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Ex post evaluation of an operating theatre

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Abstract

In this paper we present a general framework for the ex post evaluation of an operating theatre driven by different performance criteria. We tested such a framework on a real case study proposing also a comparison with the actual situation.

Keywords: Surgery process scheduling, Performance criteria, Ex post evaluation.

1 Introduction

Operating Room (OR) planning and scheduling is a research topic widely discussed in the literature, as reported in [11], in which new problems and solution methods are emerging [6,4,8,7]. Several performance criteria have been reported to evaluate the OR planning decisions [5]. Usually, the maximisation of the OR utilisation is the most adopted criterion, since ORs are the largest cost and revenue centre of hospitals [9].

Taking into account a patient–centred perspective, a preliminary comparison between two further criteria – waiting time and workload balance – has

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been reported in [1]. Such a comparison confirmed the ability of the two models to ensure a high level of OR utilisation dealing with long waiting lists, which is a common situation in many hospitals belonging to publicly funded health care systems. The two criteria provided different results. The minimisation of the waiting times is a fairness criterion among patients that allowed us to have an OR utilisation close to 100% in all cases. Conversely, the workload balance is a criterion to have a smooth workload along the week, which has been able to schedule a high number of patients in most cases.

In this paper, we would extend the analysis on the impact of these criteria when they are adopted over time. To this end, we will consider a real case study arising from a small / medium hospital in the area of Turin, Italy. Starting from a list of performed surgeries in 2016, we derived a set of information regarding the real usage of the operating theatre in such a way to replicate day-by-day (almost) exactly the use of the main resources available. The basic idea is to solve each week the current instance of the surgical case assignment problem (proved to be $\mathbb{NP}$–hard in [3]) to select the patients from the waiting list that will be operated on. Such patients are deleted from the list while the new ones are added in accordance with their real data of insertion in the waiting list. Section 2 reports the methodological approach adopted in this analysis while the ex post evaluation is discussed in Section 3. Conclusions close the paper.

2 The Methodological Approach

From the data-set provided by the hospital, we can obtain the usual information related to the patients, that is, for each patient $i \in I$, the following information are given: the waiting time w_i, expressed in days and computed from the referral day d^r; the surgery day d_i^s and the duration of the surgery p_i, expressed in minutes; the Length of Stay (LOS) μ_i, expressed in days. The data-set also provided the value r_i, which is the amount of money that the NHS reimburses the hospital for the surgery performed. Further, we estimate the weekly amount R by summing the r_i of the patients operated on that week.

To solve the weekly surgical case assignment problem, we derived the settings of the operating theatre from the data determining the set K of available operating rooms each day of the week (the set T). For each OR session (k, t) ($k \in K$ and $t \in T$), we derived the actual time capacity s_{kt}. The basic idea is to have a fair comparison in terms of available resources. Note that we do not change the master surgical schedule since we are not aware about the

availability of the surgical team(s) involved. Therefore, our assumption of considering one specialty at a time is not limiting under a block scheduling policy. The set of the patients operated on can be determined in four ways, that is, (i) replication of what actual happened, or solving the weekly surgical case assignment problem in accordance with the following three performance criteria, i.e., (ii) maximising the weekly reimbursement, (iii) minimising the waiting time of the patients, and (iv) workload balance.

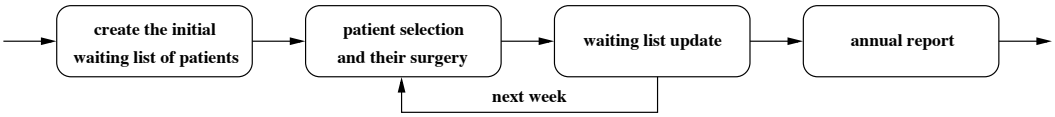

Fig. 1. Methodological framework.

Our methodological framework is depicted in Figure 1. At the beginning, the waiting list is created adding those patients whose referral day d^r is before the initial date, that is January 1st. Then, a cycle of 52 weeks starts. For each week, a set of patients is selected from the waiting list in accordance with one of the four ways (i)–(iv) discussed above: the selected patients are those operated on during the current week. At the end of the week, the waiting list is updated by deleting the patient operated on and adding the new ones according to their referral day d^r. At the end of the 52nd week, an annual report is produced.

