An Agent-Based Model of a Business Process: The Use Case of a Hospital Emergency Department

Publisher:

Springer

Published version:

DOI:10.1007/978-3-319-74030-0_8

An agent-based model of a business process: the use case of a hospital emergency department

Emilio Sulis, Antonio Di Leva

Computer Science Department, University of Torino, Italy,
{sulis,dileva}@unito.it

Abstract. An application of Artificial Intelligence is computational simulation which reproduces the behavior of a system, such as an organization. Simulations provide benefits into business process management, also by combining scenarios and what-if analysis. This study explores the adoption of agent-based modeling technique, in addition to traditional discrete event simulations. The focus is on a real case study of an hospital emergency department. Following the construction of a new hospital, managers are interested in simulating the actual flows in the new configuration before the moving. In our model, patients and operators are agents, acting due to simple behavioral rules in the environment. The different activities are placed on the map of the department, to provide immediate understanding of bottlenecks and queues. While first results were validated from managers, next steps include the comparison of resulting flows between the new and the old department. Logistics analysis includes the time for moving agents between different wards.

Keywords: Health-care Processes, Agent Based Modeling and Simulation, Emergency Department

1 Introduction

In Artificial Intelligence, several efforts were done to model complex and changing environments [1]. Three main types of computer-based simulations were recently developed by considering different modeling techniques: system dynamics, discrete event simulations, and agent based modeling.

This study investigates an application of simulations in the framework of Business Process Management (BPM) [2]. The discipline includes modeling to facilitate organizations in describe, analyze, test, and optimize business processes. Through the comparison of actual and simulated process indicators, computer-based decision support systems [3] provide effective and efficient performance analysis. Planning, management and decision-making would greatly benefit from the analysis of the outcomes of different scenarios. We performed an agent-based simulation with NetLogo, which is considered "by far the most professional platform in its appearance and documentation" [4]. Simulated results allow to detect inefficiencies, bottlenecks, constraints, and risks, as well as to estimate the performance of the system when process modifications have to be applied (new strategies, an increase of the workload, changes in workforce etc.).

The use case is a public hospital Emergency Department (ED) in Italy. We focus on public sector, as in many European Countries it is increasingly required to provide better public services at lower costs [5]. Moreover, EDs are one of the more complex areas in health-care systems, facing several challenges such as long wait times, medical risk, lack of resources. Our interest here concerns the exploration of Agent-Based Modeling (ABM), setting up the ED model to perform different experiments and analyze early results.

Hospital managers are interested in understanding the functioning of new ED, which is actually under construction. Mapping old flows into the new configuration would provide benefits to business organisation. Patients and operators are agents acting due to behavioral rules. The different activities are placed on the current map of the department, to provide immediate understanding of bottlenecks and queues. While first results were validated from managers, next steps include the comparison of flows between the new and the old ED, with a early logistics analysis, i.e. time needed to move patients and operators between different wards. In the following we introduce a review of related works in section 2, while section 3 describes data from our case study and the methodological framework. section 4 gives an insight of the model and early results. Finally, future works conclude the paper in section 5.

2 Related works

In the framework of business process modeling [6], most studies focused on design, control, and analysis of operational tasks involving humans, documents, applications [7]. Generally speaking, simulation techniques in the field of BPM have not yet been developed as they deserve [8]. Nevertheless, some applications of computer-based simulations to business process modeling regards both industrial re-engineering [9, 10], as well as the public sector. In fact, some studies adopted Discrete Event Simulation to model public policies [11], services [12], public administration processes [13], political decision-making [14], care processes in the medical field [15]. Scenario analysis has been applied to explore different options for restructuring an existing process [16] before any change is effectively made. Although agent-based computing represents a relatively new research sector, several applications in different fields were already performed. For instance, ABM was applied to psychology [17], sociology [18], economics [19].

A review of related works in the area of ABM in health sector can be found in [20]. The case of ED was implemented by agent-based simulations with respect to evacuation [21], optimization scheduling [22], disease propagation analysis [23]. The above mentioned studies largely adopted NetLogo, which easily allows to investigate different scenarios by changing configurations. To the best of our knowledge, any agent-based model comparing old and new ED has ever been developed. In addition, the possibility to address logistics of ED seem promising. Some existing studies already focused on this task in health-care [24], typically treating Lean techniques [25].

