A two-phase integrated approach for elective surgery and bed management problems

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Abstract: This paper focuses on developing a framework to support quantitative decision making for planning processes involving both OR-departments and medical departments. We propose a multi-objective optimization model that manages elective surgery scheduling, elective patients and bed scheduling at the same time in order to provide access to care in a timely manner and improve hospital efficiency. Patient waiting time, as well as patient specialty and patient length of stay are considered. The multi-objective model is solved as a single-objective in two-phase in order to maximize the number of scheduled surgeries and admit patients with early registration date. We test it on realistic instances and present computational results in terms of OR utilization and bed occupancy level. We show that the number of beds can be a bottleneck for an OR departments and that unused beds are due to gender policies and/or inconsistency with respect to patient length of stays.

Keywords: Operating room scheduling, Bed Management, Elective surgeries, Multi-objective optimization

1.Introduction

Hospitals are complex production facilities and one of their objectives is maximise efficiency, productivity and quality of care, although these objectives are often conflicting. For this reason, they should increase process optimization in order to improve provided care services level, resource utilization and minimize costs.

Operating rooms (ORs) are among the most expensive resources of a hospital and have the largest revenue. Improving productivity of OR departments is a major interest for many hospitals, because they are cost driver and profit driver. Three main stages involve the OR scheduling process:

- peri-operative: collection of patients' information and preparation for surgeries
- intra-operative: surgeries are performed
- post-operative: post-anesthesia care units, intensive care units, or wards for recovery

An operated patient has to be transferred in a recovery bed after the end of the surgery or after the post-anesthesia care units. An OR schedule directly affects the post-operative stage and unavailability of downstream resources could cause blockings between intra-operative and post-operative stages. Hospitals should provide high quality care with limited resources by developing efficient OR schedules. It is thus important to develop an OR schedule that even considers occupancy of downstream resource. A poor scheduling could generate delays or cancellations of surgeries, an excess of overtime. These mean excess cost and loss of revenue for the hospital (Latorre-Núñez et al. 2016) or blocking because no recovery beds sometimes are available. As well underlined by Bam et al. (2015), resource allocation is crucial and it affects efficient functioning of a hospital. It is a challenging problem due to the interaction of the different stages of the surgery delivery system, and the uncertainty of surgery and recovery durations. Waiting times, mainly for some surgical services, such as cancer surgery, are very long despite the existence of target waiting times. One of the main reason is due to scarce resources, increasing demand and workloads.

Professional bed managements aim at a low rate of cancelled admissions and a high occupancy rate. Bed capacity is a limited hospital resource as well as operating rooms, and both are crucial. In order to provide quality and access to care in a timely manner, it is necessary to effectively manage limited resources such as ORs and beds. OR management problems are complex and they have been attracting researchers interest, as demonstrated by the extensive literature. Moreover, bed management problems were usually addressed as only capacity problems.
However, a few papers tackled the ORs management integrated to a complex bed management.
Here, we develop an optimization model to support quantitative decision making for the planning process involving both OR-departments and medical departments. The aim is to develop a scheduling system for an OR-department and wards at the same time, and to increase OR efficiency, bed occupancy at the wards while satisfying constraints on limited resource availability. The model

accounts patient mix, estimated surgery length and patient length of stay (LOS) even for patients who undergo a surgery and need a bed in the step-down unit. Following the framework for of the healthcare planning and control of Hans et al. (2012), reported in Figure 1, we address elective patients scheduling at the tactical and offline operational level of resource capacity planning. Decisions about the tactical level of OR departments have been already made, i.e., slots of OR time are assigned to a surgical specialty or surgeon. The specific decision-making problem concerns thus the resource management and the process management at the same time. The resource management problem regards capacity planning and more specifically operating room and beds; the process management regards patient scheduling, i.e. the admission and discharge planning.

