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Dynamic configuration scheduling problem for stochastic medical resources

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ABSTRACT

Scheduling approaches for conventional surgery operating rooms in a hospital treat surgeons as bottleneck resources directly, but do not deal with stochastic medical resources, leading to an uneven human resource distribution in optimizing medical resource scheduling. Thus, this research focuses on the dynamic configuration scheduling problem for stochastic medical resources. In this paper, the surgical operating room is limited, and the arriving calls (i.e., number of patients) are dynamic. When a patient arrives, the nurse anesthetist and anesthesiologist are limited, but the medical service duration per patient is random. We introduce the drum-buffer-rope (DBR) scheduling approach to analyze which types of medical resources become bottleneck resources for optimizing operating room scheduling. After verifying the effectiveness of the DBR method in uncertain situations, the Monte Carlo simulation is demonstrated.

1. Introduction

The conventional approach to surgery operating room scheduling (ORS) in a hospital treats medical resources (i.e., physicians and nurses) as a team working directly and does not identify bottleneck resources, leading to an uneven human resource distribution in physicians' scheduling optimization [1,2]. Before surgical operations are performed, an anesthesiologist must administer anesthetics to patients being prepared for operations in the operating room. The anesthesiologist is responsible for the entire administration process, from anesthesia preparation to surgical anesthesia and recovery. Therefore, if the number of anesthesiologists is insufficient, the patients requiring anesthesia must wait in the operating room, and surgeons and surgical nurses prepared to perform the operations are forced to increase their idle time. Thus, anesthesiologists are essential to successful operations, and adequate ORS facilitates the completion of operations on time. In practice, the ORS of anesthesiologists in most hospitals is formulated manually, without using a scientific basis. For example, a common procedure used in manual scheduling is the charge nurse first generating a blank schedule with dates of required duty shifts. All anesthesiologists are asked to fill in their required dates of duty and expected dates of leave to form the ideal ORS for anesthesiologists. Such manual scheduling methods readily encounter various problems for both hospital management and physician peers. Moreover, if all anesthesiologists' duty shifts cannot be distributed evenly throughout a month, the operating rooms may lack a sufficient number of anesthesiologists, thereby leading to the cancellation of subsequent operations. Inadequate ORS may cause individual anesthesiologists' dissatisfaction or even ineffective anesthesia preparation and surgical anesthesia, directly influencing the quality of surgical operations and indirectly affecting the rights of patients.

ORS has garnered much attention from researchers [3,4]. ORS problems involve the allocations of medical resources (e.g., pre-surgical beds, operating rooms, and post-surgical recovery beds) and medical staff (e.g., nurses, physicians, anesthesiologists, and other professionals). Based on Cardoen et al.'s [3] research, the characteristics of ORS problems can be classified as patient characteristics, performance measures, decision delineation, research methodology, uncertainty, and applicability of the research. ORS problems contain multiple stochastic random variables, such as stochastic service time (e.g., surgery time or recovery time) and stochastic emergency patients' arrival time [5–9]. ORS problems can be formulated as optimization problems, such as mixed integer programming models [1,7,10] and queueing models [11–13], and are usually solved by operational research methods or informