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Innovative Applications of O.R.

Master surgery scheduling with consideration of multiple downstream units

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ABSTRACT

We consider a master surgery scheduling (MSS) problem in which block operating room (OR) time is assigned to different surgical specialties. While many MSS approaches in the literature consider only the impact of the MSS on operating theater and operating staff, we enlarge the scope to downstream resources, such as the intensive care unit (ICU) and the general wards required by the patients once they leave the OR. We first propose a stochastic analytical approach, which calculates for a given MSS the exact demand distribution for the downstream resources. We then discuss measures to define downstream costs resulting from the MSS and propose exact and heuristic algorithms to minimize these costs.

1. Introduction

Due to an aging society and technological progress, the demand for health care services is rising in industrialized countries (Hay, 2003; OECD Indicators, 2011). At the same time, cost cuts and human resource shortages lead to increasing pressure on hospital resources. Therefore, the importance of optimizing the usage of scarce resources in hospitals is self-evident. The most expensive resource in most hospitals is the operating room (OR) (Guerriero & Guido, 2011). ORs are clearly connected with other "downstream" resources, for example, the post-anesthesia care unit (PACU), the intensive care unit (ICU), and the general patient wards, hereafter referred to as "wards". Anderson, Price, Golden, Jank, and Wasil (2011) show that a high level of utilization in hospital wards leads to a higher discharge rate of patients, which might reduce the quality of care. On days with high patient inflow to the ICU the danger of readmissions (Baker, Pronovost, Morlock, Geocadin, & Holzmueller, 2009) and the probability of rejected ICU requests (McManus et al., 2003) strongly increases. Therefore, downstream units should also be considered in surgery planning for medical reasons. When planning the operating rooms and the downstream units, decision makers face a trade-off between the high complexity of a holistic view and the danger of suboptimal solutions resulting from focusing on isolated units (Vanberkel, Boucherie, Hans, Hurink, & Litvak, 2010).

Many hospitals use a so-called block-booking system when planning surgeries. In this system a medical specialty, e.g. urology, is assigned to blocks denoting a specific amount of time, e.g. a day, in one OR. These blocks can be combined into cyclical master surgery schedules (MSS), where every block is repeated after a fixed cycle, e.g. every two weeks. In planning and scheduling, problems can be categorized according to levels of a decision hierarchy (Hans, van Houdenhoven, & Hulshof, 2011): The strategic, tactical, offline-operational (i.e. planning in advance) and the online-operational (i.e. reacting/monitoring) level. In block-booking systems, decisions are made on all hierarchical levels. At the strategic level the number of blocks assigned to the specialties during a MSS cycle is determined. At the tactical level, OR-days are allocated to specialties in an MSS, such that the strategic allocation is met. At the operational level, patients are scheduled (offline) and rescheduled in case of emergencies or unexpected changes (online). An overview of OR planning may be found in Hans and Vanberkel (2011).

In the paper at hand, we discuss the tactical MSS problem, concentrating on the effect the MSS has on the patient flow to downstream inpatient care units. Surgeries performed in each block of the MSS create a flow of patients through the ICU to the ward, or directly from the OR to the wards, before they

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leave the hospital. As the PACU is part of the OR department in many hospitals, we exclude this unit in our tactical problem and denote the ICU and the ward as downstream units. This paper concentrates on the inpatient flow because outpatients leave the hospital the day of surgery and thus require only OR capacities. We define a model to calculate the distributions of recovering patients in the downstream units expected from the MSS. Based on this, we propose an approach for planning the MSS with the objective to minimize downstream costs by leveling bed demand and reducing weekend bed requests.

The remainder of this paper is organized as follows: Section 2 provides a brief overview of the relevant literature. Section 3 presents an algorithm for calculating the distribution of recovering patients in the downstream units – ICU and multiple wards. Section 4 offers a generic model to determine optimal MSSs and a discussion of relevant objective functions to determine downstream costs. In Section 5 we present a branch-and-bound algorithm and different heuristics to minimize these costs. We test the algorithms in Section 6 in an experimental investigation using data from a Dutch hospital. Finally, we discuss managerial implications, limitations, and potential extensions of our study.

2. Literature review

Operating rooms are among the most expensive resources in hospitals and is a focus of a large number of scheduling studies (Cardoen, Demeulemeester, & Beliën, 2010). For recent literature reviews on OR scheduling, see Cardoen et al. (2010) and Guerriero and Guido (2011). Articles about health care models that include both the OR and downstream units are reviewed in Vanberkel et al. (2010). In this section, we focus on articles that combine OR scheduling with the effect on downstream units, such as ICUs or wards.

