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Mathematical model for maximizing operating rooms utilization

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Abstract: The operating theater is one of the most critical and expensive hospital resources. Indeed a high percentage of the hospital admissions are due to surgical interventions. Operating room planning and scheduling is the best tool to help operating theater managers to administrate this sector. This paper proposes a mathematical model to design a surgery schedule in an operating theater considering an "open scheduling" strategy. Operating rooms are assumed to be multi functional. The main objective of the proposed model is to maximize operating rooms utilization and to minimize idle time between planned surgeries. The proposed model takes into account surgeon's availability.

Keywords: Operating rooms scheduling, open scheduling strategy, linear programming.

1. INTRODUCTION

Rising expenditures spur health care organizations to organize their processes more efficiently and effectively. Within a hospital, the operating theatre represents a key resource. About 60–70% of all hospital admissions are caused by surgical interventions (Rawal, 2001) and it has been estimated, according to the Health Care Financial Management Association, that it accounts for more than 40% of the hospital's revenue and a similar portion of its cost (Health Care Financial Management Association, 2003). Therefore, there is an increasing demand for hospital managers to redesign processes and optimize resource efficiency by using quantitative techniques, already successfully applied in industries. To this end, operational research can be applied to the surgical planning and scheduling processes by using several optimization approaches.

Three main planning strategies are applied in hospitals to construct the surgery schedule (Fei et *al.*, 2010) (Fei et *al.*, 2006):

- *Open scheduling strategy*: This strategy allows surgical cases to be assigned to an available operating room at the convenience of the surgeons (Fei, 2010), (Liu, 2011). The set of surgeries to be scheduled are known in advance for the Open scheduling strategy.
- *Block scheduling strategy*: blocks of uninterrupted operating room time are reserved for individual surgeons or surgical specialties in a periodic (often weekly or monthly) schedule. Surgeons book cases into their allotted block time only if the surgery can be completed within the assigned time. The amount of block time is based on the surgeon's or surgical specialty's historical operating room usage or some other performance criteria. Other constraints such as surgeon preferences and resource availability are also taken into account when assigning block times.
- *Modified block scheduling*: The block scheduling strategy can be modified in two ways to provide more flexibility: either some of the operating room's opening hours are reserved while others are left open, or unused time blocks are released at some agreed time before the surgery.

In the research work presented in this paper, we adopted the "open scheduling" strategy. Indeed, the block scheduling strategy imposes additional model constraints forcing the surgeries with the same specialties to be operated only in specific time blocks. In addition, block scheduling strategy is considered as a special case of open scheduling strategy (Liu et *al.*, 2011).

In this paper, we propose a mathematical programming model to help operating theater managers in developing an optimal operating room scheduling. The model developed in this work considers surgeon's availability during the day, operating room's opening hours. In this study, we assumed that operating rooms are multifunctional. Two main objectives are optimized in a way to ensure an efficient use of the operating rooms during their regular opening hours. The first objective is to maximize the utilization of the operating theater and the second is to minimize the idle time between the planned surgeries.

The paper is organized as follows. We review previous work on this problem on section 2. We present a detailed description of the operating room planning and scheduling problem in section 3. Section 4 presents the proposed model formulation. In Section 5, the proposed heuristic is presented. Section 6 reports computational results. Finally, section 7 concludes the paper.

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2. RELATED WORK

The scheduling of surgical cases requires the execution of two main steps: patients are assigned to operating rooms (advanced scheduling) and then sequenced adequately (allocation scheduling) (Cardoen et *al.*, 2009).

In the literature we distinguish between works focusing only on advanced scheduling or only on allocation scheduling (Fei et *al.*, 2009), (Cardoen et *al.*, 2009). Then, other works tackled both advanced scheduling and allocation scheduling in two separate problems or as a unique problem (Guinet, 2003), (Fei et *al.*, 2010).