In the following, we report the models of surgical case assignment problems corresponding to the three performance criteria depicted above. Let x_{ikt} be the binary decision variable that models the assignment of the patient i to the OR session (k,t) ($x_{ikt}=1$), or not ($x_{ikt}=0$).

$$M_1: \quad \max \quad z_1 = \sum_{i\in I} r_i \sum_{t\in T} y_{it} \tag{1a}$$

$$\text{s.t.} \quad \sum_{k\in K}\sum_{t\in T} x_{ikt} \le 1\,, \qquad i\in I \tag{1b}$$

$$\sum_{i\in I} p_i x_{ikt} \le s_{kt}\,, \qquad k\in K, t\in T \tag{1c}$$

$$\sum_{k\in K} x_{ikt} = y_{it}\,, \qquad i\in I, t\in T \tag{1d}$$

$$\sum_{h=t}^{\min\{t+\mu_i,\ell''\}} z_{ih} \ge \mu_i y_{it}\,, \qquad i\in I, t\in T \tag{1e}$$

$$\sum_{h=\max\{t-\mu_i,\ell'\}}^{t} y_{ih} \ge z_{it}\,, \qquad i\in I, t\in T \tag{1f}$$

$$\sum_{i \in I} z_{it} \leq L_t - \lambda_t \,, \qquad t \in T \tag{1g}$$

Constraints (1b) state that a patient can be scheduled at most once, while constraints (1c) impose that the sum of the surgery times of the patients scheduled in each OR session (k, t) may not exceed the time capacity s_{kt}. Constraints (1d) define the value of the auxiliary variables y_{it}, which is equal to 1 when the patient i is operated on the day t, 0 otherwise. Such a variable is then used to count the number of stay beds used each day t of the planning horizon T by fixing the value of the auxiliary variables z_{it}, which is equal to 1 when the patient i take up a stay bed during the day t, 0 otherwise through the constraints (1e) and (1f), in which the parameters ℓ' and ℓ'' represent the first and the last working days in T, respectively. Finally, constraints (1g) ensure that the number of patients operated on day t are limited to the number of bed available given by the number of bed L_t minus the bed λ_t occupied by patients operated on the previous week. The model M_1 seeks to maximise the weekly reimbursement as modelled by the objective function (1a).

$$M_2: \quad \max \quad z_2 = \sum_{i \in I} w_i \sum_{t \in T} y_{it} \tag{2a}$$

$$\text{s.t.} \quad (1b) - (1g)$$

$$\sum_{i \in I} r_i \sum_{t \in T} y_{it} \geq R \,, \tag{2b}$$

The model M_2 seeks to minimise the waiting time (at the moment of the planning) of the patients to be operated on. The objective function (2a) leads to a solution made of those patients having longest waiting time at the moment of planning. In other words, the model would favour those patients with longest waiting time instead of those with shorter ones. The constraint (2b) imposes that the weekly planning ensures to obtain the same reimbursement R actually obtained by the hospital.

$$M_3: \quad \max \quad z_3 = y \tag{3a}$$

$$\text{s.t.} \quad (1b) - (1g)\,, (2b)$$

$$\sum_{i \in I} z_{it} \geq y \,, \qquad t \in T \tag{3b}$$

The model M_3 balances the workload. In order to model the workload balance, we adopt a bottleneck approach: the objective function (3a) seeks to

maximise the number of busy stay beds during the day with the minimal bed usage (constraints (3b)).

3 Ex Post Evaluation

We consider the three most numerous specialties of the hospital under consideration, that is orthopaedics, urology, and general surgery. Table 1 reports the main characteristics of the three specialties.

	orthopaedics	urology	general surgery
number of surgeries	1072	1500	784
number of beds	16	30	14
max number of ORs available	4	5	4
average operating time (minutes)	420	420	420

Table 1
Main characteristics of the three specialties (year 2016).

The optimisation models adopted in the methodological framework depicted in Figure 1 have been solved by Cplex Optimization Studio 12.7.1. To limit the overall running time, a time limit of 120 seconds to each run has been introduced. Table 2 reports the main result of the overall computation according to the framework depicted in Figure 1: the overall running time is reported in the first row; the number of weekly runs reaching the time limit over 52 weeks is reported in the second row; the average and the maximum gaps are reported in the third and fourth rows, respectively.

	general surgery			orthopaedics			urology		
	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
time (secs)	726	197	27	968	545	20	1955	1239	26
# of runs	4	1	0	6	3	0	13	6	0
avg. gap	0.01%	0.00%	0.00%	0.02%	0.02%	0.00%	0.06%	0.04%	0.00%
max gap	0.24%	0.20%	0.00%	0.44%	0.58%	0.00%	0.64%	0.63%	0.00%

Table 2
Times, number of runs reaching the time limit, average and maximum gaps.

