating container shipment demand, adding complexity to the organization of liner shipping services within alliances. In this regard, this paper proposes a unified optimization framework that covers both fairness considerations and uncertain shipment demand for efficient fleet co-deployment and slot co-management in liner alliances. To maximize the alliance profit, a general deterministic model is first developed to characterize our optimization framework with deterministic demand. Subsequently, the deterministic model is extended to a two-stage robust optimization model with uncertain demand to maximize the alliance worst-case profit. The first stage involves fleet deployment decisions while the second stage addresses slot co-management decisions made after the uncertain demand is realized. A customized C&CG algorithm is applied to solve the model. To validate the efficiency of the algorithm and the effectiveness of the proposed model, a series of numerical experiments are conducted, and several strategic insights are provided to guide decision-making for liner alliances.

2 - Ports 5.0: the next revolution in sustainable ports
Lorena Bearzotti, Javier Maturana-Ross, Franco Basso, Maria Isabel Vega

Maritime transport is vital for trade but a major GHG emitter. Ports 5.0 integrates digital transformation, sustainability, and human-centered development to cut emissions, improve efficiency, and foster gender equity in the workforce. Despite automation and green energy advances, ports still face high emissions, inefficient resource use, and lack of diversity. Women remain underrepresented in leadership, limiting inclusive innovation. A sustainable system must balance technology and social equity to enhance resilience. Ports 5.0 focuses on three areas: Emerging Technologies - AI, IoT, and automation to optimize energy use; Green Energy Transition - Adoption of renewables and storage solutions and Human-Centered Management - Policies and training to boost gender inclusion in key roles. This paper developed a Sustainable Port Model, combining environmental innovation and workforce diversity, offering a replicable framework worldwide. Studies confirm that inclusive strategies enhance efficiency and sustainability. Ports 5.0 is shaping a greener, smarter, and more equitable maritime industry.

3 - Operations management in multi-energy port microgrids
Cagatay Iris

Seaports, as substantial consumers of energy, aim to adopt energy management systems in response to rising energy costs and a commitment to sustainable operations. Many ports are shifting to electricity as their primary energy source and other alternative energy sources, instead of carbon-intensive alternatives. This paper presents a mixed integer linear programming model designed to address the integrated planning and energy management challenges faced by seaports utilizing a port microgrid. The planning module of the model determines the allocation of equipment. Additionally, the planning module decides the berthing duration for each ship, influencing the hourly energy consumption of the port. The energy management aspect involves aligning energy demand and supply, considering various energy pricing schemes, bidirectional energy trading among different sources (such as the utility grid, multi-energy sources), and integrating energy storage systems. The study's findings suggest that the implementation of smart grid technology, represented by the port microgrid, can yield substantial cost savings.

■ WC-34

Wednesday, 12:30-14:00 - Room: Michael Sadler LG10

Business Applications of Knowledge and Technology

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: A. D. Amar

1 - Learning Primal Heuristics for 0-1 Knapsack Interdiction Problems
Luca Ferrarini, Stefano Gualandi, Axel Parmentier

Knapsack Interdiction Problems (KIP) are NP-hard problems of significant interest, as they model scenarios where two opposing forces interact within a leader-follower framework. The leader moves first, selecting items to restrict the follower's choices, while the follower subsequently selects items that maximize their profit from the remaining options. Despite the development of various algorithms to tackle these problems, efficiently solving large instances remains a challenge. In this work, we propose a heuristic that relaxes the interdiction constraint by solving two separate linear problems, achieving a balance between computational efficiency and solution quality. Our method leverages a Machine Learning model incorporating an InferOpt layer, a framework designed to integrate combinatorial optimization into ML pipelines by differentiating through optimization solvers. The output of this pipeline serves as the cost vector for one of the linear problems, which are then solved exactly to generate an approximate solution for the KIP. Through extensive experiments, we demonstrate that our heuristic ensures low computational time while maintaining a small optimality gap.

2 - Evaluating traditional ML models in predicting uncertainty of real estate prices
Jose A. Rodriguez-Serrano

A body of OR literature has dealt with the prediction of real estate prices, as some firms rely on accurate prediction to enable revenue management or portfolio optimization; plus it is a basic component of operations in specific sectors (e.g. insurance, market research).

Recently, machine learning (ML) is replacing old models such as OLS in valuation. Models such as random forests typically yield better metrics, such as root mean squared error (RMSE) or R2, in prediction tasks.

One drawback is that standard ML models for regression only provide point estimates (the expectation of the price conditioned on the predictors). In realistic valuation tasks, however, the point estimate alone is not enough as it ignores the uncertainty of the price; and traditional ML models are not designed to provide the conditional distribution.

In this work we propose a novel methodology to evaluate the quality of a ML model in predicting ranges, not punctual estimates. We select 5 standard ML models (linear regression, decision tree, K-NN, random forest, lightgbm), adapt them to "recover" the conditional price distribution, and compare them with new metrics on data of 3 real estate markets in Spain. We find that random forest has the best quality in predicting ranges in general, while K-NN are well-suited when constrained to small prediction ranges.

This work sheds light on using ML for valuation and other OR tasks in settings where prediction risk is critical.

3 - Identification of Circadian Cycle Disruptors in Night Shift Workers Using Machine Learning Models
Karen Nino, Julián Calixto, Dagoberto Castillo, Sepideh Abolghasem

Globalization and the expansion of industries have accelerated over time, leading to a growing demand for continuous operations in sectors such as healthcare, security, and manufacturing. This latter has raised the need of night shifts of workers disrupting the natural biological rhythm of them, which is known as circadian cycle. This cycle regulates essential bodily functions such as body temperature, digestion, and sleep. Disruptions to this cycle can have short, medium, and long-term consequences on job performance, health, and safety. This study focuses on identifying the key factors that most significantly impact the circadian cycle using machine learning techniques. Various classification algorithms such as Decision Tree, Artificial Neural Network, Random Forest, CATBoost, XGBoost, and k-Nearest Neighbors, are employed to analyze large datasets, detect patterns, and identify influential variables. Data is processed, evaluated, and filtered based on its relevance to identify the most accurate model for forecasting the factors and their combinations that influence circadian rhythm disturbances. The insights gained from this study could contribute to improved shift scheduling strategies and workplace policies aimed at mitigating the adverse effects of night shifts on workers' well-being and productivity.

■ WC-35

Wednesday, 12:30-14:00 - Room: Michael Sadler LG15

Cardinality-constrained optimization with guarantees

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: Immanuel Bomze

1 - Cardinality-Constrained Optimization for Large-Scale Portfolio
Yuan Chen, Immanuel Bomze, Nikolaus Hautsch, Bo Peng

We propose a portfolio optimization model that reconciles Keynes's advocacy for concentrated investments with Markowitz's emphasis on diversification. By incorporating cardinality constraints into the Markowitz mean-variance framework, we enable investors to focus on a small set of assets, fostering specialized expertise. Cardinality constraints allow investors to still use the sample covariance matrix in high-dimensional settings with limited data, balancing diversification needs while mitigating estimation errors inherent in such environments.

2 - Strict control of sparsity for classification problems
Immanuel Bomze, Federico D'Onofrio, Pedro Duarte Silva, Marta Monaci, Laura Palagi, Bo Peng

To ensure explainability in AI and transparency in Machine Learning, control of sparsity is crucial. However, most of the popular approaches use surrogate regularizers to reduce the number of variables involved in the classifier, which sometimes does not work as intended. Instead, we follow a recent strain of research by rigorous control of this number directly, employing an explicit cardinality constraint on the original features. The resulting nonconvex QCQP is NP-hard and we propose conic relaxations to tackle it.

3 - Geodesic Programs
Johannes Manstein

The classical simplex algorithm solves linear programs in Euclidean spaces by moving along the edges of a polyhedral feasible set. We explore an extension to a class of problems on Riemannian manifolds, which we call geodesic programs. In this setting, the feasible set is a convex polyhedron defined using the exponential map, so straight lines in the Euclidean setting are replaced by geodesics. We analyze the types of manifolds where this approach is applicable, the classes of objective functions and polyhedra for which a global minimizer can be found, and compare the properties of geodesic programs with classical linear programs. Finally, we describe an explicit simplex algorithm adapted to the Riemannian setting and examine its behavior.

■ WC-38

Wednesday, 12:30-14:00 - Room: Michael Sadler LG19

Optimization in Online Environments

Stream: Data Science meets Optimization
Invited session
Chair: Grzegorz Pawlak

1 - Evaluating the Performance Impact of Data Sovereignty Features on Data Spaces
Stanisław Galij, Grzegorz Pawlak, Slawomir Grzyb

This study examines the performance implications of implementing data sovereignty features within data spaces. The research focuses on two primary areas: the performance of the IDS Dataspace Connector in AWS, GCP, and Azure environments, and a comparative analysis of various IDS Connectors. The first part of the study involves deploying the Dataspace Connector, connecting it to the IDSA test environment, and conducting performance tests on virtual servers. The second part involves selecting open-source IDS Connectors (from the 38 implementations currently available), connecting them to the IDSA test environment, and designing comparative tests based on API analysis. These tests are executed across multiple cloud service providers and edge environments. The findings aim to provide insights into the performance trade-offs associated with data sovereignty features in data spaces.

2 - Optimal Grouping and Placement of Composite Parts in an Autoclave
Tugce Yucel, Diclehan Tezcaner Öztürk, Murat Caner Testik

Composite materials used in the aviation industry undergo a curing process in heat and pressure ovens called autoclaves. In a curing cycle, all parts that are loaded in the autoclave are heated until they reach their curing temperature, cured at that temperature for a while, and then cooled down to room temperature. The heating phase ends when all parts reach the curing temperature, which is mainly affected by how the parts are located in the autoclave. In this study, we address the heating phase of this cycle, and aim to keep its duration at minimum by placing the parts optimally in the autoclave. For the autoclave and parts considered in this study, there are no established relations between the location of the parts in the autoclave and their heating durations. In our approach, we first estimate the heating durations of parts with respect to their placements in the autoclave and the properties of the batch (like the weight, length of parts) with an Artificial Neural Network (ANN) Model. We then develop a mixed integer nonlinear programming model that groups the parts into batches, and finds the best layout for each batch in the autoclave using the estimations of the ANN Model. We test our approach on real data.

3 - Optimizing Transshipment Yard Operations in Railway Systems: A Hierarchical Approach to Enhancing Efficiency and Reducing Delays
Grzegorz Pawlak, Jacek Blazewicz, Mateusz Cichenski, Erwin Pesch, Gaurav Singh

Modern railway systems, particularly transshipment yards, are crucial in improving the efficiency of hub-and-spoke logistics, especially for containerized freight. These yards enable fast and reliable container handling through gantry cranes operating above trains. Railway transport offers a more environmentally friendly option by reducing CO2 emissions compared to air transport and is less obstructed by traffic congestion than road transport. However, delays are a significant challenge, with only 53% of trains arriving within 30 minutes of the scheduled time, largely due to inefficient handling processes in the yards. This issue stems from the need to rearrange train cars using shunting hills and track switches. To address these inefficiencies, the problem has been decomposed into five key subproblems: scheduling train service slots, assigning tracks, deciding on outbound container positions, assigning container moves to cranes, and scheduling crane operations. These subproblems, though typically solved independently, must be integrated for optimal efficiency. Solutions like optimization algorithms, real-time data integration, and automation hold potential to reduce delays, enhance crane utilization, and improve overall yard throughput, contributing to a more efficient and sustainable transport system.

■ WC-39

Wednesday, 12:30-14:00 - Room: Newlyn LG.01

Sustainable Supply Chains II

Stream: Sustainable & Resilient Systems and Infrastructures
Invited session
Chair: Tristan Becker

1 - Mitigating Demand Uncertainty: Resilient, Green Supply Chain Design for Multi-Product, Multi-Period Operations in a Changing Trade Landscape
Surya Prakash, Sachin Kumar Mangla, Harish Kumar

Tariffs and geopolitical uncertainties create significant demand uncertainty for companies by introducing price volatility, supply chain disruptions, and sustainability goals. This uncertainty can be categorized as both external (market-driven) and strategic (policy-driven). To manage this demand uncertainty, firms must adopt resilient supply chain strategies and attempt to design or redesign their supply chains under this uncertain environment. This study proposes designing resilient, robust, and sustainable (by including emissions) multi-period multi-product supply chains design under demand uncertainty. A multi-objective mixed-integer linear programming model is implemented to capture network design requirements and mathematically modeled in the AIMMS environment and solved using CPLEX 12.0. The demand uncertainty is handled using a robust optimization approach. A comparative analysis of supply chain performance is performed through supply chain cost, shipments or product flow, transportation cost, network configuration, service level, etc. for the current (before adopting resilient and robust optimization modifications) and for the proposed modified network. The results from numerical experiments and sensitivity analysis show efficient use of the proposed improved network to address the demand uncertainty. The proposed resilient sustainable supply chain configuration model outperforms the basic deterministic model if both are subjected to a certain level of uncertainty.

2 - Optimal Supply Chain Management Strategies for Remanufacturing Under Uncertainty: A Portfolio-Theoretic and Risk-Constrained Approach
Jingrong Bai, Ming Luo

Remanufacturing plays a critical role in achieving circular economy goals, yet it is often challenged by significant uncertainties in core supply, quality, and process execution. This study investigates optimal supply chain management strategies for remanufacturing under such uncertainty, focusing on key risks in core availability, quality variability, and inventory fluctuations. We develop a risk-constrained optimization framework that captures the variability of total remanufacturing cost as a measure of operational uncertainty. A static decision-making model evaluates procurement, reprocessing, and holding cost components under a fully in-house remanufacturing scenario. Building on this, a portfolio-theoretic approach is introduced to assess hybrid strategies that combine in-house and third-party core collection. Analytical results show how the optimal sourcing mix can be derived to minimize expected cost subject to risk constraints, while also accounting for diversification effects when multiple third-party providers are involved. By quantifying the trade-off between cost efficiency and risk exposure, the model offers practical insights for manufacturers seeking to enhance the resilience and sustainability of their remanufacturing supply chains.

3 - Decision-Making for Circular Manufacturing and Economy

Marco Franchino, Cansu Kandemir

Manufacturing has historically prioritised cost, lead-times, and quality over sustainability. However, the increasing environmental impact of human activities necessitates integrating sustainability into decision-making. Transitioning from a linear economy—defined by the "take-make-dispose" model—to a circular economy offers a viable solution, emphasising durability, reuse, and recyclability to reduce waste and resource depletion. This study addresses the challenges of managing end-of-life (EoL) products by developing a decision-support calculator. The tool incorporates key performance indicators (KPIs) such as material value, disassembly costs, environmental impact, and market demand to evaluate EoL alternatives based on a trade study analysis approach. It considers economic, environmental, and social factors to guide decisions on landfill disposal, material recycling, and component reuse. Validated across various products and scenarios, the calculator facilitates sustainable practices by quantifying improvements and justifying decisions. Its broader application in research and industry highlights profitable, environmentally conscious solutions, fostering the adoption of circular economy principles. This contribution demonstrates the importance of structured methodologies in aligning sustainability goals with practical manufacturing operations, promoting the integration of circular economy practices across diverse sectors.

4 - Environmental Resources and its Cost-Efficient Utilization

Muktak Tripathi

The study aims to provide insights into the cost-efficient allocation of environmental resources and further promote firms' participation in promoting United Nations Sustainable Development Goals (SDG) goals. I examine marginal cost trade-offs of the environmental resources as the determinants of firms' cost-efficiency. I first measure environmental resource efficiency by using data envelopment analysis (DEA) to peer-benchmark firms' production function that maximizes the output of total revenues given inputs of environmental resources' total costs, including soil, water, flora, fauna, and human capital. On average, firms' environmental resource efficiency is sticky, given changes in demand, and improves through greater (lesser) utilization of soil, fauna, and human capital resources (water and flora). This finding provides insights into reducing total environmental resources costs by understanding marginal cost trade-offs, optimizing allocations, and improving utilization rates. In doing so, at a minimum, firms can invest in long-term procuring and cultivating cost-efficient environmental resources for future years. I also test for the implication of environmental resource efficiency on firms' decisions by examining their commitment to climate control actions. I find efficient firms are more likely to select and opt-in to conducting climate control actions, positively affecting commitment towards carbon neutrality and global warming targets.

■ WC-40

Wednesday, 12:30-14:00 - Room: Newlyn LG.02

Sports timetabling

Stream: Sports and Entertainment
Invited session
Chair: Dilek Gunnec

1 - Scheduling youth competitions

Dries Goossens

Nearly every sports competition requires a schedule that specifies who plays whom, when, and where. While professional sports scheduling has received significant academic attention due to its economic impact, youth sports competitions also present critical challenges from a societal perspective. Unlike professional leagues, which are relatively few in number, youth sports competitions often consist of hundreds of leagues, with clubs fielding multiple teams based on age, gender, and skill level. A key challenge arises from the shared infrastructure within clubs, where the number of available fields or courts imposes strict capacity constraints. Additionally, travel time is a crucial factor, not only for reducing CO_2 emissions and transportation costs but also because many sports enforce policies limiting travel time to be no longer than the duration of the match itself. This talk discusses the complexities of large-scale youth sports scheduling, elaborates on innovative solutions, and highlights how effective scheduling and tournament design can reduce venue capacity conflicts and travel time.

2 - Sports League Scheduling with Minitournaments

Johannes Schmidt, Armin Fügenschuh, Moritz Matthias Böschow

In sport scheduling for leagues with professional teams, game days with single matches are necessary to achieve fairness, which is a fundamental criterion. Thereby, the resulting high number of required game days is accepted and the length of a season not important. In amateur or youth sports leagues, these priorities change since the teams play all matches during their leisure time. A schedule with a smaller number of game days is preferred and the teams are willing to partly renounce on the fairness for this. Thus, the idea of minitournaments arised. In this format, multiple teams meet at one home team, which is one of them, and play against each other. The travel times of all teams now depend on their assignment to the respective minitourmanets and the choice of the home team. We consider in this talk a league with minitournaments of three teams at each game day and two games between each pair of teams. Additionally, the home field advantages should be divided as evenly as possible during the season to minimize the fairness loss. We present a combinatorial optimization model to compute an optimal league schedule under different objectives, prioritizing either travel distances or fairness aspects. Furthermore, we discuss the computational efficiency of the resulting models, symmetry breaking approaches, and compare them to existing schedules for amateur basketball leagues in the State of Brandenburg.

3 - Fair Schedules for Single Round Robin Tournaments with Ranked Participants

Sten Wessel, Cor Hurkens, Frits Spieksma

We consider schedules for single round-robin (SRR) tournaments on an even number of players, where each of the players plays every other player exactly once, either at home or away. We assume that the players are sorted on a predetermined ranking, where the first player is the strongest, and the last player is the weakest player of the competition. With only one match between any pair of opponents, one team will have the asymmetric advantage of playing home, which we consider as having positive effect on the match outcome for that player.

To prevent distortion of the outcome of an SRR tournament as well as to guarantee equal treatment of the participants, we argue that each participant should face its opponents when ranked by strength in an alternating fashion with respect to the home/away advantage. For example, we consider it unfair for a player to play many home matches against top-ranked opponents, or to play many home matches against low-ranked opponents. We refer to this as ranking fairness.

We provide an explicit construction proving that so-called single-break, ranking-fair schedules exist when the number of participants is a multiple of 4. Further, we give an integer programming formulation that outputs single-break ranking-fair schedules when they exist. Finally, we show that the circle method, the most popular method to come to a schedule for an SRR tournament, does not allow ranking-fair schedules when the number of teams exceeds 8.

4 - Round-Robin Tournament Scheduling Under Total Game Attractiveness Objective

Dilek Gunnec, Ugur Guler, Tankut Atan

Tournament competitiveness plays a critical role in shaping the associated economy, influencing match attendance, viewership, merchandise sales, and related factors. Among various measures that can help increase tournament competitiveness, scheduling offers a cost-effective way for this purpose. Designing a tournament schedule with competitiveness in mind can significantly enhance a tournament's appeal. In this study, we present a new metric, the competitive difference, to

measure this appeal and propose a mathematical model tailored for round-robin tournaments. While our numerical experiments involve single round-robin tournaments, the approach can be extended to multiple round-robin tournaments as well. Using simulated match outcomes, we evaluate the impact of the generated schedules on the Big Five leagues.

■ WC-42

Wednesday, 12:30-14:00 - Room: Newlyn GR.02

Product recovery and remanufacturing

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: Qin Zhou

1 - OEM's remanufacturing strategies under full and asymmetric information on used product collector's efficiency in a reverse supply chain
Arjun Kumar, Sri Vanamalla Venkataraman

Firms adopt various sustainable methods to minimize carbon emissions. Remanufacturing is one of the effective methods to reduce carbon emissions while providing reduced cost benefits to firms. It uses end-of-life or used products as raw materials and transforms them into like-new end products, thus reducing cost and emissions significantly. Firms collect used products either themselves or they contract independent third-party collectors (TPCs) for the same. In this study we consider an original equipment manufacturer (OEM) producing two types of remanufactured products - high-grade remanufactured product and low-grade remanufactured product. The OEM contracts TPC to acquire used products. There are two types of TPCs who collects used products of high and low-quality. TPCs differ based on the proportion of high-quality used products collected and their collection efficiency. We first design a contract mechanism when OEM has full information about TPC's collection efficiency. We also design a menu of contracts when the collection efficiency of TPC is his private information.

2 - Optimal Product Recovery Strategies Under Competition
Song Liu, Maud Van den Broeke, Tanja Mlinar, Stefan Creemers

Growing environmental concerns and stricter regulations drive Original Equipment Manufacturers (OEMs) to adopt product recovery strategies, such as remanufacturing and recycling. Meanwhile, OEMs are increasingly confronted with the competition of independent remanufacturers (IRs). This triggers decision makers to investigate their optimal product recovery strategy (remanufacturing, recycling, or a combination of the two), the optimal level of product returns, and the impact of OEM-IR competition on these decisions. For this purpose, we develop an analytical model with two profit-maximizing stakeholders: the OEM and an IR. Whereas the IR only competes through remanufacturing, the OEM manufactures new products and can recover used products through remanufacturing, recycling, or both. We further examine the consequences on the environmental and social welfare performance of the OEM's and IR's product recovery strategies. We derive the optimal product recovery strategy as well as the conditions for the IR to enter the market. We find that a hybrid strategy (simultaneously remanufacturing and recycling) can be optimal, and that a higher collection cost increases the likelihood of remanufacturing for both the OEM and IR. Furthermore, we find that competition boosts the overall collection rate of used products. Our research offers managers and policy makers a deeper understanding of how competition and different cost parameters impact product recovery strategies.

3 - Collection-Disassembly Problem with Multi-Level Product Structure in Reverse Supply Chain
Muhammad Khakim Habibi

In this work, we present two MILP models of collection-disassembly problem where a fleet of vehicles is deployed to collect End-of-Life (EOL) products from collection centers and transport them to a dedicated disassembly facility. The problem studied integrates two NP hard problems, Inventory Routing Problem and Dynamical Lot-Sizing Problem, within the context of reverse supply chain. For each model, a multi-level product structure is considered where each item of the product to be disassembled is interconnected and yields different quantities obtained from the disassembly process. The first model covers the periodic decisions involving the vehicle routes, the quantity of EOL products to collect from each collection center, the quantity of each item to disassemble, the inventory level of each component, and the quantity of backlog for each item. In the second model, a facility location-based formulation is developed to provide a better lower bound of the problem.

4 - Channel Strategies for New and Remanufactured Products: The Impact of Operating Costs
Qin Zhou, Sunil Tiwari, Fanzhuo Zeng

We analyse a dyadic supply chain where a manufacturer relies on a retailer to distribute new products, remanufactured products, or both, resulting in three distribution models. If the manufacturer bypasses the retailer, it incurs operating costs to establish a direct channel. The manufacturer can adopt one of three remanufacturing strategies: remanufacturing all used products, only some, or none at all. By comparing the firms' profits across these distribution models and remanufacturing strategies, we determine the manufacturer's optimal channel choice and its effects on the retailer. Our findings reveal that, in addition to selecting among the three remanufacturing strategies, the manufacturer may use remanufacturing as a competitive threat when managing the direct distribution of remanufactured products. While the manufacturer's decision to separate distribution channels is typically at the expense of the retailer, the retailer can still benefit from this arrangement, even after losing a revenue stream, potentially creating a Pareto improvement scenario for the retailer. Additionally, we show that compared to relying on the retailer for both new and remanufactured product distribution, it is always more advantageous for the manufacturer to manage the distribution of new products directly.