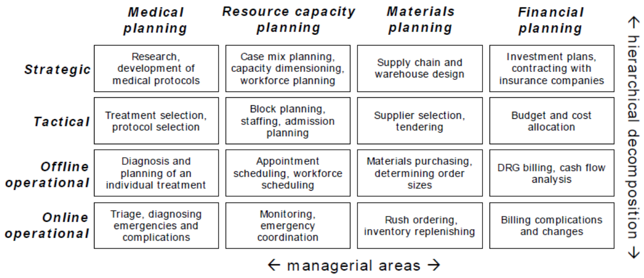

Figure 1: Framework for health care management and control of a general hospital

2. A relevant literature review

ORs scheduling is a broad topic. The number of papers related to the management of operating theaters increased considerably over the last 20 years (Cardoen et al. 2010, Guerriero and Guido 2011, Demeulemeester et al. 2013). Surgeries (named also surgical cases) are categorized in elective cases and emergency cases. Elective surgeries are the only ones that can be planned in advance; emergency cases have to be scheduled as soon as possible. Three hierarchical decision phases can be distinguished in OR scheduling problems (Guerriero and Guido 2011, Hans et al. 2012): the strategic phase aims to provide a case mix plan; the tactical phase aims at construct the so-called master surgical schedule (MSS), which determines the number and type of ORs allocated to surgical specialties over a scheduling period (usually a week) in order to both maximize and level resources utilization; operational phase, named as Surgery Scheduling Problem, is divided in allocation problem and sequencing problem. The first one assigns surgical cases to available ORs in a day; then, the surgery sequencing problem, which consists in assigning a starting time according to specific sequencing rules, is usually solved the day of surgery.

Due the complexity of the decision phases, they are usually addressed one at a time. The three phases were tackled at the same time in few research papers (e.g., Testi et al. 2007). Both tactical and operational decision levels were addressed in (Guido and Conforti, 2017), where a multiobjective optimization model was formulated to support hospital managers in managing involved resources, scheduling surgeons and surgeries, and increase OR efficiency. The most part of the relevant literature focused on only one decision phase, mainly on the operational phase, as reported in several literature reviews (e.g., Erdogan and Denton 2010, Guerriero and Guido 2011, Hans et al. 2012, Cardoen et al. 2010). Roland et al. (2006) and Roland et al. (2010) emphasize the importance of considering additional resources in the surgical case scheduling process, especially human. Post-anesthesia recovery beds were considered by Cardoen et al. (2009), that addressed the sequencing of surgical cases in a day-care environment, and by Latorre-Núñez et al. (2016). The post-surgery ward bed occupancies levelling problem was addressed by Aringhieri et al. (2015). These authors found a surgery date and assign an operating room to each patient over a given planning horizon by considering a number of ward stay beds available for each specialty and day. Nevertheless, no computational results were presented.

Bed management is a complex issue in healthcare systems and several aspects were tackled in the literature from multiple perspectives. A computer-supported bed management was developed in (Schmidt et al., 2013) in order to manage admission planning and bed assignment by considering patient LOS, which can be updated during the patients' treatment. More complex is the bed management problem introduced in (Demeester et al., 2011), because beds are resources shared by several departments, and patient requirements and preferences should be matched. Ceschia and Schaerf (2011), and Guido et al. (2018) improved with different solution approaches the results on benchmark instances. Real-world features like a range for patient admission dates and uncertain LOS of some patients were introduced in Ceschia and Schaerf (2012). This new challenging problem aims at admitting patients over a planning horizon and find the best room for patients. It was further extended with requirements of OR departments in Ceschia and Schaerf (2016), and the resulting problem can be considered a significant step towards the full integration of surgery scheduling process and patient admission scheduling problems. These authors generated a set of instances and solved them by an online approach, i.e., day-by-day due to the high complexity. Several constraints, like those on gender policies and OR time, can be violated even if penalized. As detailed in Section 4, we adapted the instances generated by Ceschia and Schaerf (2016) to the problem here addressed.

This research focuses on the operational offline level of OR planning, also named operating room scheduling, and bed management. Emergency are not considered here and it is assumed that they have dedicated ORs. To the best of our knowledge, few papers addressed the problem of planning patient admissions, schedule surgery and managing beds at the same time. In the following section, we provide a brief background and a problem description.