In the analysis reported below, we considered the results over 30 weeks, excluding the first 6 and the last 16 weeks. This is due to the fact that the available data spans only those surgeries performed in 2016. So we are missing

the information before and after this period affecting the composition of the waiting list and, by consequence, the main results of the analysis.

	general surgery				orthopaedics				urology			
	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3	M_0	M_1	M_2	M_3
U	0.77	0.96	0.97	0.90	0.65	0.81	0.91	0.77	0.62	0.91	0.91	0.82
X	11	14	13	14	18	22	26	23	23	34	34	33
B	33	43	46	43	76	108	106	88	107	143	153	141
W	141	100	69	75	136	84	83	84	133	93	53	95

Table 3
Average weekly performance values over 30 weeks.

Table 3 reports the average weekly values over the 30 weeks of analysis in which M_0 represents the actual situation (what is happened in 2016 in that specialty), and M_1, M_2 and M_3 are the columns representing the case in which the selection of the patients to be operated on is performed by the three models discussed in Section 2. The rows U, X, B and W report the utilisation of the ORs, the number of patients operated on, the reimbursement expressed in thousands of euros, and the waiting time of patient expressed in days, respectively.

The results reported in Table 3 show a generalised improvement of the OR utilisation determining an increase in the number of the patients operated on each week, and a reduction of the waiting time for each patient. The values of X for M_3 confirm the remark discussed in [1], which indicates the capability of this criterion to schedule a high number of patients in most cases. The analysis of the three performance criteria shows that M_2 seems to lead to generally better solutions than those provided by M_1 and M_3. Figure 2 depicts the length of the orthopaedics waiting list over the weeks in the four cases: it shows that M_2 and M_3 leads to a larger reduction of the waiting list with respect to M_o and M_1. We would remark that the result of model M_3 can be improved with an accurate post processing (which is out of the scope of this paper). Due to the structure of the model, it can happen that a number of patients are not selected since their selection does not change the value of the bottleneck objective function. Therefore, a simple post processing procedure, based on some bin packing heuristics, can increase the number of patient selected. Finally, the fact that M_1 tends to operate on the first 6 weeks those patients having highest r_i implies that M_2 can obtain a slightly better average value of B than M_1.

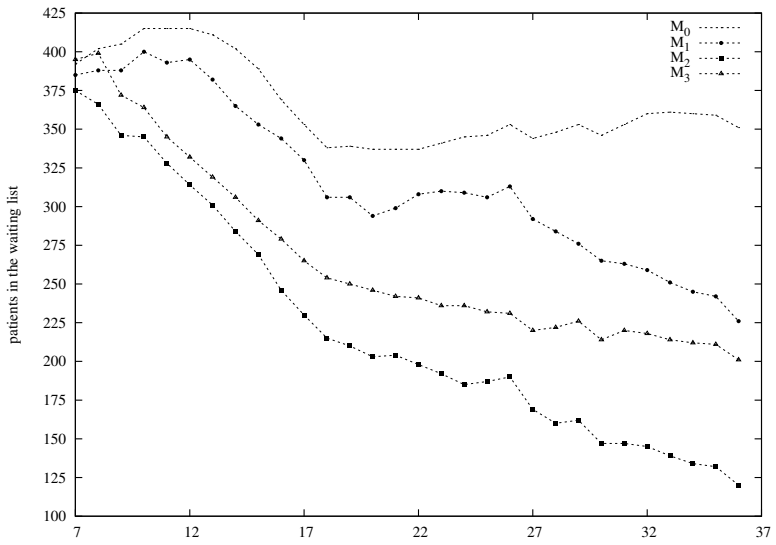

Fig. 2. Length of the waiting list over time: orthopaedics.

4 Conclusions

In this paper, we proposed a general framework for the ex post evaluation of an operating theatre. The idea is to evaluate how different performance criteria can lead the management of the operating theatre over time. Further, we compare such results with the result of the actual management policy, that is that derived from the analysis of the available data.

The analysis presented in Section 3 suggests some interesting managerial insights. The first one is that the idea of maximising the revenue determines solutions which are dominated by the two other performance criteria. On the other side, minimising the waiting time seems to generate the best solutions. The use of workload balance could be a good compromise if we also take into account the job quality of nurses and doctors working in that specialty. Although the possible differences between our models and the actual situation (e.g., the models use the actual operating time while the hospital should use an estimate), the comparison among the results of the three performance criteria and those of the actual management policy highlights the room for improving the management of the operating theatre of the considered case study. From a methodological point of view, this analysis suggests to study the impact of considering the waiting time minimisation and workload balance at the same time, as in [2]. Further research avenues could consider the use of patients' priorities in M_2 as in [3], and to extend the quantitative evaluation generating artificial instances using [10].

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