■ WC-43

Wednesday, 12:30-14:00 - Room: Newlyn GR.07

Deployment & Execution

Stream: Software for Optimization
Invited session
Chair: Frederik Proske

1 - GAMS Engine SaaS: A Cloud-Based Solution for Large-Scale Optimization Problems
Frederik Proske

GAMS Engine SaaS is a cloud-based service that allows users to run GAMS jobs on a scalable and flexible infrastructure, currently provided by Amazon Web Services (AWS). It was launched in early 2022 and has since attracted a variety of customers who benefit from its features, such as horizontal auto-scaling, instance sizing, zero maintenance, and simplified license handling. GAMS Engine SaaS is especially suitable for workloads that require large amounts of compute power and can be adapted to many different scenarios. In this presentation, we show a case study of a large international consultant agency that uses GAMS Engine SaaS to run Monte-Carlo simulations of a large energy system model in response to varying climate change scenarios. We describe how they leverage the GAMS Engine API to submit and monitor their jobs, how they select the appropriate instance type for each job, and how they can use custom non-GAMS code on Engine SaaS. We also discuss the challenges and benefits of using GAMS Engine SaaS for this type of application, and provide some insights into the future development of the service.

2 - Accelerating Optimization Workflows: FICO Xpress Workbench & Insight with Docker
Alexander Biele

Deploying optimization software often comes with challenges like software dependencies and compatibility issues. FICO Xpress Workbench and Insight Docker images now address these hurdles, enabling a seamless deployment across all platforms. This approach eliminates installation hassles, enhances the integrated user experience, and lets developers focus on optimization.

In this talk, we will demonstrate the ease of setup and minimal configuration required to achieve a unified development experience across Workbench and Insight using automated Docker-based workflows.

Additionally, we will showcase the end-to-end deployment of a Python-based optimization model, transforming it into a fully operational application with Xpress Insight. Beyond local debugging, we will highlight remote debugging capabilities, enabling developers to debug scenarios executed on a remote Xpress Insight server.

This presentation will provide practical insights into leveraging Docker for optimization workflows, making development and deployment more efficient.

3 - Balancing Energy and Performance: Efficient Allocation of Solver Jobs on High-Performance Computing Systems
Willi Leinen, Andreas Fink, Philipp Neumann

Many combinatorial optimization methods and related optimization software, particularly those for mixed-integer programming, exhibit limited scalability when utilizing parallel computing resources, whether across multiple cores or multiple nodes. Nevertheless, high-performance computing (HPC) systems continue to grow in size, with increasing core counts, memory capacity, and power consumption. Rather than dedicating all available resources to a single problem instance, HPC systems can be leveraged to solve multiple optimization instances concurrently – a common requirement in applications such as stochastic optimization, policy design for sequential decision making, parameter tuning, and optimization-as-a-service. In this work, we study strategies for efficiently allocating solver jobs across compute nodes, exploring how to schedule multiple optimization jobs across a given number of cores or nodes. Using metrics from performance monitoring and benchmarking tools as well as metered PDUs, we analyze trade-offs between energy consumption and runtime, providing insights into how to balance computational efficiency and sustainability in large-scale optimization workflows.

■ WC-44

Wednesday, 12:30-14:00 - Room: Newlyn 1.01

Improving data and methods for energy system investment

Stream: Energy Economics & Management
Invited session
Chair: Valentin Bertsch

1 - On the accurate determination of wind velocity at a point location using converging beam triple LIDAR
Anthony Brooms, Theodore Holtom

The accurate determination of wind velocity is important for assessing the suitability of sites for hosting wind farms, and for managing the operation of wind turbines in real time, in order to maximize potential energy yield, as well as the life-span and fidelity of associated infrastructure. Current industry practice relies on wind measurement systems based upon a diverging beam approach, or conical scan, which combines samples from a large circle surrounding the target measurement point, thereby essentially averaging the measurement over a large sampling region. However, with a diverging beam approach, not only is the determination of the actual velocity potentially very inaccurate, but gauging the uncertainty associated with that determination is challenging.

An alternative is to use converging beam triple LIDAR: line-of-sight measurements from three different directions, converging at the point of interest are recorded. Under the converging beam approach, not only is the velocity determination more accurate, but it is also possible to meaningfully perform an uncertainty propagation analysis for it. In this presentation, we review some results pertaining to that uncertainty analysis, and argue that configurations that minimize uncertainty are ones that maximize the volume of an associated parallelepiped of unit edge length.

2 - Battery Storage Planning Under Uncertainty
Mohammad Fattahi

The transition to renewable energy is increasing the share of renewable energy sources (RES) in power grids. However, their variability and intermittency create challenges such as load shedding and system congestion. This study examines how battery storage systems (BSS) can address these issues by balancing electricity supply and demand. A two-stage stochastic optimization model is used to determine the optimal location, size, and type of batteries, with the second stage focusing on hourly operational decisions over a year. Unlike previous studies, this research incorporates both the technical and economic characteristics of battery technologies. The New York State (NYS) power system, currently transitioning to higher renewable energy integration, serves as the case study. Using historical load and weather data from 1980 to 2019, the study accounts for uncertainties in load and RES generation through a sample average approximation approach. Results indicate that BSS can reduce renewable curtailment by 34% and load shedding by 21%, enhancing grid resilience and supporting NYS's 2030 energy targets. Additionally, the cost of expanding BSS capacity does not increase linearly, highlighting a complex relationship between costs and renewable penetration. This research provides valuable insights for the strategic deployment of BSS to create a cost-effective and reliable power grid while assessing the feasibility of NYS's 2030 energy goals.

3 - A High-Resolution Downscaling Approach for Solar Irradiance Using Statistical Parameter Matching
Olalekan Omoyele, Maximilian Hoffmann, Jann Weinand, Miguel Larrañeta, Jochen Linßen

The limited intra-hour variability of globally available hourly renewable energy system data leads to inaccuracies in the modeling of renewable energy systems. This work, therefore, presents a methodology to increase the temporal resolution of the global horizontal irradiance from one hour to one minute using non-dimensional irradiance and parameters matching for arbitrary locations. The methodology is validated using statistical methods and energy system modeling in self-sufficient buildings. The hourly annual normalized root mean square error and Kolmogorov-Smirnov Integral range from 6 - 12% and 0.1 - 0.84, respectively, for different locations consisting of varying weather conditions. The energy system optimization results of the synthetic data demonstrate superiority in terms of cost and feasibility relative to the average hourly resolution data. The use of synthetic minute resolution data has been shown to significantly improve the design accuracy of dynamic components such as inverters (where underestimation in capacity is up to 58%) and storage systems. The developed methodology facilitates more reliable energy system modeling.

4 - Agent-based building stock modeling incorporating behavioural economics applied to heat grid planning
Thilo Glißmann, Helen Ganal, Sarah Becker, Sascha Holzhauer

The evolution of the building stock is crucial for energy infrastructure planning, particularly concerning heat grids, which are essential to efficient, climate-neutral heat supply. However, the diversity of building types, uncertainties regarding current refurbishment status and heating system, and owner-specific motivations make reliable forecasting challenging. We introduce AgentHomeID, an agent-based model of the German building stock, wherein building owner agents make all energy-related decisions. Refurbishment considerations are triggered

by regulatory, technical, and personal factors. Options include measures for the building envelope and heating system, influenced by regulation, technical constraints, and infrastructure. Decisions rely on evaluations of costs, subsidies, energy performance, emissions, and measure type. The agents are categorised into private owners, whose choices reflect empirically derived heterogeneous willingness-to-pay, and institutional owners, who evaluate options based on net present value, utilising owner-subclass dependent discount factors and revenue streams. AgentHomeID is applied within the context of district heating planning. By simulating owner decisions on adopting district heating, we estimate the share of connected buildings as a measure of grid profitability. We identify poorly insulated buildings that pose challenges to reducing grid supply temperatures which facilitate the integration of renewable energy sources into the grid.

■ WC-46

Wednesday, 12:30-14:00 - Room: Newlyn 1.07

Optimal operation planning in energy systems

Stream: Energy Economics & Management
Invited session
Chair: *Roby Cremers*

1 - Worksites scheduling for Distribution System Operator
Simon Bayle, Jean Jodeau, Pierre Mordant, Saoussen Abidi, Tristan Basler, Germain Francois, Nicolas Blandamour, Lucas Selini, Olav Lafourcade, Paul Javal

Efficient scheduling of planned works within electricity distribution networks is crucial for maximizing efficiency while ensuring that all safety and operational constraints are met. This work introduces a model for scheduling network works over a multiple year time horizon, aiming to optimize the number of projects that can be undertaken while maintaining rigorous adherence to safety standards and operational requirements. The worksite planning process faces several challenges. First, the scale is large, as the objective is to ensure the feasibility of every worksite through their entire durations. We provide a fast electrical constraint analysis tool to speed up the solving process. Second, uncertainties are high: network conditions and forecasts evolve, requiring stochastic optimization. Lastly, with an increasing number of worksites, concurrent worksites are more common and can be used to the DSO' advantage. The proposed model introduces preprocessing and local search techniques to minimize the computational burden. The model and its design will be presented, before introducing numerical experiments on real data. A comparison to a historical rule-based approach will also be conducted on a French DSO's data. Finally, the opportunity of using proxies in our framework, as machine-learning-based proxy-load flow, aiming at a global solving speed-up will be discussed.

2 - Maintenance Planning for Offshore Wind Farms Under Limited Manpower and Time-Varying Costs
Roby Cremers, Rommert Dekker

With wind energy taking up a bigger share of the worldwide electricity production each year and a transition to full sustainability targeted by 2050, effective maintenance planning is essential to minimize costs and downtime. Preventive maintenance is scheduled to reduce the risk of costly corrective maintenance, but unexpected failures and workforce limitations require adjustments to planned schedules. This study addresses the challenge of scheduling multi-component maintenance for wind turbines while accounting for seasonal cost fluctuations and limited personnel availability. When the number of planned maintenance activities exceeds available manpower, one approach is to delay certain planned preventive maintenance tasks to a later period, prioritizing components where postponement has the least expected cost impact. Another strategy is to bring maintenance forward, performing tasks earlier when future workforce shortages are expected. We present heuristic-based strategies that strategically delay or advance maintenance tasks when planned activities exceed workforce. A simulation-based evaluation on a set of 80 identical components highlights how different heuristics perform under varying levels of seasonal cost fluctuations and workforce constraints. Our results show that these heuristics generally outperform naïve scheduling approaches and provide insights into which strategies are most effective under different conditions.

3 - A Novel Optimization-Based Approach for the Integrated Operation of Hydrogen and Transportation Systems
Ali Noutash, Gregorio Muñoz-Delgado, Javier Contreras

The growing adoption of renewable energy sources (RESs) and zero-emission vehicles, such as hydrogen fuel cell vehicles (FCVs), emphasizes the coupling of the transportation system (TS) and the hydrogen system (HS), which, in turn, are also linked to the power system. Due to cost efficiency, hydrogen is primarily distributed by tube trailers, which are thus affected by traffic congestion and route selection. In this work, we propose a novel sequential approach to model the integrated operation of the HS and TS. First, a dynamic traffic assignment (DTA) model is introduced for the TS. This model captures the spatio-temporal dynamics of FCV and gasoline vehicle flows on roads and incorporates paths with diverse physical features, such as speed limits, lane configurations, blockages, and traffic lights, yielding results that better reflect real-world conditions. Subsequently, a traffic analyzer algorithm determines waiting times on the TS roads by analyzing vehicle inflows and outflows derived from the DTA model results. Next, the data obtained from the traffic analyzer are used by a time-variant Floyd algorithm to find the shortest path based on distance and congestion. Finally, a mixed-integer linear programming model is proposed to schedule the HS, minimizing RES energy spillage and optimizing tube trailer trajectories. The performance of the proposed approach is illustrated with a case study based on the city of Sioux Falls, USA.

4 - Data-driven robust optimization for offshore rig scheduling under uncertainty
Silvio Hamacher, Luana Mesquita Carrilho, Fabrício Oliveira

Rig scheduling is a critical oil and gas industry activity involving substantial resource acquisition and operations investments. The process is complex due to well sequencing, technical and precedence constraints, and long planning horizons. Offshore drilling relies on expensive rigs, with daily rates reaching hundreds of thousands of dollars, and is subject to unpredictable geological conditions, economic fluctuations, and operational challenges that impact optimal scheduling outcomes. This paper addresses an offshore rig scheduling problem with uncertain processing times. We propose a robust optimization model that minimizes the worst-case total completion time, representing uncertainty through an ellipsoidal uncertainty set. Our approach generates schedules that are more resilient to processing time variations. Computational experiments using real-world instances evaluate the impact of different levels of protection against uncertainty. Results show that while higher protection levels produce less conservative and more stable schedules under disruptions, lower protection levels offer greater flexibility for adjustments. In all cases, robust solutions outperform nominal schedules that disregard uncertainty.

■ WC-47

Wednesday, 12:30-14:00 - Room: Parkinson B08

Game Theory in Retail I

Stream: Retail Operations
Invited session
Chair: *Winfried Steiner*

1 - Regulating the manipulation in online reviews
Xiaopei Zhao

Problem definition: The presence of information asymmetry leads consumers to rely on product reviews for their purchasing decisions, which gives the low type seller the incentive to manipulate the review ecosystem, particularly by purchasing fake positive reviews, which influences consumer perceptions. Considering the manipulation by the seller, savvy consumers question the authenticity of reviews, and platforms may implement algorithms to detect manipulation. In response, the low type seller may adopt more sophisticated strategies to evade platform detection and consumer suspicion. Methodology/results: This study examines the interaction between the seller, consumers, and platform using a three-stage game model. The seller possesses private information regarding product quality, and this asymmetry influences the decision to manipulate reviews. We analyze how platform regulation impacts consumer behavior, seller strategies, and social welfare. Our findings shows that an increase in the platform's regulatory does not necessarily lead to an improvement in consumer surplus and social welfare. Managerial implications: Our model clarifies the underlying reasons for a platform's adoption of various regulatory policies, while excluding the influence of objective factors, such as regulatory costs.

2 - The Role of Regulation in Sustainable Luxury: Theory and Experiments on Donations and Exclusivity
Burak Gokgur, Ayse Kocabiyikoglu, Ismail Erzurumlu

Luxury brands face increasing pressure to adopt sustainable practices while preserving exclusivity. Traditional methods like product incineration maintain scarcity but conflict with sustainability, whereas donations introduce luxury goods into the market, potentially diluting exclusivity. This raises a key question: Can luxury brands engage in product donations as a viable alternative to incineration?

We examine the strategic role of regulatory agencies in designing donation-based incentive mechanisms that promote sustainability while maintaining luxury firms' profitability. Through behavioral experiments, we reveal consumer preferences regarding donations. Building on these insights, we develop a rational expectations model capturing interactions among a luxury firm, a regulator, and a mixed consumer market. In a Stackelberg framework, the regulator sets incentives, and the firm decides on product donations. We further explore how market-specific factors influence optimal incentive levels, emphasizing the necessity of transparent communication between regulators and firms to avoid unintended consequences. Finally, we conduct additional behavioral experiments to examine whether the strategic interactions between the firm and regulator observed in practice align with the analytical outcomes. These insights offer valuable guidance for both luxury brand managers and policymakers in balancing exclusivity, sustainability, and regulatory objectives.

3 - The Right to Repair: On the Impact of Mandated Reparability
Junxia He, Benny Mantin

RTR regulations aim to extend products' lifespans by facilitating independent repairs and preventing consumers from discarding products that still hold value to mitigate environmental impacts. In this regard, product reparability plays a crucial role. To explore the mandatory reparability and its impacts on the profit, consumer surplus and waste, we develop a two-period game-theoretic model and solve the manufacturer's pricing optimization problem. Our results suggest that in the absence of mandatory reparability, manufacturers provide repairs only when their repair cost is below a certain threshold. Mandating reparability might raise this cost threshold, thereby expanding the range of repair offerings. Besides, high reparability enables self-repairs, which in turn results with the manufacturer lowering the product and repairs prices. Numerical experiments indicate that only when the level of reparability is set above a certain level can consumer surplus and waste situation get improved; otherwise, the regulation may potentially lead to an outcome that consumer surplus and waste remain unchanged, while the manufacturer's profit shrinks. In the end, the optimal reparability level depends on the welfare priorities assigned to different agents. An extremely high level of reparability is always the optimal solution to maximize the benefits of both consumers and environment, though this comes at the cost of a significant decline in the manufacturer's profit.

■ WC-48

Wednesday, 12:30-14:00 - Room: Parkinson B09

Bridging explainable decision-making and mathematical optimization II

Stream: Transparent and Fair Decision Making with Mathematical Optimization
Invited session
Chair: *Dolores Romero Morales*
Chair: *Vanesa Guerrero*

1 - Benchmarking with Constrained Parametric and Non-Parametric Models
Thomas Halskov, Peter Bogetoft, Dolores Romero Morales

Classical benchmarking methods, such as Data Envelopment Analysis (DEA), typically allow unrestricted weights on features (inputs and outputs). This often results in low discriminatory power and unrealistic evaluations. We propose a benchmarking framework that integrates explicit weight constraints into both DEA and regression-based models. These constraints can be applied at both the group level—e.g., ensuring that a minimum or maximum percentage of weights is allocated to specific categories of features—or at the individual feature level. By enhancing interpretability and transparency, weight restrictions help stakeholders better understand and trust the evaluation process. We demonstrate this approach using a dataset from Danish municipalities.

2 - Sparse soft classification trees: model variants and improved decomposition algorithm with pruning
Edoardo Amaldi, Antonio Consolo, Filippo Gandini

Classification trees are widely used Machine Learning models due to their interpretability and good accuracy. In the last decade there has been increasing interest in globally optimized trees, where all tree parameters are optimized simultaneously. Blanquero et al. (2021) introduced a nonlinear optimization formulation for training Soft Classification Trees (SCTs) with soft splits at branch nodes. Amaldi et al. (2023) presented a first node-based decomposition algorithm for training them. In this work, we propose and compare two SCT variants where every input vector falls into a single leaf node and the corresponding prediction is the class label associated to it. They satisfy the conditional computation property and are suitable for decomposition. Since training such SCTs is computationally challenging, we investigate a decomposition algorithm with different working set selection strategies, including an ad hoc data points rerouting heuristic at branch nodes. To obtain sparse and compact trees and to reduce overfitting, we combine it with a pruning step and concave approximate ell_0-norm regularization. The performance of the decomposition algorithm with different working set selection strategies is assessed on 15 well-known datasets. The impact of sparsity and pruning is evaluated in terms of tree size and testing accuracy.

3 - Shape-constrained additive regression models for surrogate MINLO problems
Marina Cuesta, Claudia D'Ambrosio, Maria Durban, Vanesa Guerrero, Renan Spencer Trindade

This work integrates mathematical optimization and statistics paradigms to advance towards the solution of complex Mixed Integer Non-Linear Optimization (MINLO) models. With a data-driven approach, our methodology proposes to build a surrogate MINLO that approximates the original one and that is more computationally tractable. Our approach uses shape-constrained smooth additive regression models based on B-splines to approximate complex functions in MINLO problems accurately. The so-obtained functions are sums

of piecewise univariate polynomials that require a non-trivial reformulation in the context of mathematical optimization to construct the surrogate MINLO. The suitability of the resulting approximation for identifying the global optimum of the original MINLO is assessed through the SC-MINLP algorithm, which exploits the separability of the surrogate formulation, as well as commercial solvers like Gurobi and Baron. Furthermore, if available, expert knowledge can be incorporated into the surrogate MINLO by imposing shape constraints like sign, monotonicity, or curvature on the approximations performed. Hence, theoretical properties of the original MINLO solution, such as upper and lower bounds, can be derived from the surrogate one. This capability makes the proposed methodology both knowledge-driven and data-driven. Promising results have been achieved in real case studies.

4 - Incorporating Prior Knowledge into Cluster Analysis: An Explainable Approach
Farnaz Farzadnia, Dolores Romero Morales

Clustering is widely used in data analysis, yet initial clusters may become obsolete as new insights emerge. A key challenge is updating clusters while maintaining consistency with prior knowledge and ensuring interpretability. This issue arises in applications like urban planning, where the Level of Traffic Stress (LTS) metric has evolved to incorporate new factors such as vehicle traffic volume. Similar challenges occur in other domains, requiring adjustments to reflect newly available information.

We propose an optimization framework that updates clusters while preserving stability and interpretability. Our model minimizes unnecessary deviations from initial clusters while allowing justified reassignments. We achieve this by formulating an optimization problem that balances intra-cluster similarity, assignment penalties, and rule-based explanations to ensure meaningful updates. By penalizing overly general rules and prioritizing informative justifications, our method enhances transparency in cluster analysis.

Experiments on benchmark datasets demonstrate that our approach produces high-quality reclustering solutions with meaningful explanations. By systematically refining clusters while preserving structure, our framework supports reliable decision-making in applications where understanding cluster changes is essential.

■ WC-49

Wednesday, 12:30-14:00 - Room: Parkinson B10

Aspects of Conic Optimization

Stream: Conic and polynomial optimization
Invited session
Chair: *Frank de Meijer*

1 - Lagrangian Duality for Mixed-Integer Semidefinite Programming and its Applications
Frank de Meijer, Renata Sotirov

Mixed-integer semidefinite programming is the extension of semidefinite programming where some or all of the variables are required to be integer. The combination of positive semidefiniteness and integrality allows to formulate many optimization problems as mixed-integer semidefinite programs (MISDPs). In this talk we consider the Lagrangian duality theory for MISDPs and show how integer Lagrangian dual bounds can be constructed. In particular, we present a hierarchy of Lagrangian dual bounds by exploiting the theory of integer positive semidefinite matrices and propose three algorithms for computing those bounds. We apply our approach to the max-k-cut problem and the box-constrained non-convex quadratic program, which demonstrate that the new bounds are substantially stronger than the semidefinite programming bound obtained by relaxing integrality.

2 - Mixed-Integer Semidefinite Programming: Alternative cutting planes and a new primal heuristic
Jan Kronqvist, Johanna Skåntorp

Here we focus on Mixed-Integer Semidefinite Programming (MISDP), and specifically solving MISDP by outer approximation techniques. We present an alternative interpretation of some known types of cutting planes, and some new techniques to derive cuts with more desirable properties. We also present a new primal heuristic that also builds on an outer approximation concept that can both find feasible solutions and produce cutting planes for the main algorithm.

3 - Convex Formulations For Training Two-Layer ReLU Neural Networks
Karthik Prakhya, Tolga Birdal, Alp Yurtsever

Solving non-convex, NP-hard optimization problems is crucial for training machine learning models, including neural networks. However, non-convexity often leads to black-box machine learning models with unclear inner workings. While convex formulations have been used for verifying neural network robustness, their application to training neural networks remains less explored. In response to this challenge, we reformulate the problem of training infinite-width two-layer ReLU networks as a convex completely positive program in a finite-dimensional (lifted) space. Despite the convexity, solving this problem remains NP-hard due to the complete positivity constraint. To overcome this challenge, we introduce a semidefinite relaxation that can be solved in polynomial time. We then experimentally evaluate the tightness of this relaxation, demonstrating its competitive performance in test accuracy across a range of classification tasks.

4 - A space-decoupling framework for optimization on bounded-rank matrices with orthogonally invariant constraints
Bin Gao

Imposing additional constraints on low-rank optimization has garnered growing interest. However, the geometry of coupled constraints hampers the well-developed low-rank structure and makes the problem nonsmooth and intricate. To this end, we propose a space-decoupling framework for optimization on bounded-rank matrices with orthogonally invariant constraints. The "space-decoupling" is reflected in several ways. We show that the tangent cone of coupled constraints is the intersection of tangent cones of each constraint. Moreover, we decouple the intertwined bounded-rank and orthogonally invariant constraints into two spaces, leading to optimization on a smooth manifold. Implementing Riemannian algorithms on this manifold is painless as long as the geometry of additional constraints is known. In addition, we unveil the equivalence between the original problem and the reformulated problem. Numerical experiments on real-world applications—spherical data fitting, graph similarity measuring, model reduction of Markov processes, reinforcement learning, low-rank SDP, and deep learning—validate the superiority of the proposed framework.

■ WC-50

Wednesday, 12:30-14:00 - Room: Parkinson B11

Systems Thinking 5

Stream: Systems Thinking
Invited session
Chair: *Matt LLoyd*

1 - Exploring self-organization and self-adaption for smart manufacturing complex networks
Zhengang Guo, Yingfeng Zhang, Sichao Liu, Xi Wang, Lihui Wang

Trends toward the globalization of the manufacturing industry and the increasing demands for small-batch, short-cycle, and highly customized products result in complexities and fluctuations in both external and internal manufacturing environments. The Industrial Internet of Things (IIoT) and the widespread use of embedded processors and sensors in factories enable collecting real-time manufacturing status data and building cyber-physical systems for smart, flexible, and resilient manufacturing systems. In this context, this paper investigates the mechanisms and methodology of self-organization and self-adaption to tackle exceptions and disturbances in discrete manufacturing processes. Specifically, a general model of smart manufacturing complex networks is constructed using scale-free networks to interconnect heterogeneous manufacturing resources represented by network vertices at multiple levels. Subsequently, analytical target cascading is used to formulate the processes of self-organizing optimal configuration and self-adaptive collaborative control for multilevel key manufacturing resources while particle swarm optimization is used to solve local problems on network vertices. An industrial case based on a Chinese engine factory demonstrates the feasibility and efficiency of the proposed model and method in handling typical exceptions, reducing manufacturing cost, manufacturing time, waiting time, and energy consumption, with reasonable computational time.

2 - OR for Systemic Change: Improving outcomes with the Public Sector Scorecard
Max Moullin

This paper discusses how OR practitioners can increase their impact and ensure clients implement their recommendations by adopting the 'eight essentials for systemic change'.

In addition to using systems approaches, the eight essentials include focussing on outcomes, engaging all stakeholders, incorporating behavioural insights, aligning strategy processes and performance metrics, and ensuring a culture of improvement, innovation and learning rather than a top-down blame culture.

The paper will then describe how these eight essentials are addressed in the Public Sector Scorecard, an outcome-focussed problem structuring framework for systemic change used in six continents. The Public Sector Scorecard has three phases: strategy mapping, service improvement, and performance measurement. It can be used alone or alongside other OR approaches such as simulation.

This paper will be of interest to academics as well as practitioners and includes a wide variety of case studies and examples.

3 - Active Withernsea to East Yorkshire Place Partner: From a hyper local Placed-Based approach to a Systemic-Place-Based approach
El Wilkinson-Cunningham

Active Withernsea (AW) is an innovative pilot program run by East Riding of Yorkshire Council (ERYC) and funded by Sport England, aiming to increase physical-activity levels in the small seaside town of Withernsea, East Yorkshire, UK. Since 2019, a community development team has supported residents to become more physically active in the short term, while simultaneously working for wider system changes in order to create a more enabling environment for physical activity in the longer term. As Sport England's deepening and expansion plan rolls out the focus for the program is in a unique place where it will move from a hyper local place based approach focusing on just one town to working across East Yorkshire as a whole, with three focus areas. This paper will explore how the learning from Active Withernsea will form the plan for the East Yorkshire Place Partner and the development of a Systemic framework to tackle physical inactivity and reduce inequalities to physical activity and also bring a systemic approach to a local authority.

4 - An Alternative History of Systems Thinking - a Call for Re-synthesis of the Subject
Roger James

Newton's famous dictum "If I have seen further, it is by standing on the shoulders of Giants" reflects progress in science and a delicate balancing act. Nature determines our thinking styles but nurture and experience shapes us. Is Systems Thinking universal and enduring, or just a reflection of the techniques popular at the times? Are the Giant's shoulders shifting?

To understand Systems Thinking as a set of principles, rather than a collection of techniques is simpler, more interesting and a platform for innovation. My 'alternative history' introduces these principles via the metaphor of a bushfire: some aspects of Systems Thinking have advanced significantly from their origin, other aspects have developed little. Between these 'hot fronts' there is scorched earth contested by dichotomies. In his essay The Culpabliss Error Stafford Beer distinguished between the underlying goal of better understanding and the noise (or complication) from techniques.

My 'alternative history' illuminates the growth of underlying complexity and highlights the confusing overlay of the fashions of technique. For students of Systems Thinking it is a recognition of fundamental principles as a route to study the mountain of books and papers. For the academic it is a plea to explore a needed re-synthesis of the subject. For the practitioner it is to appreciate individual styles and the enduring power of some old ideas together with opportunities for novelty.

■ WC-54

Wednesday, 12:30-14:00 - Room: Liberty 1.08

Stochastic models in Supply Chain Management

Stream: Stochastic modelling
Invited session
Chair: Nicola Comincioli

1 - Collaborative Shipment Consolidation for Perishable Supply Chains: A Stochastic Multi-Echelon Optimization Model
Gizem Celik, Bulent Cekic, Hande Cansın Kazanc, Mehmet Soysal

This study aims to improve logistics efficiency in the perishable product supply chain by incorporating shipment consolidation strategies to enhance collaboration among suppliers, logistics providers, and retailers while reducing food waste.A cooperative vehicle-sharing consolidation model is introduced to address transportation capacity utilization issues.This model promotes supplier cooperation to optimize capacity use and minimize expenses.It covers supplier-to-vehicle assignments, transportation to transshipment centers, and distribution to warehouses via predefined routes.Additionally, warehouse inventory levels are managed to control holding costs, considering perishability to reduce waste.A multi-period, multi-echelon network design model is developed, integrating distance-based assignment costs, truck load-dependent distribution costs, inventory, waste management, and service level constraints under supply and demand uncertainty.The model is formulated as a Chance-Constrained Stochastic Mixed Integer Linear Programming approach, using scenario-based analysis to address supply uncertainties.The feasibility of shipment consolidation is evaluated under uncertainty to optimize transportation and inventory.A case study on fresh tomato distribution in Turkey examines the impact of perishability and uncertainty on costs and waste.Practical solutions are proposed to enhance transportation efficiency in supplier-dense regions through consolidation.

2 - Network Flexibility Design Under Endogenous Supply and Demand Uncertainty
Soroush Fatemi-Anaraki, Martin Grunow, Stefan Weltge

In real-world supply networks, capacity and demand are subject to uncertainty. An effective hedging mechanism is to enable plants to produce multiple products, making them flexible. While adding flexibility can compensate for uncertainty, assigning fewer products to a plant allows for the use of specialized equipment and workforce, leading to higher efficiency due to the specialization effect. Motivated by this, we study supply networks in which capacity depends on the flexibility

design, i.e., it is an endogenous random variable, whereas demand is induced by the market and independent of the flexibility design.

For general endogenous capacity uncertainty, it is unclear whether adding any flexibility to a dedicated (inflexible) design improves the expected sales. We study conditions under which having flexibility beyond the dedicated design is sensible. Additionally, we examine the performance of the long-chain—a connected design wherein each plant (product) is incident to two products (plants)—in the presence of the specialization effect. To this end, we develop analytical results and model the problem as a two-stage stochastic program to perform numerical experiments on the impact of the specialization effect on the expected sales.

3 - Brownian price and green firms: An ETS price floor for a clean transition?
Nicola Comincioli, Simone Borghesi, Jacco Thijssen, Peter Kort, Sergio Vergalli

We examine the optimal behavior of carbon-emitting companies operating under the European Union Emission Trading System (EU ETS), under which firms are obliged to purchase emission permits on the secondary market if their emissions exceed their allowance. Specifically, we consider the scenario where firms are endowed with the (real) option to undertake a "green" investment to cut their emissions and, thus, permit expenditures. The central challenge is the determination of the optimal time for investment within a stochastic framework characterized by uncertainty in EU ETS permit prices. We address the problem for a heterogeneous group of companies with diverse technological capabilities across industrial sectors. Furthermore, we incorporate a price floor for permit prices to mirror policy efforts aimed at promoting green transition by elevating emission costs. We solve this problem analytically and through numerical simulations calibrated to real market data. In addition to offering insights into individual firm behavior, our findings can support regulators in refining environmental policies, particularly regarding the role of permits price floor and its potential to expedite the green transition.

■ WC-55

Wednesday, 12:30-14:00 - Room: Liberty 1.09

Strategic Facility Location and Inventory Prepositioning

Stream: Humanitarian Operations
Invited session
Chair: Alican Yilmaz

1 - Strategic Positioning of Temporary Emergency Medical Facilities: A Decision Support System for Earthquake Preparedness
Simona Cohen Kadosh, Sagit Kedem-Yemini, Yuval Bitan, Zilla Sinuany-Stern

This work introduces a Decision Support System (DSS) for optimal placement of Emergency Treatment Sites (ETSs) following earthquakes. ETSs are temporary medical facilities that treat minor injuries—the majority of casualties—reducing hospital overcrowding. Unlike traditional fixed-site planning, our approach adapts to specific disaster conditions. The DSS integrates three key components: a GIS-based spatial database analyzing earthquake damage and population distribution; a simulation-based decision engine evaluating potential locations based on accessibility and population proximity; and a user-friendly interface for emergency planners to quickly implement recommendations. Our DSS integrates a location network characterization with a hybrid simulation/optimization model to determine the number and optimal locations of ETSs. It is designed as a standalone tool that functions without internet connectivity (often disrupted during disasters). The DSS supports both advance planning and real-time emergency response. Though still under development, the system builds on earlier research testing various site selection methodologies. It offers emergency managers a structured yet flexible framework for ETS placement decisions. Ongoing work focuses on system refinement, field testing with actual data, and incorporating additional dynamic variables to enhance earthquake response capabilities using operations research principles.

2 - Relief supply prepositioning strategies via option contract reserve fleet vehicles
Ziyou Wu

In preparing for disasters, relief supplies can be prepositioned as tangible forms in warehouses or as intangible forms, such as production capacity. However, prepositioning relief supplies in the absence of sufficient vehicles may delay delivery time and reduce relief operation performance. Given that the budget pressure prevents the local authorities for disaster relief from keeping a large fleet in stock, they choose reserve fleet vehicles via option contract as an alternative. We propose a model to coordinate prepositioned tangible and intangible relief supplies considering fleet vehicles reserve via option contract. The objective function includes deprivation cost, which considers relief beneficiary suffering. We first obtained the optimal quantities of prepositioned tangible and intangible supplies, and then fleet vehicles. Furthermore, we propose benchmark prepositioning relief supply models without reserving fleet vehicles to compare performances among them. We proved that reserving fleet vehicles is effective in reducing operation costs, alleviating relief beneficiary suffering and improving supplier profit. The applicability of the proposed model is examined through numerical examples.

3 - Inventory prepositioning as a resilience strategy under disruption
Alican Yilmaz, Ozlem Ergun

The resilience of supply chain networks has become increasingly critical due to rising disruptions from natural disasters, trade conflicts, and terrorist activities. The severity of these disruptions highlights the need for effective resilience measures. In this study, we propose a tri-level defender-attacker-defender (DAD) model to enhance supply chain resilience through inventory prepositioning.

The DAD problem is known for its high computational complexity, with exact algorithms in the literature often facing significant scalability challenges as problem sizes increase. To mitigate this issue, we adopt a network science based approach to identify candidate critical components, thereby reducing problem size and computational overhead. Specifically, we introduce a novel node criticality measure based on betweenness centrality to identify high-impact disruption targets. This measure is evaluated across various supply chain network configurations to assess its effectiveness. Next, we integrate this criticality information into the Column-and-Constraint Generation (C&CG) framework, reducing the number of iterations required for global optimality and thereby improving the runtime performance. Finally, we validate the proposed measure through a case study on the Alaska fuel supply chain network, offering insights into its effectiveness and identifying scenarios where it may be less effective.

4 - Efficient and equitable transportation of casualties by Online Optimization in mass casualty incidents
Fatemeh Zare Bidaki, Davood Shiri, Sibel Salman

Mass casualty incidents (MCI) trigger a devastating impact on society and overwhelm emergency response systems. Following an MCI, a large number of victims suffer injuries of varying severity, each requiring urgent medical attention. Efficient and well-prioritized logistical operations are crucial to ensuring timely rescue and resource allocation and minimizing the immediate and long-term effects of MCIs. In this study, we propose an online optimization framework to address the heterogeneous ambulance routing problem (ARP) in urban areas affected by MCIs. Our Mixed-Integer Linear Programming (MILP) model incorpo rate multiple triage levels and accounts for uncertainties related to the number of recovered victims from debris, as well as potential changes in their survival status during post-disaster scenarios with the objective of maximizing the expected number of survivors. Recognizing these uncertainties, our proposed online opti mization algorithm adjusts rescue operations in real-time based on incrementally

learned incoming data. We assess the effectiveness of our online solutions by comparing them with offline model results derived from assuming perfect information. We also investigate several fairness approaches in our framework to promote healthcare equity. Ultimately, we validate our proposed approaches through computational experiments over real-world datasets.

■ WC-56

Wednesday, 12:30-14:00 - Room: Liberty 1.11

Logistics

Stream: Vehicle Routing and Logistics
Invited session
Chair: Rudolf Vetschera

1 - An efficient two stage stochastic optimization model for a joint inventory and fulfillment problem in omnichannel logistics
Shahana Kappil

This paper addresses a joint inventory and fulfillment problem under stochastic demand for an omnichannel retailer. The retailer must determine initial inventory allocations across multiple fulfillment locations before demand realization and subsequently decide from where to fulfill customer orders from available inventory after demand is observed. The objective is to minimize total expected costs, including inventory holding costs, fulfillment costs, and penalty costs for unfulfilled demand. The problem is modeled as a two-stage stochastic optimization problem. To manage the computational challenges posed by the large number of scenarios, we employ a recently developed scenario reduction method based on a modified Wasserstein distance that takes into account the cost structure. Via extensive numerical experiments, we compare its performance to the Sample Average Approximation method(SAA) and a state of the art algorithm. The results indicate that the proposed scenario reduction method leads to significantly lower cost while the SAA has lower computational times and similar performance to the state of the art algorithm.

2 - Integrating Probabilistic ETA Forecasting to Enhance On-Time Delivery in Last-Mile Logistics
Marie-Christine Heller

Last-mile delivery remains one of the most cost-intensive and unpredictable stages in logistics, with growing pressures from increasing parcel volumes, stricter city regulations, and evolving consumer expectations. Traditional scheduling methods rely on static ETA calculations that fail to adapt to real-time disruptions, leading to frequent delivery delays and inefficiencies.

This study introduces a hybrid predictive modelling framework that shifts from deterministic to probabilistic ETA forecasting, enabling dynamic time-window adjustments to improve On-Time Delivery (OTD) reliability. Instead of a single ETA estimate, the model predicts ETA distributions using quantile regression (5%, 50%, 90%) to capture uncertainty.

The approach integrates: • Historical and real-time data (traffic, weather, driver performance) • Multi-task learning models, e.g. Gradient Boosting Machines (GBMs) and Long Short-Term Memory (LSTM) networks to optimize ETA predictions and confidence intervals • Cost functions that penalize deviations outside the probabilistic range • Benchmarking against static scheduling methods using Mean Absolute Error (MAE) and delivery adherence metrics

Predictive analytics enables a shift from reactive to proactive customer service. The proposed framework not only improves OTD reliability but also contributes to optimizing resource allocation and enhancing customer satisfaction.

3 - Does carrier collaboration really require combinatorial auctions?
Rudolf Vetschera, Dmitriy Knyazev

Most approaches to carrier collaboration in logistics use combinatorial auctions, in which bundles of requests are priced and traded as entities. Literature argues that combinatorial auctions must be used because positive or negative synergies between requests exist, leading to non-additive valuations of bundles. However, economic theory shows that subadditivity is a sufficient, but not a necessary condition for the existence of a Walrasian equilibrium in which goods are priced individually. Thus it is possible that an efficient allocation of requests could be achieved by pricing and trading requests individually. We perform a large scale computational study to test how often an efficient allocation can actually be achieved by individual pricing. In the study, we consider capacitated TSP problem where a set of additional requests is allocated to carriers who already have to serve a set of requests. We then test whether there exists a set of prices so that each carrier demands the requests the carrier should serve in the efficient allocation. Our results indicate that, depending on the geographical configuration of requests, this is frequently possible. Furthermore, pricing entire bundles does not always support the efficient allocation either. Contrary to expectations, we also find that proprieties such as the number of violations of subadditivity have only a relatively small influence on the possibility to support an efficient allocation of requests.

4 - Spatially-robust discretization for the graph-free multi-agent pathfinding problem
Seyoung Oh, Kyungsik Lee

The Multi-Agent Pathfinding (MAPF) problem involves finding collision-free paths for multiple agents navigating a predefined graph. In classical MAPF, agents move along edges in discrete time steps, assuming a fixed underlying graph structure. However, these assumptions fail to capture the actual movement dynamics of agents and the flexibility required in real-world applications, limiting the applicability of traditional solutions. In this talk, we introduce Graph-Free MAPF, where agents move in continuous space rather than on a given graph. To ensure collision-free coordination while maintaining computational efficiency, we propose a spatially robust discretization method that divides space into overlapping regions and schedules agent occupancy over time. Unlike traditional grid-based approaches, our method allows greater movement flexibility while maintaining safety guarantees. We formulate the problem as an integer optimization model and develop several solution approaches. The performance of the proposed approaches is evaluated across various scenarios and compared with existing methods.

■ WC-58

Wednesday, 12:30-14:00 - Room: Liberty 1.13

Team Orienteering Problems

Stream: Vehicle Routing and Logistics
Invited session
Chair: Siamak Khayyati

1 - Optimization of Tourist Trip Routes with the Clustered Team Orienteering Problem
Elçin Kayacı, Tusan Derya, Kumru Atalay

Tourist trip planning is an optimization problem that aims to maximize tourists' satisfaction by selecting points of interest (POIs) to visit and determining the most efficient routes within a limited time frame. In this process, POIs must be organized into specific clusters, and visit sequences as well as routes within each cluster need to be determined. In this context, the Clustered Team Orienteering Problem (CTOP) provides a strong framework for optimizing the routes of multiple tours. CTOP aims to determine the routes that yield the highest total reward

by selecting POIs with varying visit values while adhering to time constraints. The primary distinction of CTOP from the well-known Team Orienteering Problem in the literature is the requirement that POIs be structured into clusters and that routes must be designed accordingly. In CTOP, visiting all clusters is not mandatory; however, if a cluster is selected, all POIs within that cluster must be visited. This study introduces a novel mathematical model for CTOP and conducts comparative analyses against existing models. The proposed model is tested on widely used benchmark datasets and evaluated in terms of solution quality and computational efficiency. The results demonstrate that the proposed model provides faster, more effective, and more practical solutions compared to existing models.

2 - Optimizing Solar-Powered Vehicle Missions: A Routing Problem for Multi-Vehicle Mars Exploration
Wojciech Burzyński, Mariusz Kaleta

The success of the Ingenuity and Perseverance Mars vehicles demonstrates the feasibility of multi-vehicle extraterrestrial missions. We belive Future Mars exploration missions will involve increasingly larger cohorts of rovers, making task and route planning a critical component of mission design. In the talk, we introduce the Solar-Powered Rover Routing Problem (SPRRP), a specialized variant of the Team Orienteering Problem (TOP), where a fleet of Martian rovers must visit a subset of Points of Interest (PoIs) to conduct research, each offering a certain benefit. The goal is to optimize rover routes and PoI selection while adhering to resource constraints.

Rovers are electrically powered, equipped with batteries and solar panels. Both movement and research activities consume energy, but unlike Electric Vehicle Routing Problems (EVRP), SPRRP relies on solar panels for energy replenishment instead of charging stations. Solar charging occurs alongside other tasks but is influenced by weather and time of day.

We present a formal problem formulation, followed by results from Mixed Integer Linear Programming (MILP) solvers. Due to the problem's complexity, we propose a metaheuristic approach. However, solution encoding methods known for related problems are not directly appliable and must be adapted for the case of solar panels.

3 - Resolution of Vehicle Routing Problems with optional visits using Hexaly
Maxime Rougier

Vehicle routing problems aim to determine efficient routes for one or more vehicles to visit a set of locations. In classic cases, every point must be visited exactly once. However, in practice, several industrial applications require models where some locations are optional. The choice of points to visit adds a new layer of combinatorial decisions. This presentation focuses on two such problems: the Team Orienteering Problem (TOP) and the Prize-Collecting VRP (PCVRP). In the TOP, the goal is to maximize collected benefits while respecting distance constraints, whereas PCVRP seeks a balance between minimizing travel distance and uncollected benefits. We explore how to model and solve these problems using Hexaly, an optimization solver combining exact and heuristic methods. Hexaly adopts a compact set-oriented modeling formalism. For routing problems the decision variables manipulated by the solver are lists, they are handled as permutations on dynamic subsets of the points. Each vehicle's route is represented as a list. The solver provides built-in set-based operators to manage constraints and objectives. This approach allows for concise and scalable formulations, making it easy to incorporate additional constraints and objectives as needed. Hexaly's solutions, after 60 seconds of computation, are within 1% of the best known solutions on academic instances for those two problems. We will also show that the solver scales to industrial cases with more than 10,000 points.

4 - An Online Optimization Framework for the Robust Capacitated Team Orienteering Problem under Uncertainty
Siamak Khayyati, Masoud Shahmanzari, Jyotirmoy Dalal, Davood Shiri

The increasing frequency and severity of natural disasters create a need for fast and robust methods for managing disaster response under uncertainty. Robust optimization incorporates the possible ranges that each uncertain parameter has and plans for the worst-case scenario given some limits on how bad the worst-case scenario can be. In this context, we propose an extension of the Capacitated Team Orienteering Problem (CTOP), namely the Robust CTOP (RCTOP) by considering the uncertainties related to node prizes, node weights, node service time and arc travel times. Solving RCTOP using commercial solvers can be time-consuming. We devise a heuristic method for solving RCTOP based on a genetic algorithm, simulating the interconnected behaviour of the uncertain parameters and the chosen solution as a sequential game. As time passes during the operation, the uncertainties for the visited nodes and arcs are resolved and as a result, better plans that were not feasible at the start of the operation might become feasible. We give an online algorithm (ORCTOP) that can utilize these opportunities to improve the solution in real time. We assess the performance of our method by applying it to a dataset derived from real-world urban networks in disaster-affected cities from the Türkiye 2023 earthquake. Using this dataset, we show the effectiveness and speed of our heuristic algorithm and the ability of the online variant to correct the initial over-conservatism of the RCTOP.

■ WC-59

Wednesday, 12:30-14:00 - Room: Liberty 1.14

Urban Mobility I

Stream: Transportation
Invited session
Chair: Min Ye

1 - Applicability Analysis of the 15-Minute City Concept: Insights from Urban Mobility Perspective
Xuan Feng

The concept of a 15-minute city proposes that residents should have access to all basic services within a short walking distance from their homes. To explore the current state of the 15-minute city's implementation at the community level and identify potential improvements, this study takes City of Toronto as an empirical case, and incorporates road network-based isochrones into an improved two-step floating catchment area model to calculate the spatial distribution of accessibility. A geographically weighted regression (GWR) model is used to analyze the impact of road network structure and the number of facilities on accessibility. The analysis results indicate that current urban infrastructure cannot meet the travel demands of the 15-minute city, particularly for walking. In the case of other "X-minute cities," extending the travel time threshold is associated with improved accessibility in certain urban areas, but these benefits are limited to regions around service hubs, while accessibility in other areas tends to show a decrease in accessibility. The impact of road network development on accessibility is minimal, while increasing the number of service facilities can significantly enhance walking accessibility, and cycling

2 - Road Space Reallocation in Car-Low and Car-Free Urban Areas
Nourhan Shokry, Shadi Sharif Azadeh, Gonçalo Correia, Bart van Arem

As cities grow and transport demand rises, road congestion increases, leading to pollution and reduced space for sustainable modes such as walking, cycling, and public transport. Traditional car-centric roads infrastructure prioritizes motor vehicles, often overlooking cyclists and public transport. Shifting road space to accommodate more bikes can reduce emissions and create healthier, more accessible cities. Existing research focuses on car-oriented road space reallocation. Strategies like Intermittent Bus Lanes and Reversible Car Lanes optimize road use but still prioritize cars. Recent studies emphasize expanding cycling infrastructure but rely on permanent physical changes, making them less adaptable. This study bridges these gaps by proposing a flexible approach to reallocate road space. The problem is formulated as a mixed-integer nonlinear optimization model using a multi-commodity minimum-cost flow approach. The model reallocates car lanes to bicycles without modifying physical infrastructure. In Zuidas, Amsterdam,

three scenarios were evaluated:(1) base case with saturated bike and car demand,(2) low-car case with 50% fewer cars, and (3) no-car case allowing only bicycles. Results show that reallocating lanes reduces bike travel time by 20% in the low-car scenario and 26% in the no-car scenario. Congested bike lanes drop by 50% in the low-car scenario and are eliminated in the no-car scenario. In addition, congested car lanes decrease by 50% in the low-car scenario.