Adan and Vissers (2002) present a deterministic integer programming approach to schedule patients based on fixed capacities in the OR, the ICU, and the ward. The ICU and ward capacities are the number of beds available for each specialty, while the OR capacity is the total available operating time per day. Additionally, the capacity of the nursing staff is considered. Based on this, a daily admission profile for different specialties that minimizes the deviation from resource utilization targets is obtained. Gartner and Kolisch (2014) propose a binary program which decides for each patient what day the patient is admitted, what day each clinical activity is undertaken and what day the patient is released. The objective is to maximize the sum of the contribution margins of all patients taking into account limited availability of clinical resources. Santibanez, Beliën, and Atkins (2007) discuss various trade-offs in tactical OR planning. They also apply a deterministic mixed-integer program and compare different objectives, e.g. maximizing throughput of patients or leveling the bed requests of downstream units. Their study differentiates between beds and nursing levels as well as between ORs and surgeons. An integer linear program (ILP) model to construct an MSS where patient types are assigned to blocks is formulated by van Oostrum et al. (2008). They seek to minimize the required OR capacity and to level hospital bed requirements. To incorporate the uncertainty of OR durations, they introduce probabilistic constraints. They solve the model in two steps. First, OR capacities are optimized without consideration of hospital-beds using so-called Operating Room Day Schedules (ORDSs), i.e. lists of surgery types that are assigned to one OR day. Then, the ORDSs are assigned to OR days in order to level hospital-bed demand. Therefore, leveling hospital-bed demand is only possible using the precomputed set of ORDSs. All four aforementioned papers model multiple downstream units with mainly deterministic approaches, while our study employs a stochastic approach.

Models for creating MSSs with leveled bed occupancy in downstream units are presented in Beliën and Demeulemeester (2007). Contrary to the articles presented above, both the number of patients and the length of stay in the hospital are assumed to be stochastic. A multinomial distribution is used to model the length of stay. The authors aim to minimize the expected bed shortage and employ a mixed-integer programming and a simulated annealing approach. The approach of Beliën and Demeulemeester (2007) differs from our approach in only allowing one downstream resource (ward), while we model the patient flow including the ICU and wards and thus consider multiple downstream units.

Min and Yih (2010) propose operational scheduling of elective surgeries that considers both uncertainty and downstream capacity constraints. They formulate a stochastic surgery scheduling problem minimizing the sum of costs directly related to patients and expected overtime costs. The downstream capacities are modeled as constraints. In contrast to their approach, which considers the operational surgery planning level, we focus on the tactical level.

Our study is based on the approach of Vanberkel et al. (2011b) where binomial distributions and discrete convolutions are used to calculate the exact distribution of recovering patients in the ward resulting from a given MSS. Vanberkel et al. (2011b) propose a set of equations to determine the distributions of ward occupancy, patient admissions, patient discharges, and the number of patients on each day of their recovery period. A case study where the algorithm is implemented in a Dutch hospital is presented in Vanberkel et al. (2011a). The authors use their approach to construct several MSSs and to choose one with a favorable ward occupancy pattern. We build upon their study by extending it in the following ways: First, Vanberkel et al. (2011b) only include one ward as a single downstream unit. As the ICU is an important bottleneck in hospitals (Litvak, van Rijsbergen, Boucherie, & Houdenhoven, 2008), we incorporate ICU bed requests as well as multiple wards in our model as a valuable extension. Second, Vanberkel et al. (2011b) do not determine the costs resulting from an MSS. As different downstream costs exist, e.g. costs for providing fixed capacities or costs for weekend staffing, we develop an approach to assign costs to specific MSSs. Third, we introduce several exact and heuristic algorithms to minimize these downstream costs.

To the best of our knowledge, the current study presents the first exact stochastic MSS approach to calculating patient occupancy distributions in the ICU and multiple wards. In addition, we present exact and heuristic algorithms to minimize costs resulting from patients in downstream units.

3. Recovering patients in downstream units

In this section, we describe a model that calculates the exact distribution of post-operative inpatients in the ICU and multiple wards resulting from a given MSS cycle. We do not further distinguish between different ICUs in this study. However, the presented approach can be extended to include several ICUs. We now present the general underlying assumptions regarding the process, the required data, and the detailed model.

After an operation several patient paths exist. In most cases, patients are admitted to a ward. In more severe cases, patients are sent to the ICU. Alternatively, patients might be discharged without being sent to a ward (e.g. due to mortality). Patients in the wards will be transferred to the ICU if their condition becomes unstable. Most patients leave the system only after recovering in a ward, but they might also leave the hospital directly from the ICU