European Journal of Operational Research 235 (2014) 138–148

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Discrete Optimization

An approach to optimize block surgical schedules

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ARTICLE INFO

Article history:
Received 5 October 2012
Accepted 15 October 2013
Available online 30 October 2013

Keywords:
Operations research in health service
Block surgical schedule
Sequential newsvendor
Normal distribution
No-shows

ABSTRACT

We provide an approach to optimize a block surgical schedule (BSS) that adheres to the block scheduling policy, using a new type of newsvendor-based model. We assume that strategic decisions assign a specialty to each Operating Room (OR) day and deal with BSS decisions that assign sub-specialties to time blocks, determining block duration as well as sequence in each OR each day with the objective of minimizing the sum of expected lateness and earliness costs. Our newsvendor approach prescribes the optimal duration of each block and the best permutation, obtained by solving the *sequential newsvendor* problem, determines the optimal block sequence. We obtain closed-form solutions for the case in which surgery durations follow the normal distribution. Furthermore, we give a closed-form solution for optimal block duration with no-shows.

1. Introduction

A block surgical schedule (BSS) prescribes the duration of the time block reserved for each specified surgery sub-specialty and sequences time blocks within each operating room (OR) day to achieve the objective of minimizing the sum of expected earliness and tardiness costs. Tactical-level decisions compose a BSS for use over the intermediate-term (e.g., month or quarter), allowing flexibility within a long-term, strategic plan, for example, to accommodate seasonal demand changes. With the goal of synthesizing a methodology to prescribe a BSS, specific research objectives of this paper are 1 a method to optimize the planned duration of each block, minimizing the sum of expected earliness and lateness costs; 2 a method to optimize the sequence (i.e., permutation) of blocks in each OR day; and 3 an extension of our method to prescribe an optimal planned block duration when no-shows are considered.

Each hospital provides a unique capacity for performing surgery through the numbers of ORs and surgical skills it offers. A surgical suite typically comprises several ORs, each of which is equipped to support one (e.g., cardiology, neurological, or orthopedic) or several (e.g., general surgery, ENT) specialties.

The typical surgical specialty comprises a number of sub-specialties. For instance, orthopedics includes hip replacement, knee replacement, femur fixation, and shoulder repair sub-specialties. Surgeries that require the same sub-specialty are medically homogeneous and require the same medical expertise of the surgeon or surgeons involved (van Oostrum et al., 2008).

Allocation (or assignment) decisions are made for the longer term (e.g., six or 12 months); we assume that they assign one specialty to each OR day. Based on specialty-to-OR-day-assignment decisions, the current paper prescribes time blocks for sub-specialties within the specialty for the intermediate term (e.g., month or quarter). To the best of our knowledge, little research had dealt with determining block duration and sequence within an OR day.

We deal with the block scheduling policy in this study. A block is the amount of time during which a specific sub-specialty is assigned to an OR. A block may be planned with the duration of two hours, half of a day, or a day, for example, to permit a surgeon to perform a series of surgeries. An alternative, the open scheduling policy, under which each surgeon can schedule his/her surgeries at any time, was common in the 1960s and 1970s but is rarely used in practice today, because it does not utilize surgeons' time as efficiently as block scheduling (Blake, Dexter, & Donald, 2002).

Once BSS determines a schedule of time blocks, including the duration and sequence of each, the day-by-day schedule for a week may be used cyclically, that is, for each week over the intermediate-term planning horizon. A cyclic schedule avoids the need to prescribe a new schedule every week and promotes coordination among surgeons, staff and other departments (e.g., post-anesthesia care unit (PACU), intensive care unit (ICU)), affording each surgeon the opportunity to promote his/her efficiency by performing surgeries consecutively and by establishing routine office hours that are compatible with the BSS.

A BSS, which is analogous to a master production schedule in a manufacturing environment, has a number of important uses. A

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0377-2217/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ejor.2013.10.040

BSS defines aggregate resource requirements of peri-operative activities and ancillary departments (e.g., PACU, ICU, nursing), not only of ORs and surgeons. Nurse managers must ensure that the set of ORs and PACUs run compatibly each day of the week (Blake & Donald, 2002) so that actual decisions adhere to the BSS as strictly as possible. Like Dexter and Hopwood (1999), Rohleder, Sabapathy, and Shorn (2005), and Samanlioglu et al. (2010), this paper focuses on ORs and does not deal with other departments. An appropriate BSS allows hospital managers to accommodate random events (e.g., a short-term shortage of surgeons or anesthetists), seasonal fluctuations in demand (e.g., summer or Christmas time), or strategic decisions that alter program emphasis (e.g., to respond to an increasing popularity of cosmetic surgery) (Blake & Donald, 2002). In particular, the operational-level uses the BSS to schedule individual patients; if actual demand levels were to deviate significantly from the those upon which BSS was based, a hospital manager should update the BSS to better accommodate them.

This research contributes from several perspectives. It provides a closed form for optimal block durations, which are given by newsvendor solutions, for the case in which surgery durations are independent and normally distributed. Hospital managers can make use of this closed form to balance the risk of a planned duration that is too short, which could force a late start of the next block (i.e., delay), should actual time exceed it; and the risk of a planned duration that is too long, which could result in expediting the next block, should actual time be less. Furthermore, we deal with a new type of newsvendor problem, which is, in fact, a series of time-based newsvendor problems that we call the *sequential newsvendor* (SNV) problem. The classic newsvendor model deals with a single time period with random demand, which is a known distribution. It prescribes the optimal order quantity to minimize the sum of costs related to expected demand over and under the order quantity. Our model prescribes the duration of each surgery time block to minimize the sum of costs related to expected early and late completion (i.e., before and after the end of the time block, respectively). Optimal block durations can be obtained via a newsvendor problem that prescribes the optimal planned ending time. We prove that the smallest-variance-first-rule (SV) optimally sequences blocks if each surgery follows a normal distribution. This research also suggests an approach to find the optimal block duration when subject to no-shows, a new and emerging topic in the healthcare setting. However, because surgery typically deals with serious health issues, no-shows are not likely to occur with the high frequency they do, for example, at primary care clinics. If no-shows occur frequently, the risk of idleness increases and is often hedged by overbooking. This research analyzes the effect of no-shows using both the ratio of earliness cost to lateness cost and the probability that a patient will be a no-show to hedge by managing planned block duration.

The remainder of this paper is organized as follows. Section 2 reviews the intermediate-term surgical scheduling literature. Section 3 presents preliminaries and Section 4 describes our solution approach. Section 5 describes the optimal block duration with no-shows. Section 6 provides insights for hospital management. Finally, Section 7 concludes and offers suggestions for future research.

2. Literature review

Few studies have addressed the tactical level of decision making that prescribes a block surgical schedule for the intermediate term. Complicating matters, there is no commonly accepted definition of intermediate-term surgical scheduling (Testi, Tanfani, & Torre, 2007; van Oostrum et al., 2008). Blake and Donald (2002), Blake and Donald (2002),Fei, Chu, Meskens, and Artiba (2008), and Fei et al. (2008) described the intermediate-term surgical scheduling process in detail, comparing it with master production scheduling in manufacturing. van Oostrum et al. (2008) discussed the pros and cons of intermediate-term surgical schedule, compared centralized and decentralized processes for planning such schedules, addressed various implementation issues and discussed suitability for hospitals with different organizational foci and culture.

Due to the absence of a standard definition, various studies have assigned surgeries to ORs as part of strategic, tactical, or operational decisions. The strategic problem of assigning specialties to ORs essentially assumes that each OR day comprises a single time block and determines the number of OR-days for each specialty. One line of research on intermediate-term decisions has investigated assigning the expected number of surgeries associated with each specialty to a specific OR day. In contrast, we regard this assignment problem as a strategic-level decision and assume that the assignment of specialties to OR days is given. Santibanez, Begen, and Atkins (2007) assigned specialties to time blocks at the intermediate term, assuming that both the total amount of OR time and the number of patients are predetermined for each specialty over the planning horizon. Following Santibanez et al. (2007), our approach invokes the assumption that the number of patients is forecast for each sub-specialty. Guinet and Chaabane (2003) and Jebali, Hajalouane, and Ladet (2006) combined the assignment of specialties to OR days, typically a strategic-level problem, and the sequencing of surgeries in each OR, considered an operational-level issue, in one model.

A number of operations research methodologies have been used to assign surgeries to ORs or blocks. Both deterministic integer programs (Kharraja, Albert, & Chaabane, 2006; Blake & Donald, 2002; Zhang, Dessouky, & Belson, 2009; Fei, Chu, & Meskens, 2009) and stochastic programs (Denton, Miller, Balasubramanian, & Huschka, 2010; Beliën, Demuelemeester, & Cardoen, 2009) have been used to prescribe intermediate-term surgical schedules. Kharraja et al. (2006) modeled the assignment of specialties to days of pre-specified duration as a cutting stock problem with the objective of minimizing penalties for under- and over-use of ORs. Blake and Donald (2002) and Zhang et al. (2009) developed an analytical solution and incorporated it in a simulation model that captures randomness (e.g., random arrivals, no-shows) and non-linearities (e.g., non-proportional allocation of demand). Fei et al. (2008) studied surgery assignment using a set-partitioning formulation and branch-and-price. Denton et al. (2010) and Beliën et al. (2009) used stochastic optimization at the operational level to assign surgeries to ORs on a day.

A number of studies have used newsvendor models to prescribe block duration. Several studies (Strum, May, & Vargas, 2000; Olivares, Terwiesch, & Cassorla, 2008; Wachtel & Dexter, 2010) have employed the newsvendor model to optimize the duration of a single block; they do not deal with sequencing blocks. This approach is more closely related to ours than is the assignment problem used, for example, by Guinet and Chaabane (2003) and Jebali et al. (2006). Guerriero and Guido (2010) and May, Spangler, Strum, and Vargas (2011) employed a newsvendor model at the strategic level to determine OR time for a specialty. Strum et al. (2000) developed a newsvendor model to find the optimal block duration based on historical workloads (e.g., numbers of surgeries performed, numbers of staff hours). Olivares et al. (2008) applied a newsvendor model to determine how much OR time to reserve for a specific cardiac surgery to balance the costs of reserving too much vs too little OR time. Wachtel and Dexter (2010) gave a systematic review of the behavioral and experimental literature associated with newsvendor problems relevant to OR management and commented on the potential significance of these studies.