3 - Coordination and Pricing Strategy in Mobility as a Service (MaaS) system
Min Ye, Jie Zhang, Maria Battarra, Gilbert Laporte, Meng Meng

Mobility as a Service (MaaS) is an innovative concept, that integrates various transportation services into a unified platform, enhancing accessibility, reducing congestion and improving efficiency. In the evolving market, MaaS operators and traditional service operators coexist, serving all customers while fostering collaboration between transportation operators. This study explores coordination and pricing strategies between operators in a competitive market with stochastic demand. We model the problem as a Stackelberg game where the traditional operator acts as a leader, setting capacity and pricing, while the MaaS operator, as a risk-averse follower, optimizes resource purchases. We analyse decentralised, centralised, and coordinated decision models, introducing a joint contract mechanism that aligns incentives between operators. The coordination framework incorporates wholesale pricing, revenue sharing, and risk-return contracts to mitigate demand uncertainty. Numerical experiments highlight the impact of market share, demand sensitivity, and risk aversion on optimal pricing and capacity decisions. Results show that a joint contract can enhance system efficiency and promote sustainable collaboration. These findings provide managerial insights for promoting operational efficiency and cooperation in MaaS ecosystems.

4 - A decomposed MIP approach for a large size workforce scheduling problem in public transport sector
Nicolas Blandamour

Workforce scheduling in public transport involves large-scale optimization with intricate constraints, including regulations, fairness, and operational rules across heterogeneous service lines. Such a problem was tackled for a leading European public transport actor. The schedules are constructed independently for each transport line, with each line involving over 100 agents whose schedules need to be defined for a one-year period.

It was solved using a three-step decomposition: (1) assigning work/rest days, (2) selecting service types, and (3) assigning specific shifts. Rest day assignment is solved using a large-scale binary MIP, adaptable to eight lines with distinct constraints. Due to project deadlines, service assignment was solved via another MIP instead of heuristics or column generation, which remain future improvements to fasten the resolution process that lasts several hours.

While such a decomposition may induce suboptimality, it allows iterative validation with business stakeholders, a key factor in change management. It also allows an alignment with existing business methodologies for better adoption. Given the substantial gains observed -up to 50% improvement on some KPIs- pursuing exact optimality was unnecessary in this preliminary phase.

Key innovations include fairness-driven optimization, workload balancing, and service hardship scores. The project is now entering industrialization for large-scale deployment and UX/UI integration.

■ WC-60

Wednesday, 12:30-14:00 - Room: Western LT

DEA applications in Banking and Finance

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: Gordana Savic

1 - Insurance industry performance analytics: A Bibliometric literature review
Gordana Savic, Isidora Gaćeša, Milan Martic, Violeta Cvetkoska

The insurance industry increasingly relies on performance analytics to drive business simplification, informed decision-making, operational efficiency, and competitive advantage. Insurers can enhance decision-making, improve productivity, and adapt to evolving market conditions by utilising sophisticated risk models and large databases. Performance analytics tools such as Data Envelopment Analysis (DEA), Stochastic Frontier Analysis (SFA), Benchmarking, and the Balanced Scorecard help insurers refine risk models, assess efficiency, and align performance with strategic goals. These tools enable insurers to quantify risk, automate processes, and improve customer satisfaction, positioning them to thrive in a competitive marketplace. Performance analytics is essential for driving innovation, long-term success, and competitiveness in the insurance industry. This study evaluates the performance analytics applied in insurance industry papers, focusing on DEA methodology using bibliometric analysis. By reviewing literature published between 2020 and 2025, the study aims to provide a comprehensive understanding of the role of performance analytics in fostering success and growth in the insurance sector.

2 - Comparative Efficiency of Bank Branches in Cape Verde: Insights from DEA
Gabriela Dos Santos, Maria Isabel Gomes

The efficiency of bank branches is a key factor in overall banking performance, especially in regions with unique geographic and economic challenges like Cape Verde. With a dispersed population and a strong reliance on emigrant remittances, optimizing banking operations is crucial. However, limited research has explored Cape Verde's specific banking challenges and the role of digital banking in improving efficiency. This study evaluates the efficiency of bank branches in a Cape Verdean bank, focusing on transactional efficiency (shifting transactions to alternative channels) and operational efficiency (branch performance in daily operations). Using Data Envelopment Analysis (DEA), a non- parametric method for efficiency assessment, the study applies the BCC model for transactional efficiency and the RDM, MSBM, and modified MSBM models for operational efficiency, addressing the challenge of negative data. By applying DEA, the study identifies efficient and inefficient branches, providing insights into best practices and areas for improvement. Findings reveal that while some branches consistently perform well, others struggle, with efficiency outcomes varying based on input selection. Additionally, no clear correlation exists between transactional and operational efficiency. These results highlight the need for further research on profit efficiency and the impact of emigrant clients on banking operations.

3 - Global nonparametric diversified frontier-based efficiency measures and Luenberger productivity indices of ESG funds
Tiantian Ren, Helu Xiao, Zhongbao Zhou

This paper combines both financial and non-financial indicators of ESG funds to construct diversified frontier-based contemporaneous and nonconvex global portfolio possibility sets, and proposes contemporaneous and nonconvex global efficiency measures for ESG funds. On these bases, the nonconvex global Luenberger productivity indices (GLPIs) are developed correspondingly. We further present an additive decomposition and analyze the full decomposition of the ESG fund efficiency measures and GLPIs. This framework allows to distinguish between overall efficiency (OE), portfolio efficiency (PE), and allocative efficiency (AE) of ESG funds as well as OE-, PE- and AE-based GLPIs within both contemporaneous and global technology settings. Utilizing the unbalanced panel data of China's ESG funds during 2018-2023, we examine the dynamic evolution of ESG fund efficiencies and GLPIs as well as their decompositions, and explore the impact of non-financial indicators on these measures.

■ WC-61

Wednesday, 12:30-14:00 - Room: Maurice Keyworth G.31

Behavioural studies in cognate domains 2

Stream: Behavioural OR
Invited session
Chair: Gordon Dash

1 - Ranking products as substitutes based on the stability of their relations with other products upon aggregation

Petr Krautwurm

This paper introduces a novel method to rank products as substitutes by examining how their relationships with other goods—specifically, whether they function as substitutes or complements—change upon aggregation. The approach builds on the idea that products close to perfect substitutes are perceived by consumers as essentially the identical, indistinguishable product, and thus should exhibit minimal shifts in their relationships with other products when treated as a single composite good. To capture these relationships, we utilize Robinson's elasticity of substitution and cross-price elasticity, evaluating how these measures vary before and after product aggregation. Applying our method to transactional retail data, we empirically demonstrate its effectiveness in capturing subtle differences in substitutability. The proposed approach provides a practical framework for analyzing consumer perceptions and decision-making, complementing traditional tools for measuring product relationships.

2 - Buy now pay later: Intertemporal preferences in installment loan choices

Jiang Jiang, Chris Anderson

Buy now pay later (BNPL) is a payment arrangement that enables consumers to make immediate purchases while spreading the payment through fixed monthly installments over time. It has gained rapid adoption across diverse markets including fashion, electronics, and travel. BNPL providers like Afterpay, Affirm and Klarna often present the purchase amount in the form of small monthly payments to attract consumers, and the payment terms are predetermined by the providers. Credit score dictates the loan amount, duration, and interest rates available to the applicants. On the other hand, as credit scores could reflect consumers' risk perceptions and spending habits, they might also be associated with the heterogenous preferences in consumers' loan choices. Additionally, when products are not consumed instantly, consumers need to balance future consumption with future payments. We introduce two types of temporal elements into the choice model: (1) anticipation utility derived from the total order amount and booking window, and (2) time discounting for future monthly payments. Utilizing a cruise line purchase dataset from a BNPL loan provider, we compare a baseline multinomial logit model with models that address endogeneity, heterogeneity, and intertemporal preferences. The results help understanding the borrowing decisions among BNPL users, providing insights to regulators for consumer protections.

3 - The impact of online promotional tools on brand image in the Qatari fashion industry

Dr Dewan Md Zahurul Islam

This paper examines impact of online promotional tools on brand image in the Qatari fashion industry. This study aims to understand how each type of promotion, monetary and non-monetary, influences consumer emotions and attitudes and whether there is a relation between societal influences and purchasing decisions. This research investigates the relationship between online promotions and brand image from the consumer's point of view. According to several studies, brand image can be manifested through consumers' emotions (Agmeka et al. 2019), attitudes (Chowdhury, 2021), and societal influences (Rincón et al., 2020). To understand the influence of online promotions on brand image, seven hypotheses were developed to test emotions, attitudes, and societal influences consumers generate when viewing online promotions. A quantitative methodology was employed in this research. An online questionnaire was drafted, pilot-tested, and finalised and then data were collected in summer 2024, and received a total of 104 valid responses from participants residing in Qatar. Data was analyzed using SPSS to test seven hypotheses developed through in-depth literature reviews. The study finds that monetary promotions significantly influence positive consumer emotions, creating excitement and a perception of high savings, which enhances brand image. Non-monetary promotions are less effective and sometimes generate feelings of low quality and value, especially when applied frequently.

4 - Efficient behaviorally biased portfolio decisions preconditioned by asset interconnectedness

Gordon Dash, Nina Kajiji

Investors continue to seek efficient asset allocation models that incorporate environmental, social, and governance (ESG) considerations while accounting for investor behavioral biases. This study integrates a machine learning-based asset return forecasting framework and layered behavioral portfolio optimization goals to enumerate efficient multi-asset portfolios. Our approach explicitly accounts for investor biases presented in the literature. Building on prior research on asset return generation, we propose an optimized multi-objective neural network framework to predict asset risk premia while extracting conditional pricing information through cross-asset information sharing and nonlinear dynamics. The ML output sets the foundation for a hierarchical multiobjective portfolio optimization model to enumerate efficiently diversified asset allocations with behavioral objectives. Simulation results reinforce and extend existing research on portfolio sustainability, network theory, and financial return interconnectivity. Overall, our findings confirm the presence of a hump-shaped ESG efficiency frontier and produce enhanced Sharpe ratios while minimizing global minimum variance portfolio drawdowns. The ML framework combined with multiobjective behavioral optimization provides new insights into managing financial market complexity amid cognitive dissonance, particularly when investors face balancing 'green' and 'brown' asset diversification strategies.

Wednesday, 14:30-16:00

■ WD-01

Wednesday, 14:30-16:00 - Room: Great Hall

Murat Köksalan

Stream: Keynotes
Keynote session
Chair: Sibel Salman

1 - Multiple Criteria Decision Making and its Applications
Murat Koksalan

Humans have been making decisions based on multiple criteria for centuries. The field of Multiple Criteria Decision Making (MCDM) has evolved over the past seven decades, with significant theoretical advancements occurring in the 1960s and 1970s. Since then, numerous algorithms have been developed to support decision-making. More recently, related fields such as multiobjective combinatorial optimization and multiobjective evolutionary optimization have attracted many researchers.

In this talk, I will distinguish between "choice" and "design" problems. The former involves selecting from a set of predefined alternatives based on multiple criteria, while the latter focuses on solving a mathematical model to create (design) new alternatives. I will briefly explore several key approaches to addressing the design problem. Additionally, I will present specialized methods we have developed, alongside my co-authors, to tackle challenges in various domains, including product and process design, public debt management, portfolio optimization, energy auctions, and unmanned aerial vehicle routing.

■ WD-03

Wednesday, 14:30-16:00 - Room: Esther Simpson 1.01

Operational Research Frontiers: the past & the future

Stream: Celebrating 50 Years of EURO
Invited session
Chair: Roberto Rossi
Chair: *Gerhard-Wilhelm Weber*

1 - A Brief History of (Inventory) Analytics
Roberto Rossi

What is uncertainty? And what is the role uncertainty plays in the decision-making process? What does it mean to "invent" something? In this talk we will explore how the art of Analytics evolved over two millennia to produce tools and techniques we use today to make decisions under uncertainty. While doing so, we will put an emphasis on key developments in the realm of accounting and inventory management, and of Artificial Intelligence, and we will reveal surprising connections across these disciplinary domains.

2 - Oxford 1957: The first international conference on OR. Topics, influence, gender
Richard Vahrenkamp

Organized by the French, British and US OR societies, the first international conference on OR took place in Oxford 1957 and was well recorded by Max Davies in a book with more than 300 pages. It shows the topics of the conference and a detailed list of the 250 participants, mainly from the NATO states and the British Commonwealth, but including two Polish mathematicians, the only ones from the communist bloc. The conference was supported by US money to cover the transatlantic flights of the US participants and was part of the US soft power against communism. Stafford Beer from the British company United Steel, who later became famous as a management consultant, gave a lecture on the simulation of production processes with mechanical analogue computers - in the absence of a digital high-speed computer: "The Mechanical Simulation of Stochastic Flows". In the main section of the book the delegates of the various countries reported on the stage of OR development in their country. On the photo of the participants one can count 10 female participants, all below the degree of a professor. In East Germany, Hannelore Fischer became the first female professor of OR in 1968, the first one in East Germany and in Europe. The conference had great influence on the formation of national OR societies in Germany, Austria and Switzerland. The societies fought to get a seat at the first IFORS conference in Aix 1960.

3 - Coordination of Drones at Scale: Decentralized Energy-aware Swarm Intelligence for Spatio-temporal Sensing
Chuhao Qin

Smart City applications, such as traffic monitoring and disaster response, often use swarms of intelligent and cooperative drones to efficiently collect sensor data over different areas of interest and time spans. However, when the required sensing becomes spatio-temporally large and varying, a collective arrangement of sensing tasks to a large number of battery-restricted and distributed drones is challenging. To address this problem, this paper introduces a scalable and energy-aware model for planning and coordination of spatio-temporal sensing. The coordination model is built upon a decentralized multi-agent collective learning algorithm (EPOS) to ensure scalability, resilience, and flexibility that existing approaches lack of. Experimental results illustrate the outstanding performance of the proposed method compared to state-of-the-art methods. Analytical results contribute a deeper understanding of how coordinated mobility of drones influences sensing performance. This novel coordination solution is applied to traffic monitoring using real-world data to demonstrate a 46.45% more accurate and 2.88% more efficient detection of vehicles as the number of drones become a scarce resource.

4 - Discrete-choice Multi-agent Optimization: Decentralized Hard Constraint Satisfaction for Smart Cities
Srijoni Majumdar

Making Smart Cities more sustainable, resilient and democratic is emerging as an endeavor of satisfying hard constraints, for instance meeting net-zero targets. Decentralized multi-agent methods for socio-technical optimization of large-scale complex infrastructures such as energy and transport networks are scalable and more privacy-preserving by design. However, they mainly focus on satisfying soft constraints to remain cost-effective. This paper introduces a new model for decentralized hard constraint satisfaction in discrete-choice combinatorial optimization problems. The model solves the cold start problem of partial information for coordination during initialization that can violate hard constraints. It also preserves a low-cost satisfaction of hard constraints in subsequent coordinated choices during which soft constraints optimization is performed. Strikingly, experimental results in real-world Smart City application scenarios such as energy, bike sharing and UAVs swarm sensing demonstrate the required behavioral shift to preserve optimality to a large extent when hard constraints are satisfied. The optimality sacrifice as moving from soft to hard constraints is measured in terms of the required behavioural shift to preserve performance, i.e. restoring altruism deficit. These findings are significant for policymakers, system operators, designers and architects to create the missing social capital of running cities in more viable trajectories.

■ WD-07

Wednesday, 14:30-16:00 - Room: Clarendon GR.01

Sustainable investments and financial performance

Stream: Risk Management in Commodities and Financial

Markets
Invited session
Chair: *Kevyn Stefanelli*

1 - Do ESG Factors Influence the Financial Performance of Financial Institutions? The Case of London as a Global Financial Center
Raminta Vaitiekuniene

Sustainability goals can be a strategic opportunity to increase financial performance based on Return on Equity (ROE), Return on Assets (ROA) and Net Income to Common Margin (NIM) in the financial sector, including banks, fintech companies, investment funds and insurance companies. The study aims to assess how Environmental, Social and Governance (ESG) scores affect the financial performance of financial institutions included in the FTSE 100 stock index (FSI) for the period 2002-2023, using the Ordinary Least Squares (OLS) method taking into account endogeneity in the panel data. FSI represents financial institutions listed on the London Stock Exchange (LSE). The LSE is one of the world's most important financial centers, exerting a significant influence on the strategic direction of financial institutions in other countries. The study findings demonstrate that the overall ESG score and individual sustainability components significantly influence the financial performance of the LSE FSI financial sector. The overall ESG score, environmental and governance sustainability pillars positively and significantly impact ROE. The overall ESG score and governance sustainability component have a positive and important impact on ROA changes. The governance sustainability score has a positive and meaningful effect on NIM. Despite the tightening of sustainability requirements, average environmental and social sustainability scores remain low in the LSE FSI financial sector.

2 - How Generative AI is Revolutionizing Stock Market Predictions in Emerging Markets
Mabutho Sibanda

Predicting stock market price movements is crucial for investors, financial institutions, and policymakers to make informed decisions, manage risks, and optimize returns. Traditional models rely on historical price data and technical indicators but often struggle with unstructured data like news and sentiment. The emergence of generative AI (Gen AI) models, such as GPT-4 and FinBERT, has introduced a paradigm shift, enabling the integration of vast textual data, including financial news, earnings reports, and social media sentiment, into predictive frameworks. This study explores the potential of these advanced LLMs in enhancing stock performance prediction, particularly in emerging markets like the Johannesburg Stock Exchange (JSE). Utilising 5-year data of the JSE-Top 40 firms from 2018 to 2023, our results show that LLMs significantly outperform traditional models in capturing sentiment-driven market dynamics, with FinBERT and GPT-4 achieving superior accuracy in processing financial text. Hybrid models combining LLM outputs with quantitative techniques yielded the best predictive results, particularly for medium to long-term forecasting. However, LLMs faced challenges in short-term, high-frequency trading scenarios, and their performance was impacted by market anomalies and low liquidity in emerging markets. These findings highlight the transformative potential of Gen AI in financial forecasting while emphasizing the need for hybrid approaches and ethical considerations.

3 - Country Policy Drives Companies' Sustainability
Sergio Hoffmann, Rita D'Ecclesia

Sustainability has become one of the central drivers affecting investors' preferences worldwide, attracting the attention of agents, researchers, and regulators. To demonstrate their commitment to sustainability, companies align their strategies with the UN sustainable goals (SDGs), and how they succeed to fulfill these, is often influenced by country policies. While numerous studies have explored sustainability performance at the corporate level, research at the country level remains limited. The role of the regulatory framework is crucial, as it significantly influences sustainability outcomes for both corporations and countries. In this paper, we introduce a national Environmental, Social, and Governance (ESG) score aggregating corporate ratings provided by LSEG Refinitiv from 2013 to 2022. We model countries' commitment to ESG issues and find that variations in country ratings closely align with the effectiveness of regulatory frameworks. To validate our index, we study its relationship with main national sustainability related metrics provided by World Bank, and we find that the national ESG rating is primarly driven by a consistent set of indicators. Using machine learning algorithms, we capture national divergences, accounting for both linear and non-linear relationships.Results show that country ratings improve over time as they rely on the local and global growing importance of sustainability.

■ WD-08

Wednesday, 14:30-16:00 - Room: Clarendon SR 2.08

Real-life applications of multi-criteria and multi-group decision making: practical issues, opportunities and challenges

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: *Salem Chakhar*
Chair: *Maria Cerreta*
Chair: *Simona Panaro*

1 - Explainable AI and Multicriteria Decision Support : Real World Applications and Perspectives
Inès Saad

The rise of artificial intelligence systems in decision domains such as healthcare, cybersecurity, data management, and education highlights the growing need for explainable models. While machine learning approaches achieve remarkable performance levels, their opacity remains a major barrier to adoption, particularly in contexts where transparency and justification of decisions are essential. The Dominance-based Rough Set Approach (DRSA) stands out as a particularly suitable method for multi-criteria classification problems, offering interpretable models that align with decision-makers' preferences. A key advantage of DRSA lies in its use of " Reference Actions ", constructed in collaboration with experts, to extract and formalize their preferences in the form of "If-Then" decision rules. These rules, both comprehensible and traceable, ensure better adoption of models by end-users. In this study, we present several extensions of DRSA, designed and applied to real-world cases across multiple sectors. We demonstrate how our explainable models go beyond providing accurate predictions by enabling decision makers such as medical professionals, cybersecurity specialists, educators, and community managers to understand, interpret, and trust the generated recommendations. Our findings emphasize that DRSA serves as a key enabler for transparent, justifiable, and expert aligned decision-making.

2 - Preference learning approach to the adaptive reuse of cultural heritage in the city of Salerno, Italy
Simona Panaro, Salem Chakhar, Salvatore Greco, Alessio Ishizaka

Recent years have seen an increased interest in the application of multi-criteria analysis (MCA) in supporting complex and conflicting problems, such as sustainable land use change. We present a case study in the city of Salerno (Italy), where the successful and unsuccessful factors of adaptive reuse of historical buildings were explored through the application of the Dominance-based Rough Set Approach (DRSA). The implementation of this approach was conducted with a group of stakeholders and encountered several challenges, including a lack of familiarity with multi-criteria analysis among participants, the cognitive effort required to specify preference parameters, limited data, redundant information, and the integration of different disciplines. The main lessons learned from this application will be discussed, and critical insights on the application of multi-criteria decision-making methods will be provided to improve the quality of public decisions.

3 - Social Multi-Criteria Evaluation in urban design and spatial planning: An educational perspective from the Evaluab experience
Maria Cerreta, Giuseppe Ciciriello, Stefano Cuntò, Laura Di Tommaso, Benedetta Grieco, Ludovica La Rocca, Caterina Loffredo, Chiara Mazzarella, Eugenio Muccio, Simona Panaro, Giuliano Poli, Sabrina Sacco, Maria Somma, Sveva Ventre, Piero Zizzania

Addressing contemporary sustainability challenges requires decision-making processes that integrate diverse stakeholder values, ensure transparency, and facilitate conflict resolution. In this context, Social Multi-Criteria Evaluation (SMCE) has emerged as a crucial framework for designing and assessing projects and policies. Among SMCE methodologies, the SOCRATES method provides distinctive advancement for enhanced decision-making by visualizing stakeholder coalitions and fostering constructive dialogues. Within this research landscape, Evaluab, the evaluation laboratory of the Department of Architecture in Naples, Italy, is establishing itself as a leading hub for the SMCE development. Through research and education, Evaluab fosters an interdisciplinary evaluation approach in planning and design. This contribution focuses on the educational perspective of the SOCRATES applications carried out by Evaluab, demonstrating the method's effectiveness in: (i) academic outputs, where SMCE is applied in master degree theses to assess alternative scenarios; (ii) educational settings, where students employ SOCRATES to select compromise solutions and manage co-design processes. By analyzing real-world applications carried out by Evaluab research team, this study highlights how SOCRATES is an evaluation method capable of orienting design, promoting participatory processes and advancing the integration of multi-criteria and multi-group assessments in urban and territorial planni

4 - The role of consensus-reaching for aggregating stakeholder groups' preferences in multi-criteria group decision-making
Klaas De Brucker, River Huang, Cathy Macharis

Actively involving stakeholder groups in multi-criteria group decision-making (MCGDM) frameworks can help policymakers understand the particular preferences of such stakeholder groups and get support from them. This is particularly important for complex projects with a large scope, such as those related to transport, the environment, or any other projects that affect the wider public and where the support from critical stakeholder groups is essential to successful project implementation. As stakeholder groups represent an extra layer in the MCGDM framework and since they often develop their own set of criteria, relevant to their own specific point of view, the question then arises how to bring together or aggregate these stakeholder viewpoints. In our paper, we discuss three different approaches for bringing together (conflicting) stakeholder points of view. We contrast approaches that rely on the use of inter-stakeholder weights with a more innovative approach (developed by ourselves) that does not explicitly use such weights but mainly focuses on the role of consensus-reaching in aggregating stakeholder groups' preferences. Finally, we illustrate these approaches using a real-life case study related to the appraisal of construction logistics scenarios in the municipality of Anderlecht, in the Brussels Capital Region of Belgium.

