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A simulation model for perioperative process improvement

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ABSTRACT

Operating rooms (ORs) are a hospital's largest cost center and greatest source of revenue. Surgical delays and cancellations lead to staff dissatisfaction due to long working hours, patient anxiety from long wait time, and extra costs for staff overtime. A discrete event simulation was used to model the perioperative process in the general surgery service at Toronto General Hospital, aiming to reduce the number of surgical cancellations and thereby improve the overall process. This model considers emergency case interruptions with different levels of urgency and takes into account the availability of five types of post-surgical beds. The effects of three scenarios on the number of surgical cancellations were examined: (1) scheduling the surgeons based on their patients usage length of post-surgical beds, (2) sequencing surgical procedures by length and variance, and (3) increasing the number of post-surgical beds. The results indicate that scheduling the surgeons in a weekly schedule based on the patients' average length of stay in the ward, sequencing surgeries in order of increasing length and variance, and adding beds to the surgical ward all reduced the number of surgical cancellations, both individually and collectively. The interactions of all of these scenarios were compared against the current system and against each other to provide a basis for future OR planning and scheduling.

1. Introduction

In Canadian hospitals, which are typically financed by global annual budgets, overuse of operating rooms is a financial risk that is frequently managed by cancelling elective surgical cases. Improving OR efficiency means shorter surgical durations, rational scheduling of various types of surgeries, and minimization of the non-operative time by reorganizing OR activities [1]. Managing ORs is a complex task due to conflicting priorities and preferences of stakeholders [2] and scarcity of costly resources. Healthcare managers must predict the increasing demand for surgical services caused by an aging population and developments in surgical techniques and technology [1,3]. In conjunction with Toronto General Hospital (TGH, Toronto, ON, Canada), we therefore propose a simulation tool to help develop surgical scheduling policies with the goal of reducing cancellations. Although simulation has been previously used to approach surgical scheduling, the novelty of our approach is that we incorporate emergency surgery disruptions and bed and nurse availability.

The poor design of perioperative processes is a common problem associated with OR management [1]. Several works have identified various factors affecting OR efficiency, which Strum et al. [4] define in terms of under-utilized and over-utilized hours of OR time. To achieve higher efficiency in ORs, such resources as staff, beds, equipment, and support services must be carefully synchronized. This synchronization is no small challenge: the shortage of beds in post-surgical units behaves as a bottleneck in the flow of patients; the accurate prediction of surgical case durations, pre-operative and post-operative lengths of stay are necessary to reach an efficient OR schedule; emergency cases are also important considerations that cause surgery delays and cancellations; delays at the start of surgeries may result in running the ORs into overtime, and this causes staff dissatisfaction due to long working hours, patient anxiety from long wait time, and incurs extra costs for staff overtime. Cendan and Good [5] estimate that for every operative month, the equivalent of five working days are wasted through inappropriate patient preparation, insufficient staffing, emergency case arrivals, congestion in the post-anesthesia care unit (PACU), and OR turnover time (the time required to prepare the OR for the next case).

Unpredictability of surgical procedure length is a significant issue in OR planning and scheduling [6,7]. The identity of the surgeon and the type of surgical procedure are the two most important determinants of surgical time [8]. Lebowitz [9] identified that approximately half of the surgical cases after the first of the day do not start on time because the preceding procedures

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Table 1
Services included in the perioperative process at TGH.

Service	Role
Pre-admit clinic	Performs the patients' pre-operative tests approximately two weeks prior to their surgery.
Pre-operative care unit (POCU)	Prepares patients physically and psychologically for the surgical operation according to their needs. The pre-operative period runs from the time the patient is admitted to the hospital to the time that the surgery begins. This area is also called the "holding area".
Post-anesthesia care unit (PACU)	Where surgical patients are transferred for nursing assessment and care while recovering from anesthesia. Vital signs, adequacy of ventilation, level of consciousness, surgical site, and level of pain are carefully monitored as the patient recovers consciousness. This unit is also called the "recovery room".
Medical surgical intensive care unit (MSICU)	Specialized unit containing the equipment, medical and nursing staff, and monitoring devices necessary to provide continuous and intensive care to acutely ill patients.
Step down unit (SDU)	Designated to provide intermediate care for the patients who need less monitoring than those in the intensive care unit, but require more monitoring than those in the hospital ward.
Medical day unit (MDU)	Admits the same-day patients from PACU and prepares them to be discharged. This unit also serves same-day patients.
Ward	A suite of rooms shared by patients who need similar care. Patients are taken to the ward from the PACU, MSICU, or SDU when they require a lesser degree of care and monitoring by medical staff, but are still not well enough to be discharged.
Alternate level of care (ALC) facilities	Provide care for patients who no longer require the intensity of resources or services provided in their current settings.

have run late. Inevitable emergency cases also disrupt the daily OR schedule and cause surgical delays and cancellations. Davenport et al. [10], Herroelen and Leus [11], and Wullink et al. [12] state that a buffer of extra time (slack) and/or resources can be used to deal with the disruptions caused by emergency cases on the daily elective schedule. Lovett and Katchburian [13] stress that assigning dedicated ORs to urgent cases can decrease overtime and the number of urgent surgeries performed after working hours. However, Barlow et al. [14], Brasel et al. [15], and Wullink et al. [16] conclude that setting ORs aside for emergency cases is costly due to low utilization rates of ORs.

OR scheduling is a well-studied problem in the operations research community, as evidenced by recent review papers [17–19]. The majority of recent operations research approaches focuses on sequencing surgeries (that is, ordering surgeries that have already been scheduled) using a variety of approaches: linear, integer, mixed-integer, and stochastic programming; simulation; and statistical analysis. However, most of the approaches exclude emergency surgery disruptions, as such disruptions are not easily incorporated into mathematical models. Additionally, "downstream" resource needs (e.g., intensive care unit beds and nurses, ward beds and nurses) are not considered in most approaches, and no scheduling approaches consider more than one stage after the operating room, even though it is common for patients to travel through three or more stages prior to leaving the hospital (e.g., operating room to intensive care unit to step-down unit to ward), though multi-stage sequencing has been examined (e.g., Bowers [20], Cardoen et al. [21]).

This study focuses on planning and scheduling issues encompassing the perioperative process of the General Surgery Department at TGH. Performed in collaboration with surgeons and nursing staff at TGH, the objective of this study was to observe the effects of applying scheduling rules on the weekly schedule of surgeons, applying sequencing rules on the surgeons' daily cases, and adding beds to post-surgical units on the number of surgical cancellations. Due to the complexity and random nature of the perioperative process, we use a discrete-event simulation (DES) to model the system based on historical data to predict changes in cancellation rates. Unlike previous simulation studies in surgical scheduling [21–26], we model the complete patient pathway from admission to discharge, accounting for downstream bed availability, nurse availability, and emergency surgery disruptions in each stage. A recent cardiothoracic study also incorporated emergency surgeries and downstream bed availability for two possible patient pathways [21]; however, patients' stays in each stage of the hospital were determined probabilistically in that study, while in our study, a patient's entire path is selected from historical records. That is, our simulation model randomly selects actual past patients to flow through the hospital, rather than randomly generating individual patient properties, which as a whole, may not be reflective of the patient population.

In order to facilitate knowledge translation and the implementation of the suggested scheduling and sequencing rules, the rules tested are simple and easily implementable without the need for the hospital to purchase commercial optimization or simulation software after the conclusion of the study. Further, we compare scheduling rule performance to the cancellation reduction of having additional ward beds in order to contextualize the impact of scheduling using a physical capacity change.

2. Material and methods

2.1. Perioperative process

The perioperative period is the time period describing the duration of a patient's surgical procedure. The period begins when the patient is scheduled and admitted to the hospital for the procedure, and ends when the patient is discharged from the hospital or sent to alternative level of care (ALC) facilities. The perioperative process for general surgery patients at TGH includes various services, as summarized in Table 1.

Depending on the type of surgery and the level of care required, patients are taken to a combination of these units. The route taken through the perioperative process depends on the type of patient. At TGH, there are three main types of surgical patients:

1. *Same-day patients:* elective patients who arrive at the hospital on the scheduled date for the surgical procedure. These patients are intended to be admitted and discharged from the hospital on the same day. They usually have short lengths of stay in the PACU, after which they are taken to the MDU to be returned home.
2. *In-patients:* elective patients who are admitted to the hospital on the scheduled date of surgery but meant to be hospitalized for one or more nights, depending on the severity of the case and level of care needed. These patients require longer recoveries under the supervision of medical staff and may stay in a combination of highly monitored and less monitored post-surgical units.