3 The use case: data and methodology

Our case study refers to an hospital ED located in the immediate surrounding of Turin, one of the largest Italian city. Managers were interested in understanding the flows in the new ED, before the moving scheduled in winter 2017.

3.1 Dataset

We consider real data of the ED in 2016, when patients involved were 46,497. The daily access follows an hourly distribution of arrivals with two peaks, one in the morning and one in the afternoon (Figure 1).

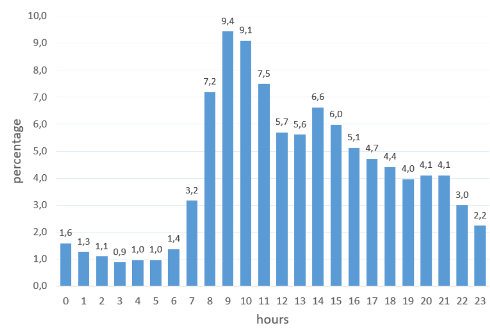

Fig. 1. The arrival of patients in the ED on average per hours in 2016

Table 1. Distribution of patients by ESI level in 2016

	R	Y	G	W	Tot
Number of patients	314	5,292	39,561	1,330	*46,497*
Percentage values	0.7	11.3	85.1	2.9	*100*

3.2 Methodology

In the framework of BPM, our analysis starts with the implementation of the actual situation of organization processes (As-Is). Simulations results will suggest different scenarios for re-engineering the restructured processes (To-Be).

Simulations. In this context, we performed a simulation to describe events, activities and decisions concerning As-Is, with the actual business processes. In particular, we based on previous works dealing with a traditional modeling technique (Discrete Event Simulation) of the same organization [26].In this case, we explored a different approach for the same case study, focusing on ABM to create agents acting (or moving) in ED.

NetLogo. We adopt the open-source programmable modeling environment NetLogo [27], which is a popular modeling software, suitable for this kind of simulations. The program manages thousands of agents (so called turtles) operating independently in a landscape made of static agents, building the background of the simulation (patches). This makes it possible to distinguish different areas of the environment corresponding to the activities of the ED, in which agents act. Figure 2 describes the ED map and the colored version of patches.

Fig. 2. ED map (left) and the corresponding NetLogo colored version (right)

Agents. The two main types of individual agents in an ED are patients and operators. We model them as turtles having several attributes which determine the flows toward different paths or activities. Main attributes for operators discriminate if they are waiting for the next activity, or busy in working with a patient. Above all, patients' attributes concern the level of priority (ESI level)

Table 2. Main attributes of agents (Patients or Operators)

Agents	Variable	Description	Cases
	op-move?	Operator have to reach the activity	T/F
O	op-in-wl?	Operators are waiting	T/F
	busy?	Operators are working	T/F
	ESI	Level of priority	red,yellow,green,white
	pathology	Main destination in ED	chi,med,ort,oth
P	pat-move?	have to reach the activity/patch	T/F
	served?	Patients are served	T/F
	pat-in-waiting-list?	Patients are waiting	T/F

as well as the pathology (see Table 2) which determine the paths towards different areas, i.e. chirurgy (chi), medicine (med), orthopedics (ort), others (oth).

Activities. All the activities are modeled as tasks which involve the corresponding agents (patients and operators) detailed in section 4. As NetLogo is well suited for modeling systems developing over time, each activity has a certain duration, obtained by a preliminary study on the basis of real values. For instance, Table 3 describes the post-triage waiting time of patients, which largely depends on both ESI level and hour of arrival: in central hours of the day (12-16) urgent cases have a low waiting-time (7.1 minutes), while not urgent cases have to wait on average about three hours (174.4 minutes).

Table 3. Average duration of post-triage waiting time depending on the hour of arrival (6 classes of four hours) and ESI level (White, Green, Yellow, Red), in 2016

	W	G	Y	R
0-4	21.3	18.3	9.1	3.0
4-8	79.6	30.5	14.3	5.3
8-12	112.8	84.9	16.6	7.0
12-16	174.4	145.5	22.8	7.1
16-20	166.8	146.6	19.1	5.5
20-24	75.9	75.9	19.9	14.0

Key Performance Indicators. The performance of the model is actually evaluated on the basis of two business process indicators:

- *Door-to-Doctor-Time (DTDT)*: The number of minutes a patient takes from the arrival in the ED to see a doctor.
- *Lenght-of-Stay (LoS)*: The number of minutes from patient arrival to the exit from the ED.