■ WD-09

Wednesday, 14:30-16:00 - Room: Clarendon SR 2.01

Quantitative methods in finance

Stream: OR in Finance and Insurance
Invited session
Chair: Ben Moews

1 - Investment, financing, strategic debt service, and liquidation
Takashi Shibata, Michi Nishihara, Yuan Tian

We develop a dynamic model of real options to examine how the introduction of both collateral and debt renegotiation (strategic debt service) affects a firm's investment and financing (capital structure) decisions. Our results reveal that such an introduction hastens investment and decreases debt issuance, leading to a decreased credit spread and increased leverage. When firms are allowed to issue one of two kinds of debt—bank (renegotiable) debt and market (non-renegotiable) debt—with collateral, firms with substantial collateral are more likely to prefer market debt rather than bank debt. These results align with previous empirical findings.

2 - Domain applications of privacy-preserving mechanisms in synthetic data disclosure of financial regulators
Ben Moews

In today's information age, the vast amounts of data collected by financial regulators such as central banks stand in contrast to sensible legislative frameworks like banking secrecy laws. These constraints, however, limit the ability of the research community to make use of the available banking microdata in areas ranging from financial inclusion to credit risk. Central banks also have a mandate to promote stability and public trust, which external data access and validation enable. For these reasons, we adapt recent developments in privacy-preserving mechanisms, machine learning, and graphical models for synthetic data generation. The resulting models feature built-in privacy guarantees and are trained on the Central Bank of Paraguay's microdata as the first implementation of synthetic banking microdata of this kind. We apply these models to three different use cases; financial inclusion indices, term deposit yield curves, and credit card transition matrices. Our results show that marginal-based inference mechanisms outperform generative adversarial approaches, with models less susceptible to post-processing information less being particularly suitable to these domain applications. The findings of our work demonstrate the utility of synthetic data generation to enhance statistical data disclosure by financial regulators, while showcasing the importance of stringent evaluation to maintain performance and privacy.

3 - How to choose a model? A consequentialist approach applied to portfolio selection in continuous-time
Moris Strub, Thaleia Zariphopoulou

We propose a consequentialist approach to model selection: Models should be determined not according to statistical criteria, but in view of how they are used. This principle is then studied in detail in the domain of continuous-time portfolio choice. We consider an econometrician with prior beliefs on the likelihood of models to transpire and faced with the task of communicating a single model to a client. The client then takes the model communicated by the econometrician and invests according to the strategy maximizing expected utility within this model. The client receives the consequential performance of trading according to the model communicated by the econometrician in a potentially different model that accurately describes the world. The objective of the econometrician is to choose the model that maximizes the consequential performance of the client, averaged over the likelihood of models to transpire and weighted according to the risk preferences of the econometrician. One of the key findings is that it is in the best to communicate a model that is more optimistic than an unbiased estimator would suggest.

■ WD-10

Wednesday, 14:30-16:00 - Room: Clarendon SR 1.06

MCDA and urban planning 3

Stream: Multiple Criteria Decision Aiding
Invited session
Chair: Francesca Abastante
Chair: *Marta Bottero*
Chair: *Isabella Lami*

1 - Weighted average unit cost of ecological-environmental equipments for Municipal Planning through the integration of Analytic Hierarchy Process and Bills of Quantities
Vanessa Assumma, David Casagrande, Valentina Cosmi, Stefano Stanghellini

The Weighted Average Unit Cost (WAUC) of Ecological-Environmental Equipments (EEEs) is calculated by integrating the Analytic Hierarchy Process (AHP) and the Bills of Quantities (BoQ). The WAUC is finalised to support public bodies in the implementation of specific agreements on direct urban interventions for a Northern Italian municipal plan. The EEEs categories (i.e. permeable surfaces, vegetation, water, and technologies) and the corresponding groups of material/solution (i.e. modular surfaces, continuous surfaces, meadows, trees, vertical gardens, drainage systems, evaporative cooling, street furniture, and mobility infrastructures) defined by the municipal plan's abacus and implementation rules, are structured into a hierarchy. After presenting the decisional tree to a group of specialists, they have assessed pairwise its elements through a questionnaire. Their judgements are imported into Superdecisions software to determine a set of priorities for the EEEs categories and one for the groups of material/solution. The average unit costs of materials/solutions are estimated through the BoQ. The first level of AHP priorities weigh the average costs of the EEE's categories, whereas the second level ones weigh the average cost of the groups of material/solution to obtain the WAUC. In this sense, the WAUC can be employed at the municipal scale for implementing new interventions with care of the ecological-environmental quality.

2 - Spatial Multicriteria Analysis to assess regional energy planning scenarios in Gotland region (Sweden)
Lucia Petronio, Vanessa Assumma, Angela Santangelo, Johanna Liljenfeldt

As European regions strive to achieve climate neutrality by 2050, the transition towards sustainable and resilient energy systems integrating renewable energy sources (RES) requires a structured and balanced approach. Addressing the lack of standardized and complete methodologies for regional energy planning (REP), this research aims to construct an interdisciplinary framework for REP combining spatial planning and decision-aiding principles for enhancing the strategic allocation of RES infrastructure. The framework's applicability is tested in Gotland, Sweden, primarily addressing regional planners, policymakers, and energy agencies responsible for designing and implementing REP strategies. This study analyses the current regional conditions and reviews energy infrastructures, regulatory frameworks, and upper-level policies; it performs a MC-SDSS on GIS to evaluate energy planning scenarios and produce a final suitability map. The considered criteria, weighted through SMARTER, are: economy, technology and infrastructure, society and culture, land-use and environment. The final phase of this framework prearranges policy recommendations to improve REP governance, ensuring continuous monitoring and adaptation. The robust foundation for integrating spatial planning and energy decision-making established in this study contributes to the ongoing discourse on sustainable energy transitions, providing valuable insights for academic research and practical policy development.

■ WD-11

Wednesday, 14:30-16:00 - Room: Clarendon SR 1.03

Chemotherapy scheduling

Stream: OR in Healthcare (ORAHS)
Invited session
Chair: *Katrin Kopfer*

1 - A Hybrid Metaheuristic for Chemotherapy Scheduling and Medication Production Under Uncertainty
Katrin Kopfer, Karl Doerner, Pamela Nolz

Infusion-administered chemotherapy is one of the most common treatments in curative and palliative cancer care. Usually administered in outpatient clinics, treatments follow a patient-specific regimen including infusion appointments combined with rest periods over a time horizon of several weeks to months and specifications on the highly individual, perishable and often costly medications. We introduce the Chemotherapy Optimization Problem (COP), which integrates patient appointment scheduling and medication production planning while accounting for stochastic patient cancellations. Patients are scheduled for their appointments in an inter- and intraday setting, determining both, their treatment days and specific times. The daily medication production includes the decision of producing patient-specific medications in advance or on demand, creating a trade-off between potential drug waste and patient waiting times. Limited resources such as consultation rooms and infusion seats restrict the integrated problem; thus, we optimize the COP to maximize resource utilization and minimize production waste using a weighted sum. We introduce new instance sets and solve the COP using a Large Neighborhood Search for tactical planning combined with a Constraint Programming Model for efficient operational scheduling. Further, we analyse the impact of stochastic patient cancellations on schedule robustness, highlighting the importance of resilient planning in outpatient oncology clinics.

2 - Optimizing Chemotherapy Drug Production: A Multi-Objective Scheduling Approach
Camille Pinçon, Nadia Lahrichi, Antoine Legrain

Chemotherapy treatment relies on the preparation of dangerous and expensive drugs, making timely and accurate drug manufacturing crucial for patient care. To address the challenges faced by hospital pharmacies, we propose a multi-objective optimization model for scheduling chemotherapy drug production. Our method aims to jointly minimize the maximum delay in delivering treatments, reduce raw material costs, and shorten overall lead times, all while considering human and material resource constraints. The approach relies on a Mixed-Integer Linear Programming model to approximate scheduling, followed by a reconstruction algorithm to generate practical schedules for pharmacists. Additionally, the model supports the selection of medications for early preparation, increasing the production buffer for subsequent days and further minimizing waste. Computational experiments, using real-world data from a regional cancer center, highlight the method's effectiveness in reducing delays, optimizing resource usage, and enhancing productivity. This scheduling framework contributes to a more efficient and cost-effective workflow in chemotherapy clinics, ultimately improving patient care and resource management.

3 - Nurse Workload Balancing for Chemotherapy Scheduling: An application at Hacettepe Oncology Hospital
Gunsu Dagistanli Calli, Meral Azizoglu

The increasing demand for chemotherapy treatments exceeds the capacity of oncology clinics, making efficient planning crucial. The first stage involves allocating patients to treatment days and the second stage schedules daily appointments to chairs and nurses. Based on observations at Hacettepe Oncology Hospital, we propose several mathematical programming models for the second stage, known as the Chemotherapy Appointment Scheduling (CAS) problem. Our models assume that patient treatment times and chair assignments are given, and they make nurse assignments. First, we determine the minimum number of nurses required to implement the given treatment times and chair schedule. For a fixed number of available nurses, we aim to balance their workloads through two objective functions: minimizing the maximum workload and minimizing the squared total deviation of nurse workloads from the mean. We show that the two objectives are equivalent when there are two nurses and propose a Mixed Integer Linear Program (MILP) to solve this. For the squared deviation problem with more than two nurses, we propose a Mixed-Integer Non-Linear Programming (MINLP) model and a Constraint Programming (CP) model. The results of our extensive computational study show all models can solve large sized instances as long as the given schedule is feasible within nurse limits.

■ WD-12

Wednesday, 14:30-16:00 - Room: Clarendon SR 1.02

Practical problems in scheduling

Stream: Scheduling and Project Management
Invited session
Chair: *Marcos Goycoolea*

1 - Production scheduling of an open pit mine under uncertainty
Marcos Goycoolea

Strategic mine planning optimization addresses the challenge of scheduling mining activities over extended time horizons, simultaneously managing material flows within complex mining networks. These problems are critically important in the mining industry, routinely involving millions of decisions spanning multiple decades. A fundamental difficulty lies in effectively managing geological uncertainty; while precise ore grade distributions remain unknown, geostatistical models provide probabilistic information. In this presentation, we formulate strategic mine planning as a stochastic programming problem and introduce innovative decomposition methods specifically designed to efficiently achieve near-optimal solutions in very large-scale scenarios. Extensive out-of-sample analysis validates the effectiveness of our approach, highlighting significant performance improvements and revealing insightful practical implications.

2 - Comparative Analysis of Evolutionary Algorithms for Energy-Aware Production Scheduling
Sascha C Burmeister, Till Niklas Rogalski, Guido Schryen

The energy transition is driving rapid growth in renewables, requiring manufacturers to balance energy demand with price awareness. Energy-aware production planning aligns demand with dynamic grid conditions, supporting renewables while reducing costs and emissions. This can be modeled as a multi-criteria scheduling problem, where the objectives extend beyond traditional metrics like makespan or required workers to also include minimizing energy costs and emissions. Due to frequent recalculations and the NP-hard multi-objective nature of the problem, evolutionary algorithms are widely used. However, research often focuses on single algorithms with limited comparative studies. This study adapts NSGA-III, HypE, and theta-DEA as memetic metaheuristics for energy-aware production scheduling, minimizing makespan, energy costs, emissions, and workforce in a real-time energy market. These adapted metaheuristics present different approaches for environmental selection. In a comparative analysis, we explore differences in solution efficiency and quality across various scenarios which are based on benchmark instances from the literature and real-world energy market data. Additionally, we estimate upper bounds on the distance between objective values obtained with our memetic metaheuristics and reference sets obtained via an exact solver.

3 - Minimizing Energy Consumption and Makespan for Unrelated Parallel Machines with Speed Scaling
Shubham Keshri, Avijit Khanra

We consider an unrelated parallel scheduling problem with release dates, setup time, and machine eligibility restrictions to minimize the makespan and the sum of processing, setup, and idle energy consumption. Discrete speed scaling is allowed, assuming that higher processing speed leads to higher processing power. Thus, the two objectives are in conflict. The epsilon-constrained method is employed to a reformulated problem of energy minimization with a bounded makespan. This problem is then decomposed into an assignment problem and single-machine scheduling problems. A Variable Neighborhood Descent (VND) algorithm is used to obtain the assignment, determining the processing energy, while the setup and idle energy are obtained using the earliest release date rule. The neighborhoods considered include shift, swap, and long chain neighborhoods. To handle the makespan constraint, weighted penalty terms are introduced into the objective function. This enables the VND algorithm to explore infeasible regions by adjusting these weights. A mixed-integer linear programming model is formulated and CPLEX solver is used to construct the approximate Pareto front, which serves as a benchmark. Results reveal the proposed VND algorithm produces high-quality, non-dominated fronts in a reasonable amount of time. Future work can consider energy cost with a time-of-use tariff, enhancing the applicability of the problem and supporting sustainable scheduling in energy intensive industries.

■ WD-17

Wednesday, 14:30-16:00 - Room: Esther Simpson 2.08

Diversity in Solutions to CO problems

Stream: Combinatorial Optimization
Invited session
Chair: *Frits Spieksma*

1 - Finding Diverse Solutions in Combinatorial Problems with a Distributive Lattice Structure
Andres Lopez Martinez, Mark de Berg, Frits Spieksma

We consider the problem of finding diverse solutions to combinatorial problems whose solution sets form a distributive lattice structure. We identify three structural conditions that, when met by a problem, ensure that a k-sized multiset of maximally-diverse solutions—measured by the sum of pairwise Hamming distances—can be found in polynomial time. We apply this framework to obtain polynomial time algorithms for finding diverse minimum s-t cuts, diverse stable matchings, and diverse circulations in planar graphs. We also show that the framework extends to two other natural diversity measures.

2 - On the ordering of sets for asymmetrical representations for generic set partitioning problems
Lars Jäger, Matthieu Gruson, Raf Jans

Set partitioning problems, also known as binary clustering problems, are of fundamental importance in operations research. A key problem in these groups is that of inherent symmetry, which can be defined as the property of solutions that can be trivially transformed into each other without altering the structure or objective function value. One solution to this problem is an asymmetrical representative formulation (ARF), first proposed by Campêlo et al. (2004). In this approach, a set of constraints is introduced to ensure that only one of the symmetric solutions is valid, thereby ensuring that the optimal solution remains in the solution space, but not multiple times. This approach has been shown to be effective in reducing the solution time and increasing quality of standard solvers. It has been observed that for some of these ARFs, the input order of the sets is important for the strength of the LP relaxation and solving time. Some authors have proposed simple problem-specific set-order policies. First, the ARF is explained by example, and second, the importance of the set-ordering is demonstrated. A new approach is used to visualize large instances for different problems in the literature. Finally, we propose a universal heuristic as an alternative to the problem-specific policies that are currently in use. These heuristics are compared to an newly developed exact approach, in order to ensure high-quality solutions.

3 - On Queens and Tours
Frits Spieksma, Pieter Jacobs, Andres Lopez Martinez

Given the complete graph on n vertices, where $n \geq 3$, we define two Hamiltonian cycles as cyclic disjoint if, for each pair of vertices, the distance between them in one Hamiltonian cycle differs from the distance between them in the other Hamiltonian cycle. We investigate the number of pairwise cyclic disjoint tours that exist in Kn. Specifically, we identify when pairs of cyclic disjoint tours can occur and provide a procedure to generate $(m-1)/2$ pairwise cyclic disjoint tours, where m is the smallest prime factor of n. Finally, we demonstrate that the number $(m-1)/2$ of pairwise cyclic disjoint tours is maximized when n is prime.

■ WD-18

Wednesday, 14:30-16:00 - Room: Esther Simpson 2.09

OR Education 4

Stream: OR Education
Invited session
Chair: *Nina Kajiji*
Chair: *Gordon Dash*
Chair: *Gerhard-Wilhelm Weber*

1 - The Quality Assurance College - a case study of Practical Education

Ian Mitchell

The Department for Energy Security and Net Zero (DESNZ) Modelling Integrity (MI) Team presents the Model Quality Assurance (QA) College as a case study of education in OR. This has run since 2017 and is based on an Explain-Demonstrate-Imitate-Practise structure. The QA system depends on a network approach with analysts conducting quality control as they build their models and quality assurance for other analysts' models. The MI Team runs the QA College a one-off session on MS -Teams lasting two and a half hours including two ten-minute intermissions. They introduce the genesis of the QA System, how to use the QA Logbook with presentations then run an interactive exercise, with a suitably sabotaged Excel training model. Each table discussed views on each question. One table would present an opinion with comments from the other tables. The designer of the training model then provided the solution with reasons. The College concludes with a description of how the MI Network operates. Covid forced a move to virtual As of March 2020 all QA Colleges ran on MS-Teams, with interactivity via the Chat for comments instead of the table discussions. Teams Forms allow every student to offer an opinion on each question which is an advantage. The evaluations have remained positive. The MI Team welcome colleagues from other Government Departments and Partner Organisations.

2 - The Role of Artificial Intelligence in Supporting Children with Special Needs in Developing Countries

Apology Zhou, Godsave Zhou

This study explores the role of artificial intelligence (AI) in supporting children with special needs in developing countries through a systematic literature review and bibliometric analysis conducted in R. Drawing from global peer-reviewed sources, the analysis highlights how AI tools—such as speech recognition, personalised learning platforms, and computer vision—are being used to address challenges faced by children with disabilities, including autism, hearing impairments, and cognitive delays. Despite the potential of these technologies, their adoption in developing countries remains limited due to infrastructural gaps, limited teacher training, and inadequate policy support. The bibliometric analysis reveals that research is predominantly concentrated in upper-middle-income countries, with fewer contributions from low-income regions. Based on the findings, the study recommends investing in teacher capacity building, expanding digital infrastructure, fostering collaborations between governments and tech developers, promoting inclusive ICT policies, and encouraging open-source AI solutions tailored to local contexts. These measures can help bridge the digital divide and promote inclusive education for learners with special needs in the Global South.

3 - Unlocking Generation Z: Spatial Data and Game Theory Redefine HR Strategies

Gerhard-Wilhelm Weber, İsmail Özcan, Jacek Dominik Śledziński

Generation Z's entry into the labor market challenges Human Resource Management (HRM), especially in talent-scarce regions like Wielkopolskie, Poland, where low unemployment sparks tough competition. These IT students, with high salary expectations and short-term loyalty, push HRM beyond typical rewards. This study mixes spatial data mining and cooperative game theory, enhancing the Multivariate Adaptive Regression Splines (MARS) model with a coalition approach. Using survey data from IT students, we predict salary expectations based on location, like distance from Poznan. Three students form a coalition, where spatial closeness boosts their group value, and Shapley values ensure fair reward sharing. Education plays a key role here, as their IT skills, shaped by modern training, drive their market power. Findings show how proximity to cities increases group potential, changing labor market trends. Unlike MARS' individual focus, this method reveals teamwork strength, giving HRM better tools for team-building and payroll strategies. It works well in tight markets but highlights spatial inequalities as an issue. Future studies could explore new teamwork factors or compare companies to student coalitions, transforming recruitment for Generation Z's unique strengths.

(This abstract bases on joint work with Prof. Maciej Safranski and Prof. Magdalena Graczyk-Kucharska from FEM, PUT, Poznan, Poland.)

■ WD-23

Wednesday, 14:30-16:00 - Room: Esther Simpson 3.01

OR Challenges for Developing Countries 2

Stream: OR for Societal Development
Invited session
Chair: *Yu-Hong Dai*
Chair: *Janny Leung*

1 - Optimal Control Techniques for Mine Planning

Honglei Xu

Australia's mining industry plays a significant role in its economy, accounting for over 13% of the total GDP in 2023-2024. Mine planning is a crucial aspect of the mining industry. In this talk, I will discuss two kinds of optimization strategies in mine planning problems. I first consider a pit shell optimization problem for open-pit planning within an optimal control framework. Next, I introduce new receding horizon control for optimal mine planning. These proposed optimization problems incorporate the actual workflow of open-pit mining activities and real-world constraints from both operational and geological aspects. Finally, numerical simulation results are presented to show the usefulness and effectiveness of the proposed methods.

2 - Integer Programming Research in China: Applications and Challenges

Yu-Hong Dai

In this talk, we first trace the development of integer programming in China, from linear programming to modern advancements. We then showcase some successful applications of integer programming in China, such as communication, logistics, and energy. Key challenges and trends, including the integration of emerging technologies like artificial intelligence, are also discussed. Drawing on China's experiences, we conclude by exploring potential research directions and opportunities for the future advancement of integer programming, with a special focus on its applicability in developing countries.

3 - School Choice in Chile

Andres Cristi, José Correa, Natalie Epstein, Rafael Epstein, Juan Escobar, Ignacio Rios, Nicolás Aramayo, Bastián Bahamondes, Carlos Bonet, Martin Castillo, Boris Epstein, Felipe Subiabre

Centralized school admission mechanisms are an attractive way of improving social welfare and fairness in large educational systems. In this talk, we will discuss the design and implementation of the recently established school choice system in Chile, which handles the applications of over 500'000 students to around 10'000 schools every year. The Chilean system presents unprecedented design challenges that make it unique. First, it is a simultaneous nationwide system, making it one of the largest school choice problems worldwide. Second, the system is used for all school grade levels, from prekindergarten to

12th grade. One of our primary goals is to favor the assignment of siblings to the same school. By adapting the standard notions of stability, we show that a stable assignment may not exist. Hence, we propose a heuristic approach that elicits preferences and breaks ties between students in the same priority group at the family level. In terms of implementation, we adapt the deferred acceptance algorithm as in other systems around the world.

4 - Subsidizing Service-Focused Social Welfare Programs: Contracted Slots or Vouchers?
Senay Solak, Wei Wei, Priyank Arora

We study operational decision-making by profit-oriented service providers under two popular service-focused subsidy welfare programs—namely, vouchers and contracted slots. In voucher programs, beneficiaries can redeem vouchers at any participating private service provider. However, these providers are only required to serve voucher holders if they have remaining capacity after accommodating full-price-paying customers from the private market. Conversely, in contracted slot programs, governments partner only with high-quality providers who commit to reserving a fixed number of slots to serve beneficiaries. We provide an operational lens to evaluate these program types, addressing the ongoing policy discourse surrounding their efficacy. To this end, we explore how program design, provider characteristics, and market dynamics influence the availability and quality of essential services delivered by service providers. By comparing equilibrium outcomes under the two program types, we identify conditions under which the government might favor vouchers or contracted slots, considering total societal impact and the total expected profits of for-profit providers. Our results provide guidance for designing operations-focused policies aimed at improving societal outcomes while ensuring alignment with private service provider incentives.

■ WD-24

Wednesday, 14:30-16:00 - Room: Esther Simpson 3.02

Tutorial: What is Behavioural OR?

Stream: Tutorials (and Workshops)
Tutorial session
Chair: *Andrea Taylor*

1 - What is Behavioural OR?
L. Alberto Franco, Raimo P. Hämäläinen, Martin Kunc

Current definitions of Behavioural OR have been criticised for being too open and unprecise. However, we should note that the openness of a definition can be seen as a natural first stage in a developing domain. In defining a new sub-field within OR, we must address the challenge of striking a balance between breath and specificity. In this tutorial, we address this challenge by providing a clearer definition of Behavioural OR with a view to helping OR academics and practitioners enter the field on a good footing. We argue that the definition formulated here can help clarify the new benefits that Behavioural OR may bring to the OR community, as well as make it distinctive from other cognate areas within and beyond OR.

