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An online optimization approach for the Real Time Management of operating rooms

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ABSTRACT

The Real Time Management (RTM) of operating rooms is the decision problem arising during the fulfilment of the surgery process scheduling of elective patients, that is the problem of supervising the execution of such a schedule and, in case of delays, to take the more rational decision regarding the surgery cancellation or the overtime assignment. The main concern of this paper is to propose a model for the RTM and to evaluate its impact on the OR performance assessed by a set of patient- and facility-centred indices. To this end, we consider a generic surgical clinical pathway for elective patients – inspired to a real case study – in which we evaluate the introduction of an online optimization approach for the RTM and some additional optimization modules to deal with the surgery process scheduling problem. To the best of our knowledge, the RTM is not clearly addressed in the literature and this is the first attempt to propose an online approach in the context of surgery process scheduling. We propose a hybrid simulation and optimization model in which simulation is used to model the inherent stochasticity and to replicate the elective patient flow on which the online approach for the RTM and the additional optimization modules operates. We report an accurate computational analysis proving the effectiveness of the proposed approach to the RTM. Finally, we demonstrate the capability and the flexibility of our approach extending our hybrid model to deal with emergency surgeries and different trained surgery teams.

1. Introduction

Problems arising in the Operating Room (OR) planning and scheduling are usually classified into three phases corresponding to three decision levels, namely strategic (long term), tactical (medium term) and operational (short term) [1]. At the operational decision level, the problem arising in the OR management is also called "surgery process scheduling" and is generally divided into two sub-problems referred to as "advanced scheduling" and "allocation scheduling" [2]. The first sub-problem consists in selecting patients from a usually long waiting list and assigning a specific surgery and OR time block to each patient over the planning horizon, which can range from one week to one month [3–10]. Given this advanced schedule, the second sub-problem determines the precise sequence of surgical procedures and the allocation of resources for each OR time block and day combination in order to implement it as efficiently as possible [11–16]. Usually, the two sub-problems have different objectives, that is to maximize the operating room utilization and to minimize the number of surgeries delayed or cancelled, respectively. Furthermore, especially when considering the inherent stochasticity of the problem, the two objectives are conflictual as discussed in [17]. For a complete overview of the problems arising in the OR management, the reader can refer to the papers [18,19] in which an exhaustive review is reported analysing in detail multiple fields related to the problem settings and summarizing significant trends in research areas of future interest.

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The literature reports few attempts to address the problem as shown in [20]. In [21] the authors showed how a computer assisted system could help mitigating the increase of over-utilization of the operating room resources such as overtime. The problem of tardiness from scheduled start times is addressed in [22] comparing the effectiveness of several procedures to reduce tardiness. The authors showed that the generation of a

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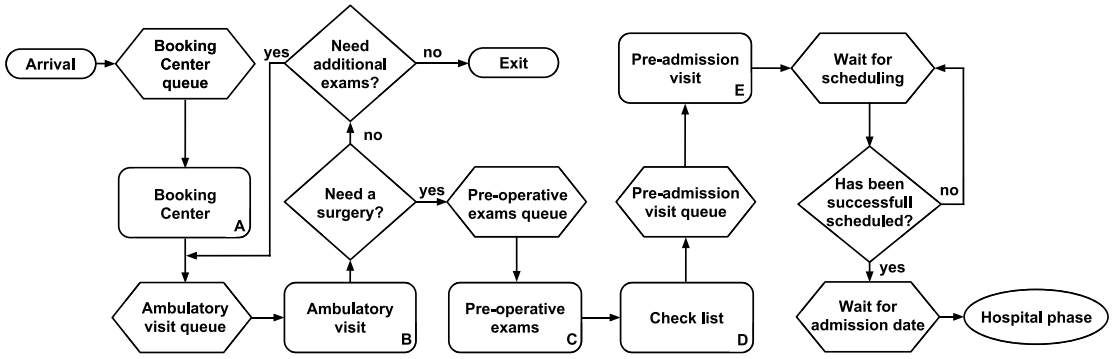

Fig. 1. Pre-admission phase flowchart.