Figure 3 describes two monitors of the simulation detailing the results of KPIs as well as the number of patients in waiting-room.

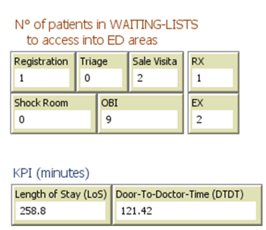

Fig. 3. Monitors related to waiting lists and KPIs

4 Initial Settings and Early Results

This section describes the initial settings concerning agents and the environment.

Agents: patients and operators. As previously discussed, we set the creation of patients by referring to the average values of the previous year (2016). Operators involved in the ED are three doctors (PHY), two triage nurses (TRN), two ED nurses (EDN) and three healthcare worker (OSS), as in the actual organisation. By modifying a form it would be possible to change these parameters: Figure 4 shows the initial configuration of the simulation.

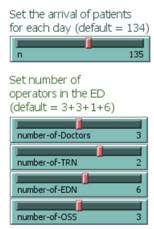

Fig. 4. NetLogo sliders for the creation of individual agents

Patches: ED activities. The activities correspond to our ED areas. Table 4 describes their colors in NetLogo map, patients (pat) or operators (op) involved, duration (by triangular distributions, seconds).

Activity	Color	Agents	Duration
Registration	Blue	Pat, EDN	Tri(100,140,120)
Triage room	Light green	Pat, TRN	Tri(300,900,600)
Visit room	Orange	Pat, PHY	Tri(940,400,1140)
Radiology	Purple	Pat, EDN	Tri(650,100,700)
Shock-Room	Red	Pat, EDN, PHY (2)	Tri(1550,500,1800)
Observation	Orange	Pat, EDN, OSS	Tri(3600,32400,18000)
Waiting room	Dark green	Pat, OSS	*undefined*

Table 4. Table of activities, patch colors, agents involved, and durations (seconds)

Managing agents: rules of behavior. The behavior of individual agents (operators and patients) follows simple rules. If agents are not involved in an activity, they are managed by two queues (FIFO). Urgent patients (red) follow a different path going immediately in shock-room. Yellow cases have the priority over the two other cases. Once an activity (corresponding to patch agents in NetLogo) are free, they call the first agent. We are planning to adopt more complicated features by adding realistic parameters (as some breaks for operators, queue scheduling management, and so on). For instance, abandons of patients who left the ED without being seen can be modeled depending on both the urgency level and the number of patients in waiting rooms.

Early Results. First results of the ABM[1] give us an idea of how patients move in ED areas. Managers confirm the initial suggestions coming from simulation: i) the blue area, corresponding to Short Intensive Observation area, is often overcrowded, as well as the long queue in waiting room (see Figure 5).

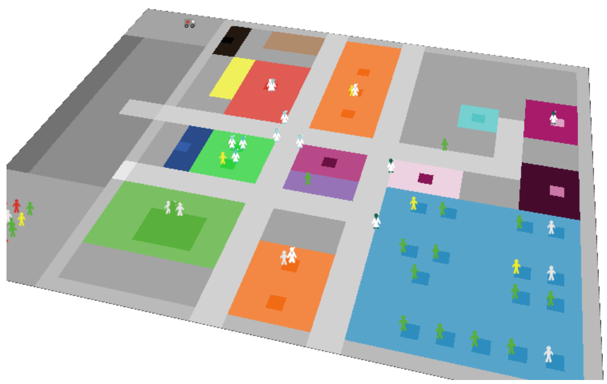

Fig. 5. Simulation output after two weeks: blue area and waiting room are overcrowded

5 Conclusions

This paper discusses the adoption of an agent-based simulation to the use case of an hospital Emergency Department. Initial parameters are derived from 2016 data. Individual agents of our simulation are dynamically created, as well as the environment in which they move is based on the real map. We are implementing the simulation closely with ED managers, before the moving in the new ED, scheduled for the next winter. In future works we are planning to improve ABM simulation by adding more realistic features to extend our set of KPIs. In addition, we plan to compare DES and ABM results.

References

1. Russell, S., Norvig, P.: A modern approach. Artificial Intelligence. Prentice-Hall, Egnlewood Cliffs **25** (1995) 27
2. Dumas, M., Rosa, M.L., Mendling, J., Reijers, H.A.: Fundamentals of Business Process Management. Springer (2013)
3. Shang, S., Seddon, P.B.: Assessing and managing the benefits of enterprise systems: the business manager's perspective. Inf. systems journal **12**(4) (2002) 271–299

[1] See OpenABM archive with our project at the address: [link to be added]

4. Railsback, S.F., Lytinen, S.L., Jackson, S.K.: Agent-based simulation platforms: Review and development recommendations. Simulation **82**(9) (2006) 609–623
5. OECD: Oecd science, technology and industry outlook 2012. OECD Publishing
6. Williams, S.: Business process modeling improves administrative control. Automation, December **44** (1967) 50
7. van der Aalst, W.M.P., Hofstede, A.H.M., Weske, M. In: Business Process Management: A Survey, Berlin, Heidelberg (2003) 1–12
8. Van der Aalst, W.M., Nakatumba, J., Rozinat, A., Russell, N.: Business process simulation. In: Handbook on BPM 1. Springer (2010) 313–338
9. Scheer, A.W., Nüttgens, M.: Aris architecture and reference models for business process management. In: Business Process Management. Springer (2000) 376–389
10. Reijers, H.A.: Design and control of workflow processes: business process management for the service industry. Springer-Verlag (2003)
11. Lempert, R.: Agent-based modeling as organizational and public policy simulators. Proceedings of the National Academy of Sciences **99**(suppl.3) (2002) 7195–7196
12. Gulledge Jr, T.R., Sommer, R.A.: Business process management: public sector implications. Business Process Management Journal **8**(4) (2002) 364–376
13. Kovacic, A., Pecek, B.: Use of simulation in a public administration process. Simulation **83**(12) (2007) 851–861
14. Rouchier, J., Thoyer, S.: Votes and lobbying in the european decision-making process: application to the european regulation on gmo release. Journal of Artificial Societies and Social Simulation **9**(3) (2006)
15. Di Leva, A., Sulis, E.: Process analysis for a hospital emergency department. International Journal of Economics and Management Systems **2**(1) (2017) 34–41
16. Lam, K., Lau, R.: A simulation approach to restructuring call centers. Business Process Management Journal **10**(4) (2004) 481–494
17. Elliott, C.D.: The Affective Reasoner: A Process Model of Emotions in a Multi-agent System. PhD thesis, Evanston, IL, USA (1992) UMI Order No. GAX92-29901.
18. Macy, M.W., Willer, R.: From factors to factors: computational sociology and agent-based modeling. Annual review of sociology **28**(1) (2002) 143–166
19. Tesfatsion, L.: Agent-based computational economics: A constructive approach to economic theory. Handbook of computational economics **2** (2006) 831–880
20. Friesen, M.R., McLeod, R.D.: A survey of agent-based modeling of hospital environments. IEEE Access **2** (2014) 227–233
21. Ren, C., Yang, C., Jin, S.: Agent-based modeling and simulation on emergency evacuation. Complex Sciences (2009) 1451–1461
22. Cabrera, E., Taboada, M., Iglesias, M.L., Epelde, F., Luque, E.: Simulation optimization for healthcare emergency departments. Procedia Computer Science **9** (2012) 1464–1473
23. Jaramillo, C., Taboada, M., Epelde, F., Rexachs, D., Luque, E.: Agent based model and simulation of mrsa transmission in emergency departments. In: Procedia Computer Science. Volume 51. (2015) 443–452
24. Landry, S., Philippe, R.: How logistics can service healthcare. Supply Chain Forum: An International Journal **5**(2) (2004) 24–30
25. Chan, H., Lo, S., Lee, L., Lo, W., Yu, W., Wu, Y., Ho, S., Yeung, R., Chan, J.: Lean techniques for the improvement of patients flow in emergency department. World journal of emergency medicine **5**(1) (2014) 24
26. Di Leva, A., Sulis, E.: A business process methodology to investigate organization management: a hospital case study. WSEAS Transactions on business and economics (14) (2017) 100–109

27. Wilensky, U.: Netlogo. http://ccl.northwestern.edu/netlogo/, Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL (1999)