■ WD-26

Wednesday, 14:30-16:00 - Room: Maurice Keyworth 1.33

Quantum Optimization

Stream: Making an Impact: The Practitioners' Stream 1
Invited session
Chair: *Axel Daian*

1 - Quantum Optimization: The Killer Use Case for Quantum Computing (90' workshop)
Axel Daian

Quantum computing has gone from the lab to the enterprise, and industry analysts cite optimization as the ideal near-term use case for quantum computers. While you may think production use of quantum computers is years away, the first commercial quantum applications in production are using D-Wave's quantum hybrid technology. This workshop will cover the following topics:

' An introduction to quantum computers, quantum annealing, and optimization solvers

' What kinds of business problems are good candidates for quantum hybrid solutions

' Real-world use case examples: how quantum hybrid is being used for optimization applications such as cellular network optimization, resource and workforce scheduling, production scheduling and other complex business problems

' How quantum systems are programmed and the tools for developers, including live demos and an introduction to Leap, D-Wave's real-time cloud service. The Leap service provides access to a portfolio of hybrid solvers, enabling enterprises to address all kinds of business problems that range in size and complexity

' How to get started with quantum for business

■ WD-30

Wednesday, 14:30-16:00 - Room: Maurice Keyworth 1.05

Shared Mobility Optimization IV

Stream: Shared Mobility Optimization
Invited session
Chair: *Beatriz Brito Oliveira*

1 - Factors of choice in urban mobility: discrete choice models for the Asprela university campus
Beatriz Brito Oliveira, Luís Meireles

Understanding individual decision-making in urban mobility is crucial for developing effective and sustainable transportation policies. This study explores mode choice behavior in a university campus setting in Porto, Portugal, using a dataset that captures revealed availability sets and choices, general preferences, socio-demographics, and trip-related factors. The dataset is rich and complex, including several potential travel alternatives and variables such as income, cost, trip duration, and satisfaction. Discrete choice models are developed and compared to assess the determinants of transportation choices and evaluate model performance. Two modeling approaches - multinomial logit and latent class models - are employed to analyze mode choice behavior, deriving insights on mobility and methodological contributions related to the trade-offs between complexity and performance. The study also derives empirical insights into the potential adoption of shared mobility in this area, analyzing survey responses that assess the respondents' affinity with shared services.

2 - Reducing CO2 Emissions in Aviation by Aircraft Sharing and Passenger Bundling Between Airlines
Yiwen Zhu, Thomas Hagspihl, Rainer Kolisch

In line with the goals of the Paris Agreement, airlines are committed to achieving net-zero carbon emissions by 2050. To help achieve this goal, we assess the potential for reducing CO2 emissions when aircraft are shared, passengers are bundled, and flight networks are restructured across airlines, comparing the status quo with optimized networks in both current and future scenarios. We develop a mixed-integer program to determine how many flights should be operated between any two pairs of airports and which aircraft type(s) should be used on each

route to minimize overall CO2 emissions. We consider aircraft performance characteristics, airport capacities, compatibilities between aircraft types and routes, the continuous flow of aircraft between airports, and demand satisfaction. Passengers may have up to two stops between their origin and destination. To solve the problem for large instances, we propose a Relax-and-Fix heuristic. First results based on real data for the European, North American and transatlantic market in 2018 show a potential to reduce CO2 emission through aircraft sharing and passenger bundling of 11.6%.

3 - Value co-creation strategy of bike-sharing platform supply chain considering forward shareholding
Juhong Gao

To promote the high-quality and sustainable development of the sharing economy in China's environment, from the perspective of platform supply chain, this study explores the impact of product quality, holding ratio, and subsidy ratio on platform supply chain members' decision-making and profits, consumer surplus, and total value, considering two types of co-creation behaviors: holding co-creation among multiple operating platform enterprises in the shared product market with the third-party logistics service provider, and governance co-creation between operating platform enterprises and consumers. The research findings show that the average usage rent competition strategy of operating platform enterprises is only related to product quality. Both operating platform enterprises' subsidies to consumers and their equity holding in the third-party logistics service provider are beneficial to their own profits, consumer surplus, and platform supply chain total value, but at the expense of third-party logistics service providers' profits. Operating platform enterprises should set a lower subsidy ratio and hold shares in the third-party logistics service provider, so as to ensure the profits of enterprises at each node of the supply chain. In addition, the third-party logistics service provider should consider expanding business or holding equity in upstream operating platform enterprises to strengthen cooperative relationships and increase profit sources.

■ WD-31

Wednesday, 14:30-16:00 - Room: Maurice Keyworth 1.06

Machine Learning for Optimization under uncertainty 2

Stream: Stochastic and Robust optimization
Invited session
Chair: Francesca Maggioni

1 - Expert Imitation for Sequential Decision Making
Prakash Gawas, Antoine Legrain, Louis-Martin Rousseau

Imitation learning, where an agent learns decision-making by mimicking expert behavior, has been widely applied in robotics and autonomous driving. This study introduces an innovative approach using DAgger, an imitation learning algorithm, to iteratively train policies for stochastic sequential decision problems (SDPs). These problems are particularly challenging when expert input is costly or unavailable. First, we define a taxonomy of experts that can be used for imitation in SDPs. We then focus on designing an effective expert within the DAgger framework, leveraging deterministic solutions derived from contextual scenarios at each decision point. A predictive model is subsequently trained to replicate the expert's behavior, enabling real-time decision-making. However, imperfect experts may provide faulty demonstrations, slowing down learning. To mitigate this, we propose a strategy incorporating multiple experts within the DAgger framework. To demonstrate the methodology's applicability, we address a dynamic employee notification timing problem for scheduling casual personnel in on-call shifts.

2 - Integrated investment, retrofit and abandonment energy system planning with multi-timescale uncertainty using stabilised adaptive Benders decomposition
Hongyu Zhang, Ignacio Grossmann, Ken McKinnon, Brage Rugstad Knudsen, Rodrigo Garcia Nava, Asgeir Tomasgard

We propose the REORIENT (REnewable resOuRce Investment for the ENergy Transition) model for energy systems planning, introducing: (1) integrated capacity expansion, retrofit, and abandonment planning, and (2) multi-horizon stochastic mixed-integer linear programming with multi-timescale uncertainty. Applied to the European energy system, the model considers: (a) investment in new hydrogen infrastructure, (b) power system capacity expansion, (c) retrofitting and abandoning North Sea oil and gas infrastructure for hydrogen, and (d) long-term oil and gas price uncertainty alongside short-term variability in time series parameters such as wind capacity factors.

To solve the model efficiently, we leverage multi-horizon stochastic programming and propose a centred point stabilised adaptive Benders decomposition. Sensitivity analysis on retrofitting costs shows that retrofitting existing pipelines is economical when costs are below 20% of new construction. Oil platform clusters continue production due to high profits, with abandonment deferred to the final investment stage. Compared to conventional planning models, REORIENT reduces North Sea investment costs by 24%. The centred point stabilised adaptive Benders algorithm achieves up to 6.8 times faster solution times than the level-method stabilised adaptive Benders.

3 - Multivariate Probabilistic Forecasting of Electricity Prices
Milos Kopa, Ilyas Agakishiev, Wolfgang Karl Härdle, Karel Kozmík, Alla Petukhina

This study extends recently introduced neural networks approach, based on a reg- ularized distributional multilayer perceptron (DMLP) technique for a multivariate case electricity price forecasting. The performance of a fully connected architecture and a LSTM architecture of neural networks are tested. Different from previous studies we incorporate dependence between multiple exchanges (EPEX and Nord Pool). The em- pirical data application analyzes two auctions in the day-ahead electricity market for the United Kingdom market. Along with statistical evaluation of probabilistic forecasts we develop a flexible bidding strategy based on risk-adjusted investor utility function. The trading application leverages the differences of the two exchanges by having long/short positions in both. Our findings demonstrate while DMLP shows similar performance compared to the benchmarks, the algorithm is considerably less computationally costly. LASSO Quantile Regression is better in terms if statistical evaluation of distributional fit, while DMLP outperforms in terms of Sharpe ratio (by 18%) in the trading application.

■ WD-34

Wednesday, 14:30-16:00 - Room: Michael Sadler LG10

Applications of Knowledge Work Technology

Stream: Advancements of OR-analytics in statistics, machine learning and data science
Invited session
Chair: A. D. Amar

1 - Adapting a DFGSP Algorithm to Maximize Knowledge Worker Satisfaction
Januj Juneja, A. D. Amar

We propose a scheduling algorithm for assigning tasks to knowledge workers based on the distributed flowshop group scheduling problem (DFGSP). We assume that the tasks are grouped into families and are

scheduled across different locations for completion based on the subactivities which are done to facilitate proper implementation of the scheduling algorithm. The objective function is constructed to provide total worker satisfaction comprising three measures - financial, work perception, and output. The lattermost measure incorporates skills and abilities through five parameters linked to (1) ratio of capital invested in intangibles to traditional assets (δt), (2) net new-knowledge-added (φt), (3) investments in intangibles per revenue dollar (σt), (4) rate of generating organization capital (μt), and (5) work completion rate (νt). The former two measures incorporate other important aspects of worker satisfaction including how approachable is the supervisor, characteristics of the assigned task, worker motivation, workplace autonomy, performance rewards, worker training and the knowhow, pressure to produce, task importance and the availability of tools needed to be efficient at work. We demonstrate the usefulness of our algorithm through the implementation of simulation experiments and conclude with some managerial implications of our research along with directions for future work in this area.

2 - Optimizing Workforce Allocation with Evolutionary Artificial Intelligence: A Case Study in Intelligent Job Scheduling
Abimbola Falodu, Alina Patelli, Aniko Ekart, Charlotte Burton

On-site maintenance job scheduling presents a complex optimisation challenge which, can cause suboptimal resource utilisation, workforce dissatisfaction, and increased operational costs. Traditional scheduling methods, widely employed across the engineering services industry, are resource heavy, and struggle to manage real-time constraints, delaying decision-making and prolonging service lags.

We introduce a novel evolutionary framework to make workforce allocation effective and efficient under realistic operational constraints. The framework comprises an innovative genetic algorithm with bespoke schedule encoding mechanisms, a clustering heuristic that improves solution quality via efficient initialisation, and a computational strategy that leverages parallelised distance matrix calculations. Dynamic workload balancing, priority-based job allocation, and a solution caching and retrieval mechanism across generations enable real-time adjustments when disruptions occur and increase the framework's operational feasibility.

Engineering service provider Thames Laboratories has automated their legacy scheduling system by adopting our framework, thus achieving significant improvements in organisational KPIs: reduced travel times and fuel consumption, balanced workloads, and streamlined callout attendance. This successful case study offers concrete proof that the systematic commercial adoption of robust AI tech leads to significantly improved operational efficiency.

3 - Systematic Literature Review of Validation and Verification of Simulation Models in Business and Manufacturing using Topic Modelling and Scientometric Analysis
Deepesh Gotherwal, Pritam Ranjan

Simulation imitates a real-world system for analyzing and finding solutions to different kinds of problems, which are generally difficult to solve analytically. Simulation has been applied extensively in Operation Research (OR) or Operation Management (OM) fields such as manufacturing, project management, defense, healthcare, supply chain, and network. Verification and validation (V&V) ensure these models are accurate and reliable. Verification checks if the conceptual model is correctly coded, while validation assesses its accuracy in representing the actual system. This study conducts a systematic literature review on V&V in simulation models, aiming to: 1. Assess the current state of V&V in business and manufacturing. 2. Identify key V&V techniques. 3. Highlight research gaps. We followed a four-step approach: 1. Collected 17,224 research articles from Scopus and Web of Science, filtering down to 300 relevant studies. 2. Used Latent Dirichlet Allocation (LDA) to identify prominent research themes. 3. Reviewed methodological papers on V&V techniques, noting a stronger focus on validation. 4. Identified future research directions. This study presents the first systematic review of V&V in business simulation models, identifying nine key themes, visualizing bibliographic clusters, and highlighting research gaps for future study.

4 - Designing the Information Entropy Performance Indicator (IEPI): A DSRM-Based Approach to Managing Process Uncertainty in Business Operations
Apostolos Mouzakitis, Anastasios Liapakis

Business Process Management (BPM) frameworks optimize workflows and manage complexity, using Key Performance Indicators (KPIs). While effective in stable environments, traditional KPIs fail to capture uncertainty and variability, especially in regulated domains like accounting. This highlights the need for alternative ways to quantify and manage uncertainty. This study presents the Information Entropy Performance Indicator (IEPI), an entropy-based measure of uncertainty in BPMN 2.0. IEPI is based on Managerial Infophysics, linking BPM with entropy-driven decisions. Grounded in information entropy, IEPI quantifies process variability and provides actionable insights to enhance operational predictability. The study employs the Design Science Research Methodology (DSRM) to iteratively design, implement, and refine IEPI. Entropy-based metrics improve process evaluation and resource allocation. The study focuses on developing and implementing IEPI in BPM. Future validation is planned; however, this phase explores feasibility. Findings connect entropy principles with BPM optimization, extending practical use. While initially BPM-focused, this lays the groundwork for entropy-driven metrics in finance, and supply chains.

■ WD-35

Wednesday, 14:30-16:00 - Room: Michael Sadler LG15

Bilevel optimization and augmented Lagrangian methods

Stream: Continuous and mixed-integer nonlinear programming: theory and algorithms
Invited session
Chair: Xinwei Liu

1 - Double-proximal augmented Lagrangian methods with improved convergence condition
Jianchao Bai

In this talk, a novel double-proximal augmented Lagrangian method (DP-ALM) will be presented for solving a family of linearly constrained convex minimization problems whose objective function is not necessarily smooth. This DP-ALM not only enjoys a flexible dual stepsize, but also contains a proximal subproblem with relatively smaller proximal parameter. By a new prediction-correction reformulation for this DP-ALM and similar variational characterizations for both the saddle-point of the problem and the generated sequences, we establish its global convergence and sublinear convergence rate in both ergodic and nonergodic senses. A toy example is taken to illustrate that the presented lower bound of proximal parameter is optimal (smallest). We also show a relaxed accelerated version as well as a linearized version of DP-ALM when the objective function has composite structures. Preliminary experiments results show that our proposed methods outperform some well-established methods.

2 - The novel interior augmented Lagrangian methods for constrained optimization
Xinwei Liu, Yu-Hong Dai

Interior-point approach is one kind of most important and effective methods for nonlinear inequality-constrained optimization, whereas classic augmented Lagrangian methods are very efficient in solving nonlinear equality-constrained optimization and convex optimization. The newly research has shown that the interior-point augmented Lagrangian function can be of higher-order smoothness, and is convex when the original optimization problem is convex. These nice properties make the novel augmented Lagrangian applicable and effective not only for convex optimization but also for non-convex optimization

problems. We summarize our interior-point augmented Lagrangian methods on non-convex and convex optimization, and point out some next research topics.

3 - Exact Solution Method for Nonlinear Bilevel Interdiction Problems: Applications in Investment and Facility Disruption
Suyog Nigudkar, Ankur Sinha, Sachin Jayaswal

Bilevel optimization is a powerful framework for modeling hierarchical decision-making problems involving multiple players. A significant subset of these problems is the Interdiction Problems, where a leader strategically disrupts the follower's objective by anticipating their optimal response. While linear interdiction problems have been extensively studied, nonlinear interdiction problems remain underexplored due to their computational complexity, particularly when involving integer variables and nonlinear objectives. This paper introduces an exact solution method for mixed-integer bilevel interdiction problems with nonlinear objectives. The proposed method iteratively refines upper and lower bounds by constructing an inner approximation of the convex hull of the follower's feasible region and approximating the nonlinear objective using a representative sample of feasible solutions. To demonstrate its effectiveness, we apply the approach to two application problems: (i) a nonlinear knapsack interdiction problem, which models diminishing marginal returns in competitive investment settings, and (ii) a capacitated facility interdiction problem, where interdiction leads to operational disruptions with nonlinear cost effects. Computational experiments demonstrate the efficiency and accuracy of the proposed method, highlighting its potential for addressing complex interdiction scenarios in strategic decision-making applications.

4 - A Fast Smoothing Damped Newton Method for Bilevel Hyperparameter Optimization for SVC
Qingna Li

Support vector classification (SVC) is a supervised learning method for classification tasks in machine learning, where hyperparameter selection has been discussed by many researchers both theoretically and practically. In this paper, we focus on solving the large-scale mathematical program with equilibrium constraint (MPEC) derived from the bilevel hyperparameter selection of machine learning classification model, which is to choose the best parameter C in L1-SVC. It is extremely challenging to design an efficient numerical algorithm to solve such MPEC due to the large number of datasets. To tackle the challenge, we smooth the complementarity constraints in the MPEC, and analyze theoretical properties of the resulting smoothing problem, including its feasible sets, Jacobian matrix and second order sufficient condition. Then we apply a damped Newton method to solve it, in which BICG-STAB algorithm is used to solve the KKT system based on its sparse square structure. Under certain assumption, the proposed smoothing damped Newton method (SDN) enjoys a quadratic rate of convergence. Finally, extensive numerical results on the datasets from the LIBSVM library verifies the high efficiency in practice with superior generalization performance of SDN over almost all the datasets used in this paper comparing with the other two methods. Further discussions on SDN also provides verification on the second-order sufficient condition, the smoothing parameter and the convergence rate.

■ WD-38

Wednesday, 14:30-16:00 - Room: Michael Sadler LG19

Privacy-Aware and Optimization-Driven AI Systems

Stream: Data Science meets Optimization
Invited session
Chair: *Sureyya Ozogur-Akyuz*
Chair: *Polat Goktas*

1 - Privacy-Preserving Robust Counterfactuals for Secure Model Interpretability
Sureyya Ozogur-Akyuz, Volkan Bakır, Polat Goktas, Fatih Kahraman

Counterfactual explanations provide model-agnostic interpretability by generating synthetic data points that alter a model's decision toward a desired outcome. We introduced DiCE-Extended, which enhances counterfactual robustness by shifting generated instances further from decision boundaries. However, while this improves stability, it does not inherently protect against adversarial attacks or ensure data privacy. To address this, we integrate Differentially Private Counterfactuals (DPC) via Functional Mechanism to extend DiCE-Extended with privacy-preserving capabilities. In our approach, we first map dataset classes into a latent space using an autoencoder, which captures intrinsic data structures while reducing dimensionality. Then, we introduce differential privacy by adding calibrated noise to prototype class representations in this latent space. These noisy prototype classes serve as references for generating DiCE-Extended counterfactuals, ensuring that adversarial actors cannot easily exploit counterfactuals for inference or data extraction. Experimental results confirm that robust-DPC counterfactuals enhance both model security and privacy without compromising interpretability.

2 - Analyzing Human Movement in Urban Spaces: The Influence of Cultural Venues, Green Infrastructure, and Fare Zones in London
Jihye Hwang, Seongsoo Jang, Yuncheol Kang

Understanding human movement in urban spaces requires an analysis of how cultural, environmental, and transportation-related factors shape mobility. This study explores the influence of cultural venues, green infrastructure, and London's fare zones on the movement patterns of international and domestic travelers. Using GPS data from mobile devices, we identify areas with high population activity intensity (PAI) at different times of the day and analyze areas of interest (AOI) to examine how urban spaces attract and sustain human activity. We investigate how major cultural venues—such as museums and historical landmarks—and access to green infrastructure, including parks and riverfronts, shape the movement patterns of both international and domestic travelers. Additionally, we analyze the role of London's fare zones in shaping public transportation usage, assessing whether fare structures significantly influence mobility choices and route selection. To detect AOI hotspots dynamically, we integrate LSTM deep learning models with spatial and environmental data, enabling real-time analysis of evolving movement patterns. Unlike static human mobility studies, this approach dynamically tracks evolving urban dynamics. The findings will support urban planning and transportation strategies by optimizing cultural venue accessibility for travelers, enhancing green infrastructure to promote sustainable mobility, and guiding fare zone policies to support balanced urban development.

3 - Optimizing pricing strategies through learning the market structure
Khosroparviz Naderivarandi, Ezgi Karabulut, Burak Gokgur

This study explores the integration of market structure learning into pricing strategies to maximize revenue in e-commerce and retail environments. We consider the problem of determining the revenue maximizing price of a single product in a market of heterogeneous consumers segmented by their product valuations; and analyze the pricing strategies for varying levels of prior market structure knowledge. The proposed mechanisms utilize customer preference data, and adopt a two-stage approach: an offline learning stage that focuses on learning market structure, including the number of segments and their sizes and valuations, and an online learning stage that prioritizes revenue maximization and iteratively updates these estimates to refine pricing strategies dynamically. Experimental results demonstrate the effectiveness of these methods in adapting to different levels of market knowledge, revealing the economic value of learning market structure in achieving near optimal revenues. Our findings suggest that even with limited prior market knowledge, firms can benefit from incremental learning strategies to reach profit levels that are relatively close to those achieved in full-information scenarios.

4 - A Hybrid Matheuristic and Clustering Algorithm to Solve the Districting Problem in Public Bicycles Shared Systems
Guillermo Cabrera-Guerrero, Pablo Andrés Maya Duque, Jalid Danoun, Carolina Lagos

Bicycle Sharing Systems (BSS) have emerged as an alternative to traditional commuting methods. Despite its benefits, BSS's efficient management and optimization face inherent challenges, ranging from system demand variations to station capacity constraints. This paper addresses a tactical problem in BSS, namely the districting problem. The problem aims to find a network configuration where the stations are allocated to cluster centres so that each cluster meets balance constraints. The problem is modelled as an IP problem. Previously, we implemented a matheuristic based on a local search algorithm which selects the centre of each cluster of stations. Then, a mathematical solver solves the allocation of the stations to the centres, considering balancing constraints. In that paper, we limited our local search to choosing a cluster centre within predefined clusters to reduce the search space. This paper investigates the effect of the clustering strategy on the local search's performance. Thus, we implement two clustering strategies to provide the local search algorithm with better clusters. We try the well-known k-means and fuzzy c-means algorithms to provide our local search matheuristic algorithm with different grids to seek. The results significantly improve performance compared to the arbitrary predefined grid used in our previous work. Also, results show that some grid designs tend to be better than others and, thus, impact the final results.

■ WD-39

Wednesday, 14:30-16:00 - Room: Newlyn LG.01

Sustainable & Resilient Cities

Stream: Sustainable & Resilient Systems and Infrastructures
Invited session
Chair: Iris Forma

1 - Evaluation of the effectiveness of light greening interventions for the reduction of risks to citizens' health. Naples's north district
Anna Limmatola, Valeria D'Ambrosio, Ferdinando Di Martino, Federica Dell'Acqua

The Bologna Charter 2017 recognizes green infrastructures as essential elements for the construction of ecosystem services with great connective potential. In this regard, we know that a green area has a different capacity to absorb GHG pollutants depending on the types of vegetation that compose it, their state of health and whether they are native species. This study aims to find a measure, through the application of a GIS-Based methodology, capable of evaluating the effectiveness of light greening interventions, in terms of benefits for the population, with the aim of reducing risks to citizens' health, measuring the ex-ante and ex-post parameters within a given district. We are in the midst of a climate crisis, which translates into risks to citizens' health. Fine dust killed 238,000 people in Europe in 2020 alone, of which considering other sources of pollution, in Italy there are a total of 311 thousand deaths. Diseases and pathologies from GHGs affect above all that part of the population that falls within the poorest and weakest sections of society, and it is for them first and foremost that concrete, immediate and lasting measures must be studied and implemented that ensure well-being in terms of health and liveability.