Many researchers have tried to develop an efficient model for assigning surgical cases to the operating theatre. Among all these studies, we present only those considering the open scheduling strategy. Fei et *al.* (2009) constructed a weekly surgery schedule based on an open scheduling strategy. They developed an integer programming model to assign elective surgeries with deterministic durations into multifunctional operating rooms. The objective is to maximize utilization of operating rooms and to minimize their overtime cost. The problem was solved in two steps: firstly, the surgery date is assigned to each patient; secondly, the sequence of the surgeries on each operating room is determined. For the first step, the authors constructed a mathematical model. This model complies with the availability of operating rooms and surgeons. For the second step, a column generation based heuristic procedure is proposed. Randomly generated instances were used to test the proposed model and confirmed that the proposed algorithm can obtain a near optimal solution.

Later, the same authors (Fei et *al.*, 2010) formulated a multi-objective mathematical model taking into account the same objectives. As for what they did before, the authors adopted a two-phase model for weekly planning and daily scheduling. They solved the set-partitioning model for the first phase by a column-generation-based heuristic and then solve the hybrid flow-shop model for the second phase with a hybrid genetic algorithm using a tabu procedure. Through three performance indicators and using real data, the results obtained showed that the obtained surgery schedule opens fewer operating rooms and maximizes the utilization of regular opening hours of operating rooms.

Guinet and Chaabane (2003) solved heuristically the operating theatre planning problem by proposing an extension of the Hungarian method. The objective is to minimize the waiting time and to maximize the resource efficiency. In the first phase, patients are assigned to operating rooms over a horizon of time. Constraints taken into account are regular opening hours, maximum overtime hours allowed by the labor legislation, and the type of equipment available in each operating room. In the second phase, interventions are rescheduled on a daily basis, in order to integrate characteristics of human and material resources synchronization.

The main limitation of the approaches presented in (Guinet and Chaabane, 2003), is that surgeon's agendas are not considered. Authors in (Jebali et *al.*, 2006) overcome these limitations and developed a two-step approach to deal with the daily operating room scheduling problem considering an "open scheduling" strategy. The first step assigns surgeries to operating rooms. The problem is mathematically represented as a mixed integer programming. The second step deals with the sequencing problem. This problem is formulated as a two stages hybrid flow shop, whose objective is to minimize the total overtime. Besides resources usage constraints, the surgery sequencing problem considers the recovery room beds availability as a bottleneck resource. Authors proposed two different strategies. The first strategy defines the sequence of surgeries in each operating room. With the second one, it is possible to redefine the assignment of surgeries. The results of the computational experiments showed good performance of surgeries sequencing without considering the re-assignment.

Chaabane et *al.* (2008) proposed two methods, embedded in an open scheduling strategy. The two methods differ in the objective function. The first aims to minimize the gap between the total supply and the weekly requests of the surgical specialties, while the second aims to minimize over-time cost and the patient waiting time. The aforementioned authors propose various approaches for operating room planning and scheduling. Either taking into account advanced scheduling and allocation scheduling in two separate problems or as a unique one.

This work falls within elective case scheduling and simultaneously considers the advanced scheduling and the allocation scheduling under an "open scheduling strategy".

3. PROBLEM DESCRIPTION

The operating theatre planning and scheduling are the two important steps, which aim to make a surgical case programming with the objective of obtaining a realizable and efficient surgical case schedule. In a given time period, the operating theater managers are faced with complex decision problems. First assigning surgical disciplines to operating room sessions. Then assigning elective surgeries to operating room sessions. Finally sequencing surgeries within each operating room session.

We propose a mathematical formulation of the planning and scheduling elective surgeries problem. The proposed model is considered as a linear integer program. Two main decisions are determined once our linear program is solved. The first decision is the specialty assignment to each operating room during each day on the planning horizon. The second decision is the starting time of each surgery, precising its day and operating room.

We assume that operating rooms are multifunctional. Besides, we assume that when a specialty is assigned to an operating room during a day, it is not possible to assign a surgery from another specialty in this room during that day. Although from one day to another, different specialties can be assigned to a given operating room.