3. Background and problem description

The block scheduling strategy consists in assigning OR time for a week or more time: OR blocks are assigned to surgeons and/or surgical group according to requirements and availability. An example of a weekly MSS related to two ORs and surgical specialties is in Figure 2. Observe that each OR block is assigned to a surgical specialty and has a proper length, which is defined as the time between the opening hour and the closing time.

	Monday	Thuesday	Wednesday	Thursday	Friday
OR1	General 7.30-12.30 300 mins	General 7.30-12.30 300 mins	Ortho 7.30-12.30 300 mins	Urology 7.30-12.30 300 mins	Ent 7.00-12.30 330 mins
	Ortho 13.30-19.30 360 mins	Urology 13.30-19.30 360 mins	General 13.00-20.00 420 mins	Ortho 13.30-19.30 360 mins	Urology 13.30-19.30 360 mins
OR2	Cardiac 7.30-12.30 300 mins	Neuro 7.30-12.30 300 mins	Cardiac 7.30-12.30 300 mins	Cardiac 7.30-12.30 300 mins	Neuro 7.30-12.30 300 mins
	Vascular 13.30-19.30 360 mins	General 13.00-20.00 420 mins	Vascular 13.30-19.30 360 mins	Cardiac 13.30-19.30 300 mins	Vascular 13.30-19.30 360 mins

Figure 2: An example of a MSS

From a patient's perspective, the process starts when a medical specialist decides that surgery has to be performed. An admission registration form is filled with information related to a description of the treatment, expected surgery duration, expected length of stay in the hospital. The form is processed at the central admissions department and the patient is placed on the waiting list. Per each surgical specialty there is thus a waiting list. Surgical cases can be assigned only to an OR block with the appropriate surgical specialty and the OR block capacity has to be respected. OR efficiency is measured by two indices: OR idle time and OR overtime, which affect OR utilization and consequently cost. Inefficiencies due to idle time and overtime are equivalent to substantial costs for the hospital management and should therefore both be minimized.

As already underlined, the surgery scheduling is even affected by bed availability. Hospital rooms are located in departments, they have a defined capacity given by the number of beds and are subject to gender policy, and in some cases to age policy. Admissions of patients who have to undergo a surgery should be planned on the basis of available OR time and expected LOS, because an OR schedule is strictly linked to the used MSS and bed capacity.

Moreover, beds are shared resources by OR departments and medical departments. The main issue is how to allocate beds to surgical cases and patients without a planned surgery, who need to be hospitalized for a defined period. These patients are inserted in appropriate waiting lists related to their medical specialties. A scheme of the addressed problem is reported in Figure 3: there are several waiting lists with elective patients that have to be scheduled. Their admission implies firstly a suitable room assignment for consecutive nights; then, an OR block assignment if patient has to undergo a surgery.

The criteria we use to improve hospital efficiency and patient flow are OR utilization and ward utilization.

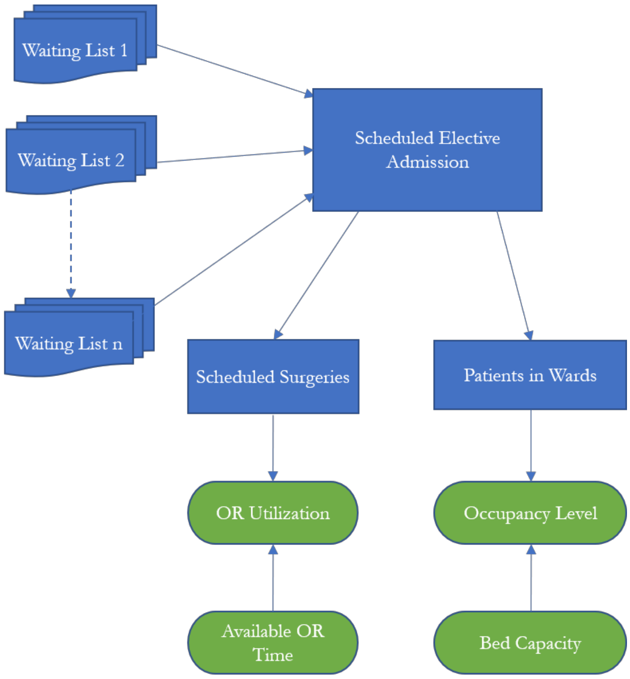

Figure 3: Scheme of the framework

3.1. An optimization model for patient admission, surgery and rooms scheduling problems

Before to describe the optimization model, we introduce the used notation and then the set of decision variables.

Notation

Let *P* and *PS* be the set of elective patients and elective surgeries, respectively, waiting to be scheduled. *PS* is a subset of *P*. Each patient has a registration date and an estimated LOS denoted as L_p. All patients have a LOS at least of one night. Let *S* be the set of specialties and *SS* the set of surgical specialties. *R*, *B*, and *D*, denote the set of rooms, OR blocks, and days in the planning horizon, indexed by *r*, *b*, and *d*, respectively. cap_r denotes the number of beds in room *r*, that is, its capacity. Let $\bar{R}_p$ be the set of rooms feasible for patient *p*, i.e., it is the set of rooms where patient *p* can be assigned because both gender policy and treated specialty are compatible. Every admitted patient has to be assigned to a room among those in $\bar{R}_p$ and has to be discharged over the planning horizon. On the basis of the L_p value, we compute a maximum admission date per each patient, denoted by a_p. Patient registration date is used to compute waited time with respect to the first day of the current planning horizon.

For each patient in *PS* is known: surgical specialty, length of surgery, and the interval in days between admission date and surgery date. They are denoted by $s_p \in SS$, ls_p, δ_p, respectively. The setup time is considered in the length of surgery because non-sequence-dependent.

An MSS has been already defined, that is, every OR block has been already assigned to a surgical group/surgeon. $av_{bd,ss} = 1,$ if OR block *b* on day *d* is assigned to surgical specialty *ss*; its value is 0 otherwise. The OR block length is denoted by lb_{db} . We define PS_{ss} and $B_{ss,d}$ as the set of waiting surgical cases and the set of OR blocks assigned on day *d*, respectively, for each surgical specialty $ss \in SS$. It is assumed that $max_{p \in ss}\, ls_p \le max_{b \in B_{ss,d}}\, lb_{db}$, $\forall\, ss \in SS$, that is, there exists at least one OR block feasible for every surgical case.

If a patient is admitted to hospital, he/she is also assigned to a room for a number of consecutive nights equal to his/her LOS. In addition, if this patient has to undergo a surgery, he/she is assigned to a suitable OR exactly δ_p days after admission date.

Decision variables

We define the decision variables and their meaning as follows. ad_{prd}=1 if patient $p \in P$ is admitted on day d and he/she is assigned to room $r \in \bar{R}_p$; x_{prd}=1 if he/she is in room $r \in \bar{R}_p$ on day d. These variables take value 0 otherwise. $sur_{pdb} = 1$ if patient $p \in PS$ is assigned to OR block *b* of day *d*.

3.2 Optimization model formulation

The following multi-objective optimization model aims to

(a) define patient admissions; (b) schedule surgeries according to available OR time, as defined by the MSS; (c) assign all admitted patients to rooms according to their gender, medical/surgical specialty, and room capacity.