2 - Reducing Total Trip Time and Vehicle Emission through Park-and-Ride — methods and case-study
Ayane Nakamura, Fabiana Ferracina, Naoki Sakata, Takahiro Noguchi, Hiroyasu Ando

This study addresses important issues of traffic congestion and vehicle emissions in urban areas by developing a comprehensive mathematical framework to evaluate Park-and-Ride (PnR) systems. The proposed approach integrates queueing theory and emissions modeling to simultaneously assess waiting times, travel times, and vehicle emissions under various PnR usage scenarios. The methodology employs a novel combination of Monte Carlo simulation and matrix geometric analytic methods to analyze a queueing network representing PnR facilities and road traffic. Emissions are calculated using the Methodologies for Estimating Air Pollutant Emissions from Transport (MEET) framework. In this study, the social cost of emissions and total trip time (SCETT) is introduced as a comprehensive metric for evaluating PnR system performance. A case study of Tsukuba, Japan demonstrates the model's applicability, revealing potential reductions in social costs related to total trip time and emissions through optimized PnR policies. Specifically, the study found that implementing optimal bus frequency and capacity policies could reduce total social costs by up to 30% compared to current conditions. This research contributes to the literature by providing a unified framework for evaluating PnR systems that considers both time and environmental costs, offering valuable insights for urban planners and policymakers seeking to improve transportation sustainability.

3 - AI-Driven GIS for Dynamic Flood Risk Assessment: Integrating MCDA, Remote Sensing, and Real-Time Climate Analytics
Amirbahador Kouchakkapourchali

As climate change intensifies extreme weather events, traditional flood risk models struggle to provide dynamic and data-driven assessments. This study introduces a novel AI-powered GIS framework that combines Multi-Criteria Decision Analysis (MCDA) with real-time climate data and machine learning for adaptive flood risk prediction. Using the Analytic Hierarchy Process (AHP), risk factors—including precipitation anomalies, elevation, land use dynamics, soil permeability, and hydrological networks—are weighted and processed through Python-based geospatial analysis. Satellite-derived climate data and remote sensing imagery enable real-time hazard detection, while AI-driven pattern recognition enhances predictive accuracy. The framework generates an interactive flood risk map, dynamically updating based on changing environmental conditions. By bridging GIS, artificial intelligence, and climate analytics, this approach offers an automated, scalable tool for real-time disaster resilience, empowering policymakers with precise, data-driven insights for climate adaptation and urban planning.

■ WD-42

Wednesday, 14:30-16:00 - Room: Newlyn GR.02

Recycling supply chains

Stream: Circular & Sustainable Supply Chains
Invited session
Chair: Christos Papanagnou

1 - Multiobjective Decision-Making for PET Bottle Recycling: A MILP-Based Approach for a Sustainable Circular Economy
Ali Zahedi, Eva Selene Hernández Gress, José-Fernando Camacho-Vallejo, Mostafa Hajiaghaeikeshteli

The rapid increase in PET bottle consumption brings attention to proper reaction for production and consumption. In this talk, we focus on water PET bottles within Circular Supply Chain, aiming to study recycling PET destination (between close-loop and open-loop PET bottle recycling) to identify the most sustainable pathway in terms of material circularity, energy consumption, and cost-effectiveness. While close-loop recycling focuses on restoring PET bottle waste to new PET bottles, repurposing emphasizes creating new applications of PET bottle waste such as civil construction, 3D printing filament, and polyester fiber. A circular economy network is designed from the phase of

PET bottle production from vPET (close-loop recycling) and four additional open-loop recycling models (bottle-to-polyester fiber, bottle-to-3D printing filament, and bottle-to-concrete). To examine the three indicators through a quantitative model, a mixed integer linear programming model with three objectives is proposed to minimize process cost, minimize energy consumption, and maximize material circulation. The model is solved by the Lp-metric method via CPLEX solver for a case study of 37 convenience shops determine the optimal recycling strategy under each cost-effectiveness, material circularity, and energy consumption preferences. Preliminary results highlight the trade-off between three preferences, serving as a reliable guide to move toward a sustainable circular economy for PET bottles.

2 - A closed loop supply chain with testing and validation of public recycling policies.
Vicente Andrés Marín Vélez, Francisco J. Tapia-Ubeda

Recently, there has been a considerable requirement for integrating sustainability into the management of supply chains networks. However, not all these aspects have been studied or evaluated within the optimization models developed, which are applied for the design of the supply chain network. The aim of this research is to establish a framework based on optimization models for designing the supply chain network by including all aspects of sustainability. This would enable the management of both household and industrial waste. A testing process will be carried out to evaluate the networks behavior under different public policies that impact the various level of the network. Additionally, the framework aims at finding the optimal configuration of the network for each of the policies considered. With the implementation of this proposed framework, decision-making at various organizational levels is facilitated, promoting sustainability practices and the adoption of public policies improving performance in supply chains. Synthetical instances are tested, and the results obtained confirm and reinforce the relevance of the integration of these decisions and sustainability aspects for supply chain network design.

3 - Optimizing Collection and Recycling in Plastic Waste Supply Chain - A Game Theoretic Approach
Manu Mathew, Bhavinkumar Shah

Managing plastic waste efficiently and sustainably is a major challenge to most emerging economies. To address this, the Indian government implemented Extended Producer Responsibility (EPR), making producers responsible to manage post-consumer plastic waste. Unlike other waste types, the Central Pollution Control Board has mandated recycled plastic use in new products alongside recycling targets. However, recycled plastic pellets (rPET) are often expensive and of lower quality necessitating extra processing resulting into higher operational costs for the manufacturers or brand owners who tend to explore alternative recycling strategies. In this study, we develop a two-echelon model consisting of a brand owner and an external recycler to determine the impacts of PET collection and reuse mandates on their supply chain profit in the centralised and decentralised supply chain. To understand the dynamics between brand owner and external recycler, we propose a Stackelberg game theory model. For the decentralised supply chain, we demonstrate how a two-part tariff improves total supply chain profit. This study shows, higher EPR targets drive outsourcing, raising recycler rPET price. Elevated costs of virgin plastic boost the collection efforts made by brand owner, lowering rPET prices. We discuss various conditions while proposing a well-designed two-part tariff contract that is beneficial to both players to achieve higher supply chain efficiency and profits.

4 - Dynamics and stability in Recycling-Enhanced Supply Chains
Christos Papanagnou

This study examines the role of third-party centres in reverse supply chains, focusing on their ability to streamline product returns, refurbishment, and remanufacturing to enhance overall supply chain performance. A three-echelon reverse supply chain model is considered consisting of a retailer, a hybrid third-party centre, and a manufacturer. The model explores the impact of third-party centres on the efficiency of handling returned products, with a focus on inventory replenishment strategies and minimising order variability (bullwhip effect).

A state-space model is developed to capture the dynamics of the model. The flow of information (orders) moves backward, while product flows move both forward and backward. The model assumes a continuous replenishment policy, with inventory levels monitored through a base-stock policy at both the retailer and third-party centre.

The study's findings indicate that the presence of a third-party centre reduces lead times for returned products and enhances inventory stability. The proportional control mechanism improves order stability, reducing variability and mitigating the bullwhip effect in the reverse supply chain. The results suggest that strategic third-party involvement in return logistics can enhance customer satisfaction by ensuring rapid product replenishment.

■ WD-43

Wednesday, 14:30-16:00 - Room: Newlyn GR.07

Algorithms and Applications

Stream: Software for Optimization
Invited session
Chair: *Tobias Achterberg*

1 - From Infeasibility to Feasibility - Improvement Heuristics to Find First Feasibles for MIPs
Tobias Achterberg

Relaxation Induced Neighborhood Search (RINS) and other large neighborhood search (LNS) improvement heuristics for mixed integer programs (MIPs) explore some neighborhood around a given feasible solution to find other solutions with better objective value. This often leads to a chain of improving solutions with a high quality solution at its end, even if the starting solution is rather poor.

RINS and its variants are the most important heuristic ingredients in Gurobi to find good solutions quickly. But they have one issue: they can only be employed after an initial feasible solution has been found.

This initial feasible solution is usually found by other heuristics, so-called "start heuristics", like rounding of LP solutions, fix-and-dive, or the Feasibility Pump.

In this talk, we discuss a different approach, which works surprisingly well: similar in spirit to the Feasibility Pump, consider infeasible integral vectors as input to the improvement heuristics and search in the neighborhood for vectors with small violation to act as new starting point for the next LNS improvement heuristic invocation.

2 - Implementing a generic Logic-Based Benders Decomposition in SCIP
Sachin Rajendran, Elina Rönnberg, Stephen Maher

Logic-Based Benders Decomposition (LBBD) is a powerful approach for solving discrete optimization problems with certain structures. While LBBD is often tailored for specific problem types, our goal is to develop a generic purpose LBBD framework within SCIP — a leading solver for Constraint Integer Programming (CIP). A key advantage of implementing in SCIP is the ability to use CIP-solving features, which combine Constraint Programming (CP), Mixed Integer Programming, and Satisfiability techniques. As opposed to CIP, which approaches constraints individually, LBBD treats the CP subproblem as a whole, thus we can leverage strong CP solvers for the subproblems.

Currently, SCIP offers some built-in components that can support LBBD, but extensions are necessary to create a fully functional and flexible LBBD framework. Existing features in SCIP, such as the classical Benders decomposition framework and constraint handlers, can be leveraged for LBBD implementation. In our current work, we target problems with implication structures and feasibility subproblems. For these we implement acceleration techniques such as cut strengthening and identifying irreducible infeasible subsystems. For future work we aim to utilize research on LBBD and develop a full-featured generic LBBD solver in SCIP.

3 - Primal and Dual Bounds for Multi-period Security Constrained AC-OPF
Matias Villagra, *Daniel Bienstock*

In this talk, we present fast and scalable algorithms for computing primal and dual bounds of challenging Multi-Period Security Constrained AC-OPF instances from the ARPA-E Grid Optimization Competition.

■ WD-44

Wednesday, 14:30-16:00 - Room: Newlyn 1.01

Advanced methods for designing and operating energy systems under uncertainty

Stream: Energy Economics & Management
Invited session
Chair: Benedict Brosius

1 - Assessing Renewable Energy Curtailment: Metrics, Impacts, and Mitigation Strategies
Seyed Ehsan Ahmadi, *Mohammad Fattahi*

As renewable energy sources (RES) expand, curtailment becomes a major issue, impacting grid reliability and investment feasibility. This study quantifies curtailment's effects on congestion, infrastructure risk, and energy transition decisions. By incorporating uncertainty in both load and RES generation, we introduce key metrics, including annual curtailed energy, peak curtailment levels, curtailment as a percentage of total RES generation, financial cost of curtailment, and revenue loss due to curtailed energy. Using a sample average approximation approach and historical load and weather data from 1980 to 2019 in New York State, we examine curtailment's relationship with RES expansion. Our findings show that a 20% increase in RES leads to a 5.52-fold rise in curtailment, exposing grid limitations. While energy storage is often proposed as a solution, our results reveal that adding 3,000 MW of storage only reduces curtailment by 1.28%, proving its limited effectiveness under high-curtailment conditions. These findings highlight the need for alternatives beyond grid-based strategies. Power-to-X (P2X) technologies, which convert surplus RES into hydrogen, synthetic fuels, or heat, provide a more effective option for minimizing curtailment and optimizing energy use. This research presents a structured framework for assessing curtailment risks and investment opportunities, supporting a more resilient and adaptive energy transition.

2 - Optimal Microgrid Sizing and Operation with Distributionally Robust Optimization
Gulfem Er, *Christine Currie*, *Gevorg Stepanyan*

In this study, we examine the optimal sizing and operation of a grid-connected microgrid system that includes wind turbines, photovoltaic (PV) panels, and batteries. Microgrids are small-scale power systems that enhance energy resilience, integrate renewable energy sources, and reduce dependency on centralized grids. The main challenge arises from the uncertainties from renewable energy sources, such as the intermittency of wind and solar production, which leads to significant variability in power generation. To address these uncertainties we employ a two-stage distributionally robust optimization approach. In the first stage, we make sizing decisions to minimize component-related costs. In the second stage, we focus on operational decisions regarding battery management and power exchanges with the grid to minimize operational costs. This approach reduces the risk of incorrectly sizing system components by considering the worst-case distribution within the ambiguity set. Finally, we reformulate the problem into a tractable Mixed-Integer Linear Programming (MILP) formulation, which we solve using Gurobi Python. We use the presented model to design a microgrid based on similar systems in the UK, utilizing publicly available data from Octopus Energy Ltd.

3 - Modeling the stochastic and sequential real-time operation of energy systems during design optimization via multi-step Benders decomposition
Benedict Brosius, *Daniel Jost*, *Frederike Kuperjans*, *Benedikt Nilges*, *Niklas von der Assen*

Design optimization methods are widely used to identify the optimal design of integrated energy systems (IESs). For simplicity, most design optimization methods assume perfect foresight over the operational time horizon. However, the real-time IES operation is stochastic and sequential due to uncertain forecasts and limited forecast horizons. Thus, design optimization models that assume perfect foresight will estimate unattainable operational cost, leading to suboptimal designs. The perfect foresight assumption particularly affects the operation of storages, which are essential for integrating large shares of renewables.

This study proposes a novel multi-step design optimization method that increases the stochastic and sequential detail of IES operation in each step. The method is based on Benders decomposition, where the operational subproblem is a stochastic rolling horizon operational optimization, a common approach for the real-time IES operation.

In two IES case studies, we compare the designs resulting from our novel method to designs generated with the perfect foresight assumption. We evaluate all designs via stochastic rolling horizon operational optimization. Compared to assuming perfect foresight, our method reduces the total objective value by 1.3%. In addition, it greatly increases reliability, reducing the expected undersupply by up to 56.8%. These findings reveal the need to reflect the stochastic and sequential IES operation during design optimization.

4 - Optimizing Hydrogen Production via Electrolysis: A Case Study of Ribeirão Preto and São Carlos, Brazil
Alexandre Leoneti, *Gul Hameed*, *Michael Short*, *Marcelo Nagano*, *Amin Zarei*, *Jéssica Campoli*, *Veit Schagon*

Brazil holds a strategic position in the global energy transition due to its highly renewable energy matrix. According to the Brazilian Ministry of Mines and Energy National (Brazil, 2024a), 49.1% of the country's total energy supply comes from renewable sources, making Brazil one of the nations with the cleanest energy matrix in the world. In the electricity sector, this share is even higher, with more than 88% of electricity generation coming from sources such as hydropower, wind, solar, and biomass (Brazil, 2024a). Yet, Brazil may become one of the world's most competitive producers of green hydrogen, leveraging its abundant renewable energy and expanding infrastructure. The National Hydrogen Program (PNH2), by the Brazilian government in 2021, aims to foster research, development, and investment in hydrogen sector, aligning the country with international sustainability goals (Brazil, 2021). In particular, Brazil has established strategic goals for advancing low-carbon hydrogen through the 2023-2025 Triennial Work Plan, part of the PNH2. By 2025, the country aims to expand the implementation of pilot hydrogen plants across all regions. By 2030, the goal is to position itself as one of the world's most competitive producers in this sector. By 2035, the strategy includes the creation of hydrogen hubs, integrating production, distribution, and consumption efficiently.

■ WD-47

Wednesday, 14:30-16:00 - Room: Parkinson B08

Game Theory in Retail II

Stream: Retail Operations
Invited session
Chair: Winfried Steiner

1 - Dynamic Transshipment Price Negotiations
Nagihan Comez Dolgan, *Metin Cakanyildirim*, *Kathryn E. Stecke*

We study transshipments among independent retailers during a sales season and orders to suppliers are modeled. Instead of the extreme strategies of complete or no sharing, most independent retailers prefer a flexible sharing strategy that can be developed via appropriately setting endogenous transshipment prices. We dynamically study retailers' transshipment price negotiations, and hierarchically addresses the coordination of transshipments and orders. After a stock out, retailers seek a mutually acceptable transshipment price. When no retailer has absolute power to single-handedly obtain the monetary benefit of a transshipment, retailers can negotiate.

A coordinating transshipment price interval is found for each period and inventory level at the requested retailer. A time and inventory dependent price interval, if non-empty, includes all of the coordinating transshipment prices; if empty, the transshipment is unacceptable. A bargaining framework yields a unique transshipment price from this interval. The price is either static or dynamic depending on retailer powers, but always constitutes a martingale process. To coordinate retailer orders under any negotiated prices, a mechanism whereby each retailer pays to the other retailer an extra amount for orders, called purchase cost sharing, is introduced. By adjusting the cost of a unit, the cost sharing mechanism eliminates suboptimal stocking and so coordinates retailer orders and can be made Pareto-improving.

2 - Traditional Sales versus Subscription Rentals in Retail: Business Model Choice, Price and Assortment Competition
Oben Ceryan, Aditya Jain, Tolga Aydinliyim, Mehmet Altug

Motivated by the emergence of rental business models that cater to variety-seeking customers through subscription services, we examine the economics of the "subscription rental business model" in contrast to the traditional "seller business model." We formulate the utility function of variety-seeking customers based on Salop's (1979) circular model of spatial competition and use it to determine demand functions for each business type as a function of price and assortment size. First, we consider a monopolist firm's choice between the two models and show that the rental business model optimally chooses a higher assortment. Consequently, this business model prevails only when assortment and transaction costs are small. We then analyze competition between a rental firm and a seller firm. Our analysis shows that when assortment costs are moderate, both firms can coexist without competing on price. In these cases, the equilibrium is characterized by the rental firm choosing a larger assortment and the seller firm contracting its assortment.

3 - Retailers' Parallel Importation and Service Provision in a Supply Chain: Incentives and Impacts
Xiang Zhu

We employ a game-theoretic approach to examine intricate relationships between retailers' strategic decisions of parallel importation and service provision. Considering a scenario where a manufacturer distributes products through a retailer in a low willingness-to-pay (WTP) market (L) and directly in a high WTP market (H), we analyze consequences of the retailer's choice to provide services in market L while engaging in parallel importation from market L to H. Our findings reveal that the pursuit of parallel importation causes a decline in the retailer's service level, and a growth in consumers' WTP in market H corresponds to a diminished service level in market L. Additionally, the retailer's provision of services weakens its incentive for parallel importation but intensifies conflicts with the manufacturer. Although the combined strategy enhances overall consumer surplus, consumers in market L consistently suffer from parallel importation. Moreover, even though the markets are interconnected owing to parallel importation, the retailer's service provision does not visibly affect the potential service level of the manufacturer in market H.

■ WD-48

Wednesday, 14:30-16:00 - Room: Parkinson B09

Bridging explainable decision-making and mathematical optimization III

Stream: Transparent and Fair Decision Making with Mathematical Optimization
Invited session
Chair: Vanesa Guerrero
Chair: *Emilio Carrizosa*

1 - Soft decision trees for survival analysis
Antonio Consolo, Edoardo Amaldi, Emilio Carrizosa

Decision trees are widely used in survival analysis due to their interpretability and capacity to capture complex relationships. Survival trees, which estimate the timing of specific events based on censored historical data, are traditionally constructed using heuristic methods. Recently, there has been increasing interest in globally optimized trees, where the entire tree is trained by minimizing an error function over all its parameters. We propose a new soft survival tree model (SST), with a soft splitting rule at each branch node, trained via a nonlinear optimization formulation amenable to decomposition. SSTs provide for every input vector a specific survival function associated to a single leaf node, satisfying the conditional computation property. SST and the training formulation combine flexibility with interpretability: any smooth survival function estimated through maximum likelihood can be used, while the leaf nodes represent clusters of distinct survival curves corresponding to different data points. Numerical experiments on 15 well-known datasets show that SSTs, with parametric and spline-based semiparametric survival functions, trained using an adaptation of the node-based decomposition algorithm proposed by Consolo et al. (2024) for soft regression trees, outperform three benchmark survival trees in terms of four widely-used discrimination and calibration metrics. Moreover, we show how SSTs can be extended to consider group fairness.

2 - Fair and sparse Bayesian logistic regression.
Rafael Jiménez-Llamas, Emilio Carrizosa, Pepa Ramirez Cobo

In this work we propose a novel version of the Mean Field Variational Inference approach to Bayesian logistic regression that produces fair and sparse solutions. This is accomplished by an appropriate prior selection and a penalization term dependent on the unfairness of posterior predictions that leads to a set of CAVI equations whose (sparse) solutions ensure fairness on the predictions in a private manner. The numerical illustrations show how the new method results in a trade-off between performance, sparsity and fairness, which eases the potential users' making decision process.

3 - A conic optimization framework for shape-constrained functional regression analysis
Vanesa Guerrero, Maria Durban, Cristina Molero-Río, Jesús Secilla Martínez

Functional regression refers to regression models that incorporate functional covariates, a functional response, or both. In many cases, prior knowledge from fields such as biology, medicine, or engineering suggests that the estimated functional coefficients should satisfy specific shape constraints, such as non-negativity, monotonicity, or convexity/concavity. However, standard unconstrained estimation methods do not naturally enforce these constraints. This study explores whether the combination of conic optimization and penalized splines (P-splines) proposed by Navarro-García, Guerrero, and Durbán (2023) can achieve better performance than recent methods in the literature for estimating shape-constrained functional regression coefficients. The evaluation is conducted using both simulated and real datasets.

4 - On Disperse (Generalized) Linear Models
Emilio Carrizosa, Renato De Leone, Marica Magagnini

Linear models are key in Explainable Machine Learning, since they provide an easy-to-understand meaning to their coefficients and the impact of the different features in predictions. However, not all accurate linear models may be equally appealing because of secondary objectives such as sparsity or other measurement costs. For this reason, several methods have been proposed in the literature to address the multiobjective problem of joint optimization of accuracy and other secondary criteria, the lasso being the most popular approach.

In this talk we propose a different strategy: we explore how different linear models with a good accuracy can be. We do this by considering a biobjective p-dispersion model, in which p models are sought jointly maximizing an overall accuracy measure as well as a dispersion measure. Several metrics are used to measure dispersion, including a function of the distance between their parameters, the set of features used to predict, and the distance between the distribution of the predictions in a set of records. Moreover, different scenarios for the feasible region are considered, e.g. whether the p models are to be chosen from, or added to, a list of pre-selected linear models, like lasso models.

All these variants are expressed as biojective nonlinear mixed integer optimization problems, numerically tested.

Although we focus on linear models, the paradigm is extended to generalized linear models.

■ WD-49

Wednesday, 14:30-16:00 - Room: Parkinson B10

Advances in Conic Optimization and Applications

Stream: Conic and polynomial optimization
Invited session
Chair: *Bissan Ghaddar*
Chair: *Tim Graulich*

1 - Duality in Conic Reformulations of Standard Convex Programming Problems
Jakub Hrdina

Convex conic linear programming problems are problems of minimizing a linear function over the intersection of an affine subspace with a convex cone. Since every convex set can be embedded into a convex cone, standard convex programming problems can be equivalently reformulated as convex conic linear programming problems. We focus on examining duality and its aspects in such reformulations. In addition, we concentrate on the relationship between the conic version of the Slater condition and the weak version of the Slater condition for standard convex programming problems.

2 - Leveraging similarities in Grid Topologies for Learning in Power Systems
Tim Graulich, Marie Münster, Bissan Ghaddar, Rasmus Bramstoft

The optimal power flow (OPF) problem, particularly the alternating current formulation (AC-OPF), is fundamental to the operation of electricity grids. However, it presents a significant computational challenge due to its non-linear and non-convex nature. In recent years, machine learning (ML) has gained attention as a promising tool for enhancing the efficiency of solving the AC-OPF problem. While many studies focus on improving the predictive performance of these ML models, a frequently remaining caveat is the fixed topology requirement for these techniques. Thus, whenever the grid topology changes, new training samples need to be generated, and the models retrained. An expensive process, especially for large systems.

This study aims to investigate the potential of identifying similarities between different grid topologies, especially common generator characteristics, to improve the adaptive performance of ML methods. This research seeks to reduce the issue of the fixed topology requirement, remaining in many proposed ML solutions and ultimately enhance the decision-making process for power grid operations.

3 - Obtuse almost-equiangular sets
Bram Bekker

For t between -1 and 1, a set of points on the (n−1)-dimensional unit sphere is called t-almost equiangular if among any three distinct points there is a pair with inner product t. We propose a semidefinite programming upper bound for the maximum cardinality α(n,t) of such a set based on an extension of the Lovász theta number to hypergraphs. This bound is at least as good as previously known bounds and for many values of n and t it is better.

We also refine existing spectral methods to show that α(n,t) is at most 2(n+1) for all n and nonpositive t, with equality only at t = −1/n. This allows us to show the uniqueness of the optimal construction at t = −1/n for n at most 5 and to enumerate all possible constructions for n equal to 2 and 3 and nonpositve t.

