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Innovative Applications of O.R.

Optimal distribution of operating hours over operating rooms using probabilities

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ABSTRACT

Usually, all operating rooms in a hospital have the same daily capacity although differing operating hours might be advantageous to match the demand. We propose and evaluate an optimization model that tactically distributes the total available operating time over the different operating rooms in order to improve performance. The probability of a perfect day without overtime or cancellations serves as objective criterion. Hence, the solution obtained has a maximum probability of no overtime or cancellations in all operating rooms. Uncertainties handled are mainly the surgery duration of patients and the daily number of patients to treat. To assess the number of patients, a method for sampling from multidimensional distribution functions for health care purposes is introduced. It is demonstrated that optimal operating hours for operating rooms can significantly influence key performance indicators such as overtime, rescheduling of patients and utilization. Implications for research and practical purposes can be deduced from an extensive simulation study with realistic data.

1. Introduction

Facing an increasing demand for health care supply, hospitals need to carefully balance their use of resources to ensure economic efficiency and best care for their patients. The operating theater (OT) contributes substantially to costs and revenues and requires particular attention in the dimensioning of capacities. Usually, in literature as well as in practice, every operating room (OR) in the OT is assigned with the same capacity per day resulting in the same daily regular operating time for all ORs. In this paper, we show that using the capacity differently to distribute operating time unevenly over the ORs can be advantageous. Uncertain parameters, like the number of patients and their treatment duration, complicate the planning procedure in the OT and hinder the realization of plans. As a result, interests of different stakeholders are difficult to achieve, plans are changed on short notice and undesirable measures have to be taken. Therefore, proper consideration of uncertain parameters supports good planning. The complex decision-making process of capacity allocation in operating theater planning is performed at three planning levels: strategic, tactical and operational (Guerriero & Guido, 2011; Hulshof, Kortbeek, Boucherie, Hans, & Bakker, 2012). At a strategic level, decisions are made on constructional circumstances like the number of operating rooms. In addition, global settings like the total OR capacity and available OR capacities for each department are specified. Furthermore, the hospital decides on the types and maximal number of patients to accept for admission to determine the hospital's case mix as far as possible. Decisions on the tactical level affect the medium-term plan. This includes the development of a master surgical schedule, i.e., the allocation of strategically fixed capacity over the ORs and also shift planning of the staff. In this contribution, we propose an optimization model to tactically decide on the distribution of OT capacity over the different ORs in order to improve quality of care for the patients and working conditions for the staff. Based on strategic and tactical decisions, short term decisions are made at an operational level. With the exact knowledge of the number of patients to be treated on a specific day, a detailed patient planning is done. Each patient is assigned to an operating day, room and time. This defines the order of surgeries in each room. To evaluate the influence of the tactical decision made by our optimization, we analyze the effects of adjusted and optimized operating hours on the operational level in a simulation study. Since each planning level highly depends on the decisions made one level above, it is indispensable to include lower-level information to efficiently provide decision support. Perfect predictions of uncertain parameters, like the exact number of patients and medical requirements, cannot be made in advance, therefore, estimations as precise as possible are used. In this context, Harper (2002) emphasizes the need for patient classification techniques for a better management of hospital resources. Instead

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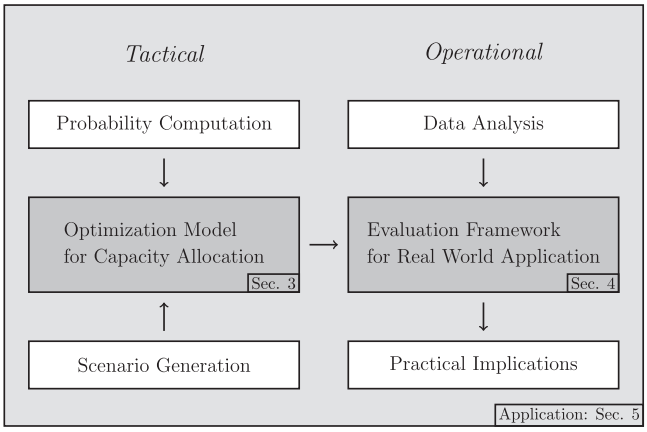

Fig. 1. Remainder of this paper.

of considering each patient individually, patients are clustered according to their medical requirements and the required equipment of their ORs. The hospital's individual case mix is based upon this classification.