Objective function (1) and objective function (2) maximize the number of planned surgeries and the number of admitted patients, respectively.

$$\text{Max } \sum_{p \in PS} \sum_b \sum_d sur_{pbd} \quad (1)$$

$$\text{Max } \sum_{p \in P} \sum_r \sum_d ad_{prd} \quad (2)$$

Constraints (3)-(4) ensure that each patient at most only once is admitted and has to be assigned only to one room among those feasible.

$$\sum_{r \in \bar{R}_p} \sum_{d \le a_p} ad_{prd} \le 1 \qquad \forall\, p \quad (3)$$

$$\sum_{r \in \bar{R}_p} x_{prd} \le 1 \qquad \forall\, p, d \quad (4)$$

Constraints (5)-(6) define patient stay as consecutive L_p nights.

$$\sum_{k \ge d}^{d+L_p-1} x_{prk} \ge ad_{prd}\, L_p \quad \forall\, p, d \le a_p, r \in \bar{R}_p \quad (5)$$

$$\sum_k x_{prk} = L_p \sum_{d=1}^{a_p} ad_{prd} \quad \forall\, p, r \in \bar{R}_p \quad (6)$$

Constraints (7) are on room capacity per day, that is, the number of patients assigned to a room cannot be greater than the number of beds:

$$\sum_{p \in P | r \in \bar{R}_p} x_{prd} \le cap_r \qquad \forall\, r \in R, d \in D \quad (7)$$

Constraints (8)-(9) ensure that each patient $p \in PS$ undergoes surgery δ_p days after his/her admission, as required, if he/she is admitted to the hospital

$$sur_{pbd} = \sum_{r \in \bar{R}_p} ad_{pr,d-\delta_p} \quad \forall p \in PS \mid \delta_p > 0, \quad d \le a_p + \delta_p, b \quad (8)$$

$$sur_{pbd} = \sum_{r \in \bar{R}_p} ad_{prd} \qquad \forall\, p \in PS | \delta_p = 0, d \le a_p, b \quad (9)$$

Constraints (10) state that a patient undergoes surgery only once, and it is performed in only one OR block assigned to his/her specialty, as Constraints (11) define

$$\sum_{d \in D} \sum_{b \in B_{sp_pd}} sur_{pdb} \le 1 \quad \forall\, ss,\ p \in PS_{ss} \quad (10)$$

$$sur_{pdb} \le av_{bds_p} \qquad \forall\, ss, p \in PS_{ss}, b, d \quad (11)$$

Constraints (12) are on OR capacity, i.e., the overall surgery length is not greater than OR block.

$$\sum_{p \in PS_{ss}} ls_p sur_{pdb} \le lb_{db} \qquad \forall\, ss \in SS, b \in B_{ss,d}, d \in D \quad (12)$$

Finally, the following Constraints (13)-(15) are integrity relations.

$$ad_{prd} \in \{0,1\} \qquad \forall\, p \in P, r \in \bar{R}_p, d \le a_p \quad (13)$$

$$x_{prd} \in \{0,1\} \qquad \forall\, p \in P, r \in \bar{R}_p, d \quad (14)$$

$$sur_{pdb} \in \{0,1\} \qquad \forall\, p \in PS, d, b \quad (15)$$

4 Solution approach, computational results and quantitative analysis

In this section, we describe a two-phase approach designed to solve Model (1)-(15). Then, we test the model on a set of instances, which are solved by the proposed approach and report computational results and a discussion.

4.1 A two-phase approach

In order to reduce patient waiting time and increase hospital efficiency, we develop and implement the following approach in two phases:

Phase 1: schedule surgeries on the basis of patient registration, that is, patients with long waiting time should be scheduled before those with a more recent registration date. This phase implements the first-come first served rule and only objective function (1) is optimized. More specifically, we cluster patients on the basis of the registration date; then we run Model (1)-(15) on each cluster. We firstly solve the model on the cluster related to patients with early registration date; the last run was on the cluster with the last registration date. This strategy implements an equity access for patients. All scheduled patients are thus assigned to a room for consecutive nights as required by their specific LOS.

Phase 2: schedule admissions of elective patients with no surgery on the basis of patient registration. These patients are assigned to rooms by taking into consideration bed availability. This phase takes into account of the residual room capacity because there are patients already admitted and assigned to rooms in the first phase. Only objective function (2) is optimized.

Each patient has to be admitted within a known range of days and assigned to suitable rooms on the basis of specific patient characteristics and resources availability. A resulting schedule obtained by the two-phase approach defines: 1) admission date, assigned room and eventually the assigned OR block and date of surgery per each admitted patient; 2) the set of surgeries per each OR block; 3) the set of patients assigned to each room on each day.

The two-phase approach is implemented and tested on some realistic instances derived from those generated for similar problems by Ceschia and Schaerf, (2016), as described in the following.

4.2 Instances

As already stated in Section 2, the instances generated by Ceschia and Schaerf (2016) for a problem similar to that here addressed, were solved by an online approach, i.e., day-by-day. These instances differ mainly for size. The planning horizon is between 14 and 28 days. As noticed by the authors, the generated instances are infeasible over the defined planning horizon, thus they solved the instances by doubling the planning horizon. This means that the instances with an original planning horizon of 14 days were solved over 28 days, and resource availability is thus doubled. Before to present the results, we describe how the instances of Ceschia and Schaerf (2016), were modified. In the Ceschia and Schaerf' model each patient could be assigned to rooms in departments where his/her specialty is not present; gender policies can be violated and there are also rooms without gender policy or with the so called dependent gender policy, that is, the gender of patients occupying a room could change over the time. Each surgical specialty could use a defined OR overtime and an overall overtime per day is allowed. In our problem, a number of ward stay beds are available for each specialty, a patient must to be assigned to the correct ward, no gender policy violations and OR overtime are allowed. Our model is thus more constrained than the Ceschia and Schaerf' model.

The main differences of our approach with respect to that proposed in Ceschia and Schaerf (2016) are:

- we do not double the planning horizon but select surgical cases and patients to be hospitalized on the basis of their registration date
- we solve the problem in an offline manner, that is, it is assumed that patient registration dates precede the first day of the planning horizon

4.3 Computational results

The computational experiments were carried out for testing our optimization model. Model (1)-(15) was implemented in OPL and solved by IBM CPLEX 12.6.1.

We solved 15 instances, which differ for size and complexity. Each instance has a number of patients waiting for admission to the hospital, and some of them are waiting to undergo a surgery. The associated MSS defines the available ORs and the assigned surgical specialties. The overall available OR time and the overall required OR time, which is given as sum of the expected surgery durations, are then known. The planning horizon is two weeks. The results show an average OR time of 67% and a ward utilization of 78%. Here, we present details on only three instances to illustrate the found schedules, their practical use, and discuss the results.

The main features of the three instances are summarised in Table 1 in terms of overall number of patients, number of specialty, number of beds, number of patients waiting for surgery, number of surgical specialties, related overall available OR time and required OR time. Available OR time and required OR time are reported in hours.

Table 1: main characteristics of the three illustrated instances

	P	S	Bed	PS	SS	available OR	req OR time
I1	220	5	17	61	2	{18, 54}	{32, 88}
I2	176	3	52	60	3	{42, 18, 48}	{48, 4, 31}
I3	439	9	67	195	5	{30,42,30,30,48}	54,62,16,47,37

Instance I1 has five specialties, two surgical specialties, and only 17 available beds. There are 220 waiting patients to be hospitalised; 14 and 17 patients, in SS1 and SS2, respectively, are waiting to undergo surgery. Instance I2 has 52 beds, which are all dedicated to the surgical wards. Instance I3, is the largest instance: there are nine specialties and five surgical specialties. The average patient' LOS in nights is 2.8, 2.5 and 2.6, for I1, I2, and I3, respectively. The elapsed waited time with respect to the patient registration date is between 14 days and 1 day. As shown in Table 1, the overall required OR time is usually greater than that available.

We solve the instances by the two-phase approach. The results are related to: (a) the sequence of patients admitted in a given room over the planning horizon, that is, for each admitted patient is defined both admission date and assigned room; (b) For each planned surgical case is obtained the assigned OR block and the date of surgery. As illustrative example, the schedule related to room 11 of instance I1 over the planning horizon is reported in Figure 4. This room is a single for male patients and it is assigned over the overall planning horizon to four patients. Per each day is reported the patient code identifier, and the day of planned surgery, which is denoted by "sur". For example, patient P122 is admitted on the first day and his/her intervention is planned next day, as required by patient parameter δ_p. The four patients are thus in the related OR block schedules on day 2, 6, 7, and 8, when surgery is planned.