modified or auxiliary OR schedule that compensates for known causes of tardiness can be a good solution to reduce tardiness even if its impact proportionally increases as the number of cases involved. The problem of rescheduling the elective patients upon the arrival of emergency patients is addressed in [23,24]. The authors proposed a MILP model which considers the overtime cost of the operating rooms and/or the post-anaesthesia care units, the cost of postponing or preponing elective surgeries, and the cost of turning down the emergency patients. They proposed a genetic algorithm for its approximate and faster solution. The results of the case study suggest that, instead of shuffling the elective surgeries, it would be worthwhile to consider performing the elective surgeries using the overtime of the operating rooms. Note that the problem of rescheduling patients can be addressed as a particular job shop scheduling problem [25,26] but these experiences cannot directly applied to the operating room context due to its peculiarity in the evaluation of a solution, as we will show in the following. Strategies to move a patient from an operating room to another and based on statistical remarks are proposed in [27–29].

To the best of our knowledge, this is the first attempt to propose an online approach in the context of the operating room management.

The main concern of this paper is to propose a model for the RTM and to evaluate its impact on the OR performance assessed by a set of patient- and facility-centred indices. To this end, we consider a generic surgical clinical pathway for elective patients – inspired to a real case study – in which we evaluate the introduction of an online optimization approach for the RTM and some additional optimization modules to deal with the surgery process scheduling problem.

A Clinical Pathway (CP) can be defined as "health-care structured multidisciplinary plans that describe spatial and temporal sequences of activities to be performed, based on the scientific and technical knowledge and the organizational, professional and technological available resources" [30].

As reported in [31], health care optimization problems are challenging, often requiring the adoption of unconventional solution methodologies. The solution approach proposed herein belongs to this family. We propose a hybrid simulation and optimization model in which simulation is used to model the inherent stochasticity and to replicate the elective patient flow on which the online approach for the RTM and the additional optimization modules operates.

The paper is organized as follows. The three phases of a generic surgical clinical pathway are described in Section 2 pointing out the corresponding optimization problem arising in each phase. Our hybrid simulation and optimization model is discussed in Section 3. In Section 4 we report an accurate computational analysis in order to prove the effectiveness of the proposed approach to the RTM, and to evaluate the impact of the optimization on the management of a surgical pathway. In Sections 4.5 and 4.6 we demonstrate the capability and the flexibility of our approach extending our hybrid model to deal with emergency surgeries and different trained surgery teams. Section 5 closes the paper.

2. Surgical clinical pathway and optimization problems

The definition of the surgical pathway is inspired to that presented and analysed in [32] for the thyroid surgical treatment. The reader can refer to this paper for further details. From a management point of view, a surgical pathway can be seen as made up of three phases.

The first phase concerns the *pre-admission phase* and it is related to all the activities regarding patients before their admission (see Fig. 1).

In this phase, a relevant information is the Diagnosis Related Group (DRG). A DRG defines a general time limit before which the patient should be operated on. Note that the DRG refers to the access time (i.e., days to surgery) and not to the waiting time on the day of surgery. In our context, a *Urgency Related Group* (URG) is assigned to each patient belonging to the same DRG: the URG states a more accurate time limit called *Maximum Time Before Treatment* (MTBT). In other words, URG allows to define a partition of the patients in the same DRG in order to prioritize their surgical operation. The optimization problem arising in this phase is the advanced scheduling problem, which consists in the selection of patients from the (usually long) waiting list and in their assignment to an *OR session* (i.e., an operating room on a given day) in such a way that several operative constraints are satisfied (number of beds available during the patient stay, total time available for the OR session, and so on). Our objective is to maximize the utilization of the operating rooms in each day in such a way to guarantee that each patient is operated within the time limit defined by the URG. This problem is well known in the literature as Surgical Case Assignment Problem (SCAP) [33].

The *hospital phase* is concerned with all the activities involving the admitted patient stay except for those related to the operating theatre as depicted in Fig. 2(a). The relevant information in this phase is the Length Of Stay (LOS) of each patient, that is the number of days required before the discharge. The optimization problem arising in this phase is the allocation scheduling problem, which consists in finding a sequence of patients to determine the order in which they are operated on. The objective is to minimize the risk of cancellation, while keeping an acceptable utilization rate with respect to the available operating time taking into account a patient-centred point of view (considering waiting time, class of urgency, possible previous referrals).

Fig. 2(b) depicts the *operating theatre phase*, which is a component of the hospital phase, as highlighted in Fig. 2(a).