■ WD-54

Wednesday, 14:30-16:00 - Room: Liberty 1.08

Stochastic Models and Optimal Control

Stream: Stochastic modelling
Invited session
Chair: *Epaminondas Kyriakidis*

1 - Interactive Robo-Advising through Scoring Mechanism
Yuwei Wang, Hoi Ying Wong

We investigate discrete-time predictable exploratory forward performance processes (PEFPPs) within a reinforcement learning framework, motivated by the practical consideration that a client's chosen investment strategy may deviate slightly from one that precisely corresponds to her risk aversion. By employing Tsallis entropy to quantify the level of model exploration and the client's uncertainty about her risk aversion, we construct and analyze PEFPPs for both the CARA and CRRA classes, along with the corresponding density function of the optimal investment strategies. This provides a theoretical foundation for our scoring mechanism, which is based on an acceptance-rejection method and the optimal control distribution induced by the PEFPPs. We demonstrate that the optimal exploratory control attains its maximal density at the optimal strategy derived in the absence of exploration. Furthermore, we establish a one-to-one correspondence between the client's score and the risk aversion parameter, so that for any fixed guess, the client's feedback score uniquely determines actual preferences. Furthermore, we propose an interactive robo-advising framework that, instead of requiring the client to specify risk aversion as a fixed input, infers her preferences by eliciting scores for recommended strategies. Using these scores, we iteratively refine our recommendation, aiming for the proposed strategy to exceed the client's acceptance threshold, while accounting for feedback errors.

2 - Optimal control of a damaging population through total catastrophes
Epaminondas Kyriakidis

A pest population grows in an area according to a simple deterministic immigration-birth-death process. The pest population may be controlled by some action that introduces total catastrophes. The length of time until the occurrence of a catastrophe is exponentially distributed. We restrict our attention to the class P of control-limit policies that take controlling action if and only if the pest population size exceeds a critical number. The control-limit policy which minimizes the expected long-run average cost per unit time within the class P is found.

The optimal control-limit policy is compared with the optimal control-limit policy that we obtain in the case in which the pest population grows according to the simple stochastic immigration-birth-death process. Numerical results are provided to illustrate the theoretical results.

3 - Dynamic Control of Multiclass Omnichannel Production Systems: Applications to Dynamic Pricing in Restaurants
Nasser Barjesteh, Amir Alwan

The rise of omnichannel production systems has transformed various industries, introducing new challenges in demand and operations management. One notable development is the adoption of dynamic pricing in omnichannel restaurants. Motivated by these trends, we develop a stochastic processing network model for an omnichannel production system serving price- and delay-sensitive customers. The firm offers a mix of make-to-order (MTO) and make-to-stock (MTS) goods, available through both walk-in and online channels, at multiple quote times. The objective is to maximize the long-run average expected profit through dynamic pricing, production scheduling, and order rejection decisions. MTO orders incur both earliness and tardiness costs, while MTS orders face tardiness and inventory holding costs. Walk-in customers have finite patience and may abandon the system if their wait time is excessive.

Since this problem appears analytically intractable, we consider an approximating Brownian control problem in the heavy-traffic regime. We prove that the optimal policy is a two-sided barrier policy with a state-dependent drift rate, for which we derive a closed-form solution. We then propose a joint dynamic pricing, scheduling, and rejection policy by interpreting this solution in the context of the original production system. Finally, we demonstrate the effectiveness of our proposed policy through a comprehensive simulation study and offer managerial insights.

4 - Stochastic Income and Optimal Policies: A New Analysis
Seyoung Park, Alain Bensoussan, Adannah Duruoha, Viswanath Ramakrishna

This paper provides a new analysis for optimal consumption and investment policies with stochastic income. Our analysis gives some kind of procedure for solving the Bellman equation with the dimension reduction scheme developed. In particular, we provide an interpretation of the reduced problem based on the probabilistic approach. The value funciton and optimal strategies are all explicitly characterized with analytic comparative statics provided, which is helpful to understand much of the economics in the paper. We also develop with the convergence theorem a numerical algorithm for policy iteration and solve the Bellman equation as a sequence of solutions to ordinary differential equations. Finally, the decision to invest more or fewer equity in the stock market in the presence of stochastic income is influenced, to a large extent, by the way in which how high risk aversion and income-to-wealth ratio are exhibited.

■ WD-55

Wednesday, 14:30-16:00 - Room: Liberty 1.09

Decision Support for Complex Humanitarian Crises

Stream: Humanitarian Operations
Invited session
Chair: *Vedat Bayram*

1 - A web-based decision support interface for the assessment and optimisation of physical access to humanitarian site locations
Andries Heyns, Jose Luis Alvarez, Kit Daniel Searle

Humanitarian interventions often occur in environments with limited transport infrastructure and challenging terrain. In these contexts — where people may travel hours or days to reach services — evaluating access to services in terms of travel time is crucial. This helps identify service coverage gaps and can aid in the identification of future site locations. Example services include health clinics, vaccination points, shelters, water and sanitation points, and distribution centres.

Médecins Sans Frontières (MSF) UK/Ireland is developing a web-based decision support interface that leverages an advanced accessibility model. The interface automates data collection and processing, providing realistic travel time estimates that almost anyone can use. Alternative tools for such analyses require specialised expertise and data, making them inaccessible to many humanitarian decision-makers.

The platform can simulate service accessibility "shocks" from disasters or political events that impact travel behaviour. Furthermore, a multi-objective genetic algorithm is incorporated to optimise new site locations — maximising population coverage while minimising travel effort. Using novel strategies for dealing with large datasets, it optimises the placement of between M and N new sites with a variable-length chromosome approach.

2 - Two sides of the same precarious coin: Addressing Conflict and Climate Crises through Mindanao's Lens
Patience Saungweme, Stefan Spinler

Forced displacement is increasingly driven by integrated shocks, yet there exist limitations in how migration policies and humanitarian response mechanisms account for their combined effects. This case study explores the interplay between conflict and climate-induced displacement in Mindanao, a case uniquely illustrating complex crises. We examine how these shocks shape displacement dynamics and decision-making processes of both affected populations and intervening humanitarian actors. Using a mixed-methods approach, we integrate quantitative simulations of migration and response dynamics and their impact, with qualitative disaster preparedness perceptions data. Findings shed light on misalignments existing between humanitarian operations responses and socio-political realities of displaced communities, along with their implications on long-term food security and sustainable livelihoods recovery. By bridging the gap between displaced populations' needs and institutional responses, this research provides insights into humanitarian operations and policy adaptations necessary for more effective humanitarian responses and enhanced community resilience. We provide initial directions for how integrated strategies can be operationalized through conflict- and climate-sensitive humanitarian response design and leadership, enabling the shift from short-term aid to long-term support that ensures sustainable food security and livelihoods recovery when complex crises become protracted.

3 - Enhancing Social Aid Delivery with Public Transport: A Learning-based Optimization Framework
Vedat Bayram, Barış Yıldız, Vahid Akbari, Ali Dogru, Pinar Keskinocak

Social aid programs require regular distribution of aid in non-disaster conditions to beneficiaries living in urban areas where poverty and hunger concentrate. Effective social aid distribution in large urban areas faces critical logistical challenges, including high transportation costs, inefficient resource allocation, and limited fleet capacity. In this study, we propose a novel two-echelon distribution system that integrates public transportation networks (PTNs) and volunteer couriers to enhance efficiency, cost-effectiveness, and sustainability. Our approach employs a learning-based decomposition methodology, which partitions the problem into a PTN-based backbone model and last-mile routing subproblems, leveraging machine learning to optimize delivery flows. We collaborate with the Ankara Metropolitan Municipality to benchmark our system against current social aid distribution practices. Our findings underscore the potential of integrating PTNs into urban social logistics, offering a scalable, cost-efficient, and environmentally sustainable solution for aid distribution in metropolitan areas.

■ WD-56

Wednesday, 14:30-16:00 - Room: Liberty 1.11

Green Distribution

Stream: Vehicle Routing and Logistics
Invited session
Chair: Edgar Possani

1 - The pollution-routing problem with speed optimization and uneven topography
David Lai, Yasel Costa, Emrah Demir, Alexandre Florio, Tom van Woensel

This paper considers a joint pollution-routing with time windows and speed optimization problem (PRP-SO) where vehicle speed, payload, and road grade influence fuel costs and CO2e emissions. We present two advanced optimization methods (i.e., approximate and exact) for solving the PRP-SO. The approximate strategy solves large-scale instances of the problem with a Tabu search-based metaheuristic coupled with an efficient fixed-sequence speed optimization algorithm. The second strategy consists of a tailored branch-and-price (BP) algorithm to manage speed optimization within the pricing problem. We test both methods on modified Solomon benchmarks and newly constructed real-life instance sets. Our BP algorithm successfully solves the majority of instances involving up to 50 customers and many instances with 75 and 100 customers. The heuristic can find near-optimal solutions to all instances and requires less than one minute of computational time per instance. Results on real-world instances suggest several managerial insights. First, fuel savings of up to 53% can be achieved when explicitly considering arc payloads and road grades. Second, fuel savings and emission reduction can be achieved by scheduling uphill customers later along the routes. Lastly, we show that ignoring elevation information when planning routes leads to highly inaccurate fuel consumption estimates.

2 - Optimising Medical Instrument Delivery Systems to Reduce CO2 Emissions in Healthcare
Ramzi Fayad

Abstract Objective:This paper explores optimising transportation and delivery systems for medical instruments in healthcare to reduce CO2 emissions. A case study examines the delivery of medical instruments to health centres in Leeds, UK, evaluates current practices and their environmental impact, aiming to identify inefficiencies that cause unnecessary emissions and delays in medical supply delivery. Methods:This study introduces a two-stage approach that combines Genetic Algorithm (GA) with the Clarke-Wright Savings Algorithm (CWS) to address the Vehicle Routing Problem (VRP). The CWS minimises transportation costs and distance travelled, and the number and capacity of trucks used through savings calculations, while the GA iteratively refines routes. This framework enhances the efficiency of CWS for initial solutions and the optimisation strengths of GA, resulting in improved routing effectiveness. Results:The two-stage approach significantly reduces transportation costs and CO2 emissions compared to traditional methods. Integrating electric and hybrid vehicles with optimised routing improves medical supplies delivery, highlighting the potential of multimodal strategies to enhance operational effectiveness. Conclusion:The integration of the Clarke-Wright savings algorithm and genetic algorithms offers a strong framework for optimising transportation in the medical sector. This two-stage approach can achieve sustainable practices while ensuring high service efficiency.

3 - Minimising transport costs and CO2 emissions: a vehicle routing and inventory control model for coin distribution.
Edgar Possani, Carlos Alfaro, Mariana Gomez Vargas

The distribution of metallic coins is a challenging process that most Central Banks face. In this paper we propose a mathematical programming model to optimise the routing and inventory levels to satisfying the demand of banking places to minimise both traveling costs as well as CO2 emissions. We solve the bi-objective model via an epsilon-constraint approach and a heuristic dependent on the definition of the serviceable neighbourhood for the regional distribution centers. We show the advantages of implementing this model, discuss the trade-off of minimising cost versus emissions, as well as various sensitivity analysis for a planning period of one year for the Central Bank of Mexico.

■ WD-58

Wednesday, 14:30-16:00 - Room: Liberty 1.13

Exact Algorithms for Vehicle Routing

Stream: Vehicle Routing and Logistics
Invited session
Chair: Massimo Di Francesco

1 - Branch-and-Price Approach for Two-Echelon Vehicle Routing Problem with Vehicle Synchronization
Milad Elyasi, Edhem Sakarya, Sonja Rohmer, Okan Ozener, Ali Ekici, Tom van Woensel

The rapid rise of e-commerce and grocery deliveries in urban areas is putting pressure on city infrastructure, leading to increased freight traffic, worsening congestion, and higher levels of air and noise pollution. This study addresses these challenges by proposing the Two-Echelon Prize-Collecting Vehicle Routing Problem with Time Windows and Vehicle Synchronization. The model utilizes smaller low- or zero-emission vehicles for deliveries, supported by larger trucks. Smaller vehicles, limited in capacity, handle small orders and require replenishment at depots or via larger trucks, which can also deliver both small and large items. Coordinating these fleets in cities, while considering capacity limits, tight delivery windows, vehicle synchronization, and selective order fulfillment, is complex. The problem is modeled on a time-expanded network, with network reduction applied to account for time constraints. A branch-and-price algorithm is introduced, solving instances with up to 200 customers and outperforming a leading optimization solver. The study also offers insights on synchronization, fleet management, and optimal depot/satellite placement.

2 - Two-index formulations for the traveling purchaser problem with incompatibily constraints
Raquel Bernardino, Daniel Santos

The Traveling Purchaser Problem with Incompatibility Constraints (TPP-IC) generalizes the classical Traveling Purchaser Problem (TPP) by introducing constraints that prevent certain items from being transported together. This problem arises in various real-world applications, such as hazardous materials transportation, where incompatible products must be handled separately to ensure safety and compliance. In this study, we propose a novel mixed-integer programming (MIP) formulation that models item incompatibilities using compatibility graphs. Compatibility graphs are used to model the incompatibility constraints implicitly, which makes it possible to use two-index formulations rather than a traditional three-index formulation to formulate the TPP-IC. Several compact and non-compact formulations are proposed for the TPP-IC, which are compared both theoretically and empirically. Additionally, valid inequalities are used to improve the quality of the linear programming relaxation values obtained by the formulations. A branch-and-cut framework is used to address the non-compact models. Preliminary computational results show that the two-index formulations provide better linear programming relaxation values than the three-index formulation, which we hope will contribute to the two-index models being more efficient than the three-index models in obtaining the optimal values.

3 - A Branch and Price algorithm for a mmulti-compartment multi-trip petrol replenishment problem
Massimo Di Francesco, Roberto Wolfler-Calvo, Simone Zanda

This paper addresses a new multi-compartment multi-trip Vehicle Routing Problem (VRP) with time windows in which tanker trucks carry different types of products separated by heterogeneous compartments. Moreover, the content of a compartment among can be split among several customers, even if any customer must served by a vehicle only. The objective is to determine the allocation of products to compartments and the least-cost routes. The problem is modeled by a mixed-Integer Linear Programming formulation. We present a Branch-and-Price algorithm for this problem. The algorithm is tested on data from an Italian petroleum transportation company and instances adapted from the literature.

■ WD-59

Wednesday, 14:30-16:00 - Room: Liberty 1.14

Urban Mobility II

Stream: Transportation
Invited session
Chair: Julia Bennell

1 - Optimal Multimodal Public Transportation Network Design Considering Population Density and Distribution
Masao Takeuchi, Tsutomu Suzuki

Urban public transportation systems typically consist of multimodal networks, including high-cost but fast railways and low-cost but slower bus services. Travelers choose optimal routes within these networks, yet few studies have comprehensively analyzed the impact of introducing multiple transportation modes and optimizing their combinations based on population density and distribution. This study aims to minimize costs for both operators and users while examining the effects of multimodal integration and optimal mode sharing. We formulate the problem of configuring transit modes to minimize total costs as a mixed-integer programming model and solve it for hypothetical cities using genetic algorithms and simulated annealing. The key findings of this study are as follows: First, the total transportation cost can be reduced by integrating multiple transit modes. Second, introducing a high-speed transit mode in the city center leads to the aggregation of travel corridors. Third, in cities with dispersed populations, suburban users experience increased costs, while the central transportation network becomes less dense. These results provide fundamental insights into the optimal design of multimodal public transportation systems based on regional characteristics.

2 - Optimization of Multimodal Tourist Trip Design Using Variable Neighborhood Search
Hesamaddin Elyasi, Milad Elyasi, Okan Ozener, Tom van Woensel

This study addresses the Multimodal Tourist Trip Design Problem (MTTDP), focusing on optimizing personalized travel plans in urban environments, with Istanbul as a case study. The problem involves designing efficient itineraries that integrate various transportation modes, such as walking, public transport, and private vehicles, while considering user preferences, travel time, and cost. We propose an advanced optimization framework using Variable Neighborhood Search (VNS), a metaheuristic algorithm, to explore the solution space effectively. The VNS approach iteratively refines solutions by systematically changing the neighborhoods of current solutions, offering flexibility and the ability to escape local optima. The model incorporates budget constraints and the importance of maximizing user satisfaction across multiple factors. Experimental results show that the VNS-based approach significantly outperforms traditional heuristic methods in terms of efficiency, providing highly personalized, feasible, and cost-effective travel plans for urban tourists.

3 - First and last mile problem in the case of island contexts
Marilisa Botte, Anna Limmatola

The first and last mile problem is a key factor to be addressed to develop a sustainable mobility framework. In other words, it is crucial that users' mobility choices to move from the starting point of their journey to a transport hub (the "first mile") and from the transport hub to their final destination (the "last mile") rely on environmentally friendly transport services; otherwise, the adoption of a sustainable choice for the main mode risks being undermined. Generally, where distances to be covered are not suitable for the walking mode, solutions such as shuttle services, shared micromobility options or small electric buses could help bridge the gap. This is true in urban frameworks, but it is even more challenging in the case of island contexts which generally present complex and fragile ecosystems and strive to balance connectivity, sustainability, and economic growth. Indeed, such territories are geographically isolated and require maritime transport to connect them with the mainland. This unique characteristic means that, unlike in more urbanized areas, the primary mode of transportation is often by boat, ferry, or cargo ship and, therefore, it is vital to address the complexities of moving people to and from the port. This work makes a first attempt at modeling such an issue in a real island context, with a particular focus on mainland-island commuters during the off-season.

4 - A review on the state of practice of demand responsive transport in the UK
Julia Bennell, Chiara Calastri, Christine Currie, Rym M'Hallah, Shobhit Saxena

The need for demand responsive transportive (DRT) in the UK public transport ecosystem has been long identified, with the first service implemented in the early 1980s. Despite such early initiation and a consistent push from the UK government, DRT remains confined to serving the needs of rural areas without any significant penetration in urban regions. In this article, we investigate the key challenges in broadening the scope of DRT from a rural alternative mode to a mainstream urban and rural mode of transport. The paper draws from the published literature and from the experience of DRT providers in practice. First, we review the literature and identify the need for new methods and approaches that enable a sustainable transformation of DRT. We focus on the social and operational challenges associated with designing a financially sustainable DRT service considering topics on both demand and supply aspects. Second, we report on a comprehensive discussion with stakeholders, including the experience of current DRT providers in the UK and user-specific focus. Subsequently, we qualitatively evaluated how DRT can supplement gaps in the current transport provision. Third, we contextualize the challenges we identified in DRT operations in other countries to highlight potential learning and new policy-specific solutions. Finally, we share our conclusions on what is needed to provide a more effective and efficient DRT service that caters to a wider population in the UK.

■ WD-60

Wednesday, 14:30-16:00 - Room: Western LT

DEA applications in Economic Modeling

Stream: Data Envelopment Analysis and its applications
Invited session
Chair: Kristiaan Kerstens

1 - Incentive Regulation of Power Distribution and Nonconvexities:Why Economists are Wrong, and Engineers are Only Half Right
Kristiaan Kerstens, Stefano Nasini, Miguel Pereira

Incentive regulation in many countries makes use of frontier benchmarking to determine the RPI-X type of formula to be applied to electricity distributors. Convexity is almost universally imposed on technologies and cost functions modelling electricity distribution by both

economists and engineers. However, in the engineering literature, it is well known that the physical laws involving the power flow going through the electricity grid entail the nonconvexity of the electricity distribution problem. This contribution is the first to investigate to which extent convex and nonconvex cost functions, as specified in the economic literature at the firm level, yield the same cost estimates. We explore the economics and engineering perspectives of the electricity distribution problem. Using secondary data from Finland and Iran, we show that the convexity hypothesis can be most often rejected. We also spell out the different implications of convex and nonconvex cost estimates for RPI-X cost norms. We hope our contribution makes regulators think twice about the use of the traditional convex cost models to regulate an industry that is intrinsically nonconvex and where the convex models provide a poor approximation of the nonconvex reality.

2 - Properties of the Translog Production Function with Applications to Synthetic Data Generation
Bernadett Bertóková, Maria Trnovska

The translog production function has gained significant attention in recent years due to its flexibility and ability to model diverse production processes. Unlike the Cobb-Douglas function, the translog function can capture varying elasticities of input substitution and different types of returns to scale. However, it remains a valid production function only when specific parameter conditions are met. In this study, we analyse these conditions and present a methodology for generating synthetic production datasets under both constant and variable returns to scale. These datasets provide a foundation for Monte Carlo simulations, enabling a comprehensive evaluation of Data Envelopment Analysis (DEA) models. The applicability of our approach is further demonstrated through a case study.

3 - A hybrid cost efficiency model under fixed and non-fixed prices: A case study on the Polish justice courts
Dimitrios-Georgios Sotiros, Magdalena Kapelko, Sebastian Tomczak

Courts of justice, apart from handling legal matters, should pursue operating with an efficient allocation of public resources and therefore, their economic efficiency should be regularly assessed. However, the studies evaluating the efficiency of justice courts rarely focus on the economic dimension. To fill this gap, the contribution of this study is twofold. Firstly, from the methodological point of view, we propose a new hybrid cost efficiency measurement framework capable of handling exogenously fixed and non-fixed prices and allowing the latter to be endogenously optimized, which is consistent with the general functioning of justice courts. Other advantages of the proposed framework include the possibility of acquiring realistic targets for the utilized resources and for the non-fixed prices and the identification of cost-demand relationships. Secondly, from the empirical point of view, we show the applicability of this new framework in the context of Polish district courts observed over the period 2017-2021. The results show a rather low average cost and allocative efficiency values of approximately 0.4 with only 10% of the courts being efficient. Interestingly, on average, the model suggests an increase in the number of all court employees and in non-fixed salaries, while a reduction in the volume of capital is proposed. The results also suggest that the reallocation of resources can lead to a significant reduction of pending cases or even to their elimination.

Wednesday, 16:30-17:30

■ WE-01

Wednesday, 16:30-17:30 - Room: Great Hall

Kalyan Talluri

Stream: Plenaries
Plenary session
Chair: *Julia Bennell*

1 - OR problems in Automated Pricing
Kalyan Talluri

Revenue Management and Dynamic Pricing is aa very prominent and successful application area of Operations Research. It is widely used in many service industries (Airlines, Ride Hailing, Railways, Hotels and so on). In this talk I will describe some of the challenges in implementing a fully automated dynamic pricing system and the many open Operations Research problems that can improve the systems and make them more robust and have bigger impact on industrial practice.

Wednesday, 17:30-18:45

■ WF-01

Wednesday, 17:30-18:45 - Room: Great Hall

Closing

Stream: Opening and Closing
Plenary session
Chair: *Julia Bennell*
Chair: *Sajid Siraj*

STREAMS

Advanced Lot Sizing and Inventory Strategies

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Track(s): 30

Advancements of OR-analytics in statistics, machine learning and data science

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Track(s): 34

Analytics

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Track(s): 49

Automated Timetabling

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Track(s): 10

Behavioural OR

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Track(s): 33 61

Celebrating 50 Years of EURO

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Track(s): 3

Circular & Sustainable Supply Chains

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Track(s): 42

Combinatorial Optimization

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Track(s): 15 17 20

Computational Biology, Bioinformatics and Medicine

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Track(s): 56

Conic and polynomial optimization

Miguel Anjos
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Track(s): 49

Continuous and mixed-integer nonlinear programming: theory and algorithms

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Track(s): 35

Cutting and packing (ESICUP)

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Track(s): 21

Data Envelopment Analysis and its applications

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Track(s): 60

Data Science meets Optimization

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Track(s): 4 38

Decision Analysis

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Track(s): 33

Decision Support Systems

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Track(s): 28

Energy Economics & Management

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EURO Excellence in Practice Award

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EURO Journals 50th Anniversary

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EURO Prize for OR for the Common Good

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Game Theory and Mathematical Economics

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Humanitarian Operations

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Multiobjective and vector optimization

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Network Optimization

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Opening and Closing

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OR Journals

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Risk Management in Commodities and Financial Markets

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Scheduling and Project Management

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Sports and Entertainment

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Stochastic and Robust optimization

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Stochastic modelling

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Systems Thinking

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Transparent and Fair Decision Making with Mathematical Optimization

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Variational analysis, equilibria and nonsmooth optimization

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Vehicle Routing and Logistics

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