Figure 4: Scheduled patient in a room over the planning horizon

As above underlined, the required OR time is greater than its availability, and only a percentage of surgical cases can be scheduled, as shown in Figure 5 and Figure 6, where results of instance I1 and I2 are illustrated.

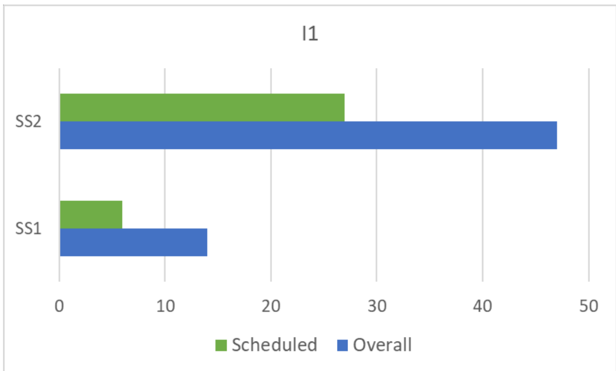

Figure 5: Scheduled surgical cases of instance I1

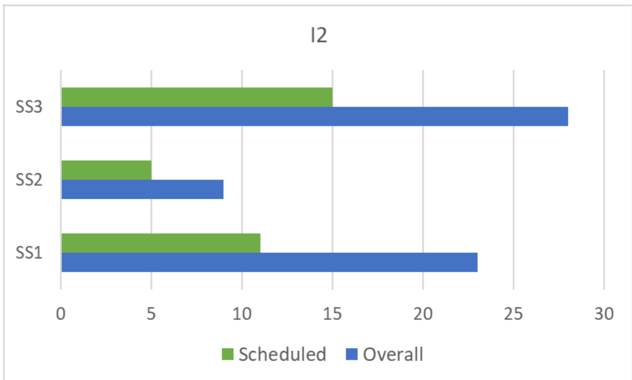

Figure 6: Scheduled surgical cases of instance I2

More specifically, the overall OR time utilization is 75% for both surgical specialties of I1, and it is in the range 54-65 % for the three surgical specialties of instance I2. These results are even due to the number of available beds less than that demanded. In other words, even the number of beds in wards is a bottleneck, mainly in some departments and on some days. The second phase of the solution approach aims at increasing hospital efficiency by maximizing bed utilization and reducing waiting lists. Thus, the goal of this phase is to increase patient flow in the hospital. We illustrate the result of the second phase on the largest instance, i.e., I3. Even the surgical cases of this instances are not all scheduled for the same reasons above explained. More specifically, only 72 patients with surgery are admitted during the planning horizon, that is 36,9 %, and they define an utilization bed of 37%. The second phase maximises bed utilization. The result is that 142 elective patients are admitted, that is 58.20% of patients without surgery and waiting to be admitted.
Figure 7 depicts the resulting bed utilization for instance I3, underling the number of beds occupied by patients who undergo surgery, the number of beds occupied by patients without surgery, and the number of free beds over the planning horizon. The overall number of free beds is due to room inconsistency because room gender policy and specific patient requirements, such as specialty and patient LOS.