Dependent on the case mix, existing capacities have to be optimally distributed at a tactical level. Thus, the question arises if the common practice of distributing the total OT capacity evenly over the ORs impairs performance of the OT. This paper covers that topic and addresses the optimal allocation of the available total OT capacity over the individual ORs with regard to the case mix. We propose an integer linear program (ILP) to optimally allocate OR operating hours at a tactical level taking the uncertain surgery duration and daily number of patients into account. The aim is to minimize induced undesirable measures like overtime or postponements of surgeries at the operational level. For health care purposes, we develop a generally applicable new method to generate scenarios for varying numbers of patients to be integrated in the optimization model. Subsequently, using a stochastic discrete event simulation, we evaluate at an operational level how main performance criteria and stakeholders are influenced by different allocations of operating hours and whether the consideration of a given case mix in the determination of operating hours will improve the performance.

Major contributions of our work are

- determining optimal operating hours for each OR,
- a holistic consideration of the OT to represent dependencies between ORs,
- an innovative handling of uncertain treatment duration,
- proposing a generally applicable new method for heuristically generating scenarios representing the hospital's case mix,
- deducing practical results from a realistic application.

The remainder of the paper is structured as follows: Section 2 summarizes existing literature related to this paper. The next three sections follow the schematic overview in Fig. 1. In Section 3, we propose an ILP to optimally distribute given OT capacity over ORs while maximizing the probability that neither overtime occurs nor planned surgeries have to be canceled. The optimal solution will be evaluated using a generalizable concept for evaluation of tactical decisions at an operational level. This concept will be presented in Section 4 and it will be applied to data obtained from a large German hospital for thoracic and cardiovascular surgery in Section 5 (see surrounding box in Fig. 1). Additionally, data processing and data analysis is reflected, results are discussed and practical implications are derived from the evaluation. A conclusion and outlook is given in Section 6.

2. Related literature

In recent years, a lot of research has focused on the problem of operating theater planning. Comprehensive reviews of operating room planning and scheduling have been carried out by Cardoen, Demeulemeester, and Beliën (2010); May, Spangler, Strum, and Vargas (2011) and Guerriero and Guido (2011). In these papers, several deterministic, stochastic and dynamic models for capacity dimensioning, capacity allocation and patient scheduling were evaluated. We will tactically determine operating hours for ORs, considering uncertain surgery duration and uncertain patient occurrence and evaluate them at an operational level. Hence, the following review is structured into literature regarding operating hours, uncertainty in OT planning and evaluation methods.

2.1. Operating hours

The existing approaches mainly focus on allocating capacity to specialties within fixed OR operating hours (Agnetis et al., 2014; Dexter & Traub, 2002). Usually, the OR block length is given and evenly distributed over the different operating rooms (see e.g. Beliën, Demeulemeester, & Cardoen, 2009 or Ma & Demeulemeester, 2013). Decisions are only made regarding the number of operating room openings (Roland, Di Martinelly, & Riane, 2006; van Houdenhoven, van Oostrum, Hans, Wullink, & Kazemier, 2007; van Oostrum et al., 2008) and analysis of OR time extensions (see e.g. Testi & Tànfani, 2009). In the scope of testing different alternatives, Dexter and Macario (2002) analyze the influence of different OR hours and show great potential for optimization. For this reason, Koppka, Schacht, Wiesche, Bapumia, and Werners (2018) propose a linear optimization model to determine optimal OR operating hours. They show that differing individual OR operating hours for the same total OT capacity can considerably reduce staff overtime and patients rescheduling. In their model, the uncertainty of surgery duration does not reflect the entire scope of uncertainty. We extend the handling of uncertainty in this paper considerably.

2.2. Uncertainty

Uncertainty complicates the design and management of efficient OR planning. The main challenge in determining optimal OR hours is to provide sufficient capacity with respect to a varying number of patients, uncertain surgery duration as well as an uncertain occurrence of emergency patients. At a tactical level, the available OR capacity has to be balanced between elective patients and emergencies. Van Riet and Demeulemeester (2015) and Ferrand, Magazine, and Rao (2014) classify the existing contributions according to the strategies for dealing with emergencies: dedicated, hybrid and flexible capacity planning. Most studies on OR planning assume that emergency surgeries are performed in a particular emergency OR. This implies that emergencies are not taken into account when planning elective surgeries. However, Wullink et al. (2007) have shown that in terms of waiting time, staff overtime, and OR utilization, it is preferable to schedule the emergency surgeries in the next available elective OR. Furthermore, at a tactical decision level, OR time for emergencies must be guaranteed. Thus, in this contribution, a flexible strategy is chosen considering no separate OR for emergencies, but sharing the OR capacity between elective and non-elective patients.

Additionally, uncertainty in surgery duration has to be considered, since deviations from the planned duration directly influence OR planning in terms of idle time or overtime as well as cancellation of surgeries. Information on surgery durations can be obtained from historical data or can be specified by experts (Denton, Miller, Balasubramanian, & Huschka, 2010). In most hospitals, estimates for surgery durations are obtained by relatively simple methods

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