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A stochastic optimization and simulation approach for scheduling operating rooms and recovery beds in an orthopedic surgery department ☆

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ABSTRACT

This paper studies the problem of scheduling elective surgery patients in the orthopedic surgery division of Habib Bourguiba hospital in Tunisia. Two types of resources are considered: Operating Rooms (OR) and Recovery Beds (RB). The problem consists of optimizing the assignment of surgeries to OR's and planning the recoveries in order to avoid them in the OR's when no bed is available in the recovery room. The proposed solution takes into account the uncertainty in surgery and recovery durations and the capacity of resources. In a first phase, an additive slack was given to the total duration of each surgery in the waiting list. Then a knapsack model is proposed to choose operations to be scheduled in the selected day. The selected operations are assigned to the different operating rooms using a mixed integer programming model with the aim of wisely using the operating rooms' time and minimizing the makespan. In a second phase, a discrete event simulation model is suggested to compare the new model and the head surgeon actual practise to evaluate the global performance of the proposed model. The efficiency of the suggested solution is then validated by an illustrating example which shows that a substantial amount of operations and hence cost can be saved. Larger instances with sizeable waiting lists are solved to convince surgery schedulers of the utility of the approach.

1. Introduction

Healthcare services have experienced an enormous growth. For instance, in the United States healthcare expenditures in 2007 crossed $2.2 trillion, which accounts for 16.2% of the gross domestic product (Vijayakumar, Pratik, Scott, Barnes, & Gallimore, 2013). These expenditures have been increasing rapidly for the last few decades, and will reach 19.5% of the US GDP by 2017 (Zhao & Li, 2014). The operating room or the surgical suite is regarded as the engine of a hospital. It represents the largest cost as well as the largest revenue center (Denton, Viapiano, & Vogl, 2007). In public hospitals, this unit contributes to the highest expenditure with almost no revenues. As result, OR management has become a very important issue for hospital managers to control surgery's costs in order to provide acceptable quality services. One of the benefits to be derived from improving OR management is a better coordination between the demand for hospital and the existing resources such as: OR, surgeons, beds and nurses Magerlein and Martin (1978). Hence, hospitals are faced with rationally using their resources to prevent undertime, overtime and the increase in waiting lists.

The operating room scheduling problem has been intensively studied in the literature from decision scientist's perspectives (Cardoen, Demeulemeester, & Belien, 2010; Przasnyski, 1986). They used many operations research tools and decision support systems which are becoming more and more available to solve such problems (Ozkarahan, Emrah, Edis, & Mizrak Ozfirat., 2013).

Similar to the rest of the world, Tunisian hospitals have to deal with the OR planning and scheduling problem. The problem must be solved because of its importance in practice and to make the scheduling tasks easier for head surgeons. Instead of carrying out many tasks mentally and manually, surgeries' schedulers have to be provided with computerized decision support system to choose from many operations in the waiting list and to assign them to the rooms.

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In this paper, we propose a daily scheduling approach for elective patients in the orthopedic surgery division of a Tunisian hospital. In a first step we model the problem of selecting the list of surgeries to be handled as a knapsack problem. The aim of this model is to minimize simultaneously the overtime and the underutilization of OR's. As a second step, we propose an MILP for assigning the list of the selected surgeries to the different OR's with the objectives of minimizing both the maximum completion time and the total waiting time of each room. We also propose a discrete event simulation model to evaluate the proposed solution to determine recovery beds assignment of each operated patient.

For the OR scheduling there is two scheduling system: block scheduling and open scheduling. Denton et al. (2007): in the block scheduling time slots are attributed to every specialty. So that each surgeon can only operate in the time slots attributed to its specialty. On the other hand in the open scheduling system, surgeries are assigned to ORs to create a schedule prior to the day of surgery. In our case we are interested in the open scheduling system because we treat a single specialty which is the orthopedic.

2. Literature review

Many researchers in the field of healthcare have assessed the work of the operating room unit. Some of them looked at the picture globally in terms of improving master surgical schedules (Belien & Demeulemeester, 2007; VanOostrum, Bredenhoff, & Hans, 2010; VanOostrum et al., 2008). Belien and Demeulemeester (2007), for instance, treated the problem by considering a block assignment of the operating room time to specialties. They proposed a number of mixed integer programming based heuristics and meta-heuristics. These models take into account stochastic numbers of patients per operating room block and a stochastic length of stay for each operated patient. The surgical process can be treated as more than one stage problem with parallel identical operating rooms. For instance, Augusto, Xie, and Perdomo (2009) investigated the impact of allowing patient recovery in operating rooms. The problem is modeled as a 4-stage hybrid flowshop. Lagrangian relaxation-based method was used to solve the model. The variability of surgery duration (including setup, anesthesia, surgery...) is among the factors that make managing operating room a difficult task. Managing the uncertainty is one of the operating room related issue that has been highly treated in the last decades (Adan, Bekkers, Dellaert, Jeunet, & Vissers, 2011). Lehtonen (2013) thought about improving productivity by focusing on the time categories of operations. They propose the use of more accurate case categories and combine them in scheduling. Four surgery categorization scenarios are proposed with the aim of minimizing scheduling inefficiency. The productivity of these scenarios was analyzed by simulation and newsvendor model. Min and Yih (2010a) treated the problem of scheduling elective patient in the Surgical Intensive Care Unit (SICU) with uncertain surgeries durations and downstream resources. The problem was formulated as a stochastic mixed integer programming model. Persson and Persson (2010) focused on the problem of meeting the uncertainty in demand of patient arrival and surgery duration at a department of orthopedic surgery in Sweden. A discrete-event simulation model is proposed to show how different management policies can affect different performance metrics such as patient waiting time, cancellations and the utilization of OR time.

The literature of planning and scheduling the OR's is rich one. Here is a set papers dealing with the problem. Table 1 represents the legend of aspects considered in the papers listed in Table 2. These papers are indicated to partially (P), or totally (T) treat an aspect (see Meskens et al., 2013 for similar table) (see Table 3).

Table 1
Legend of aspects considered.

Aspect	Column
Number and availability of surgeons	1
Number and availability of nurses	2
Number and availability of anesthetists	3
Number and availability of stretcher-bearers	4
Amount of material	5
Re-usable or disposable material	6
Specific material	7
Surgeon's preferences	8
recovery room	9
Stochastic aspects (emergency...)	10
Patient priorities	11
Surgical team affinities	12
Versatility of operating rooms	13
Tested on real time	14
Multiobjective optimization	15
Simulation model	16

Denton et al. (2007) stated that due to significant uncertainty in surgery durations, scheduling of OR's can be very challenging. Longer than average surgery durations result in late starts not only for the next surgery in the schedule, but for the rest of the surgeries in the day as well. Late starts also result in direct costs associated with overtime staffing when the last surgery of the day finishes later than the scheduled shift end time. In their paper, authors described a stochastic optimization model and some practical heuristics for computing OR schedule that hedge against the uncertainty in surgery durations. They focused on the simultaneous effects of sequencing surgeries and scheduling start times. They found from test results that a simple sequencing rule based on surgery duration variance (highest variance operation latest) can be used to generate substantial reductions in total surgeon and OR team waiting, OR idling, and overtime costs. Two types of operating room schedules are considered in the literature. The first type treats the elective patients without considering the emergency cases. The other one takes into account the assignment of emergency patient; either by incorporating them, in the schedule, in a real time. Or by reserving a part of the available operating time for the urgent cases that can be occurred during the week. Lamiri, Xie, Dolgui, and Grimaud (2008) treated the problem with two types of demand for surgery: elective surgery and emergency surgery. In a first step, a stochastic mathematical programming model is proposed to assign elective cases to different periods with the aim of minimizing overtime costs and the sum of elective patient related costs. Then a combination of a Monte Carlo simulation with Mixed Integer Programming is proposed to solve the problem. Dexter and Macario (2007) stated that if a high probability of taking longer than scheduled, then increasing the case's scheduled duration could reduce over-utilized operating room time. In another paper Dexter et al. (2006) were concerned with knee and hip surgeries. They investigated factors that can increase or decrease operating room time. They found out that the labor cost is mostly the main factor.

The performance of the operating rooms can be related to various concerns such as minimizing related costs, minimizing waiting time, maximizing the operating room utilization, etc. Lovejoy and Li (2002) investigated the trade-offs among three performance criteria (wait to get on schedule, scheduled procedure start-time reliability, and hospital profits). Their paper presented supporting analysis for process improvements and suggestions for optimal participation-inducing staff contracts for extending OR hours of operation. Kuo, Schroeder, and Bollinger (2003) developed a linear programming model to schedule the OR, their objective was financial: to maximize revenues by reassignment of the surgeons' OR time. Jebali, Hadj Alouane, and Ladet (2006) came up with two