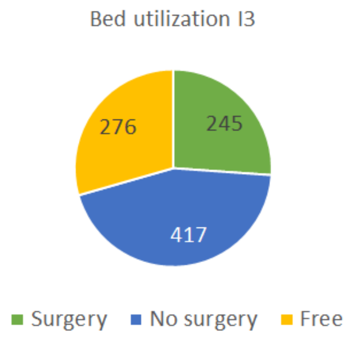

Figure 7: Bed utilization for instance I3

Conclusions

In this paper, we proposed a research framework consisting in an integrated approach based on mathematical programming to address the management of elective surgeries, elective patients and bed management at the same time. The multi-objective model developed in this paper can support hospital staff in planning decision and predict how the hospital reacts to patient flow. It can be a useful tool to improve the productivity level of OR departments and medical departments. Moreover, the developed solution approach implements the first come-first served rule and allows to obtain an equity access for patients. Patients with early registration date are scheduled. Unused beds are due to inconsistency, such as patient LOS greater than the available beds on consecutive nights. On the basis of the results on a set of instances, the tool is able to support a decision maker in managing surgical cases assignments, increase bed utilization and reduce patient waiting time, i.e., waiting lists. It can be adapted to several cases with different objectives and integrated in a bed management system, in order to increase patient flow and reduce hospital costs.

References

Aringhieri R, Landa P., Tanfani E., (2015) *Assigning surgery cases to operating rooms: A VNS approach for leveling ward beds,* Electronic Notes in Discrete Mathematics 47, 173-180.

Bam M., Denton B. T., Van Oyen M. P., Cowen M. E. (2017) *Surgery scheduling with recovery resources,* IISE Transactions, 49(10), 942-955.

Cardoen B., Demeulemeester E., Beliën J.(2009) *Sequencing surgical cases in a day-care environment: An exact branch-and-price approach*, Computers & Operations Research, 36 (9), 2660-2669.

Cardoen B., Demeulemeester E., Beliën J. (2010) *Operating room planning and scheduling: A literature review*. European Journal of Operational Research, 201(3), 921-932.

Ceschia, S. and Schaerf, A. (2011) *Local search and lower bounds for the patient admission scheduling problem*. Computers & Operations Research, 38 (10), 1452-1463

Ceschia, S. and Schaerf, A. (2012). *Modelling and solving the dynamic patient admission scheduling problem under uncertainty.* Artificial Intelligence in Medicine, 56 (3), 199-205.

Ceschia, S. and Schaerf, A. (2016) *Dynamic patient admission scheduling with operating room constraints, flexible horizons, and patient delays*. Journal of Scheduling, 19 (4), 377-389

Demeester P, Souffriau W, De Causmaecker P, Vanden Berghe G (2010). *A hybrid tabu search algorithm for automatically assigning patients to beds*, Artificial Intelligence in Medicine, 48 (1), 61-70

Demeulemeester E., Beliën J., Cardoen B., Samudra M. (2013) *Operating Room Planning and Scheduling*. In: Denton B. (eds) Handbook of Healthcare Operations Management. International Series in Operations Research & Management Science, vol 184. Springer, New York, NY

Erdogan, S. A. and Denton, B. T. (2010). *Surgery Planning and Scheduling*. John Wiley & Sons, Inc

Guerriero F. and Guido R. (2011), *Operational research in the management of the operating theatre: a survey*. Health care management science, 14(1), 89-114.

Guido R, Conforti D (2017) *A hybrid genetic approach for solving an integrated multi-objective operating room planning and scheduling problem*, Computers & Operations Research, 87, 270-282.

Hans, E.W. and van Houdenhoven, M. and Hulshof, P.J.H. (2012) *A Framework for Healthcare Planning and Control*. In: Hall R. (eds) Handbook of Healthcare System Scheduling. International Series in Operations Research & Management Science, vol 168. Springer, Boston, MA

Latorre-Núñez G, Lüer-Villagra A, Marianov V, Obreque C, Ramis F, Neriz L (2016) *Scheduling operating rooms with consideration of all resources, post anesthesia beds and emergency surgeries*, Computers & Industrial Engineering, 97, 248-257.

Ma, G. and Demeulemeester, E. (2013) *A multilevel integrative approach to hospital case mix and capacity planning*, Computers & Operations Research, 40, 2198-2207.

Schmidt R., Geisler S. and Spreckelsen C. (2013) *Decision support for hospital bed management using adaptable individual length of stay estimations and shared resources*. BMC Medical Informatics and Decision Making, 13(3).

Testi, A, Tanfani, E., and Torre, G. (2007) *A three-phase approach for operating theatre schedules*, Health Care Management Science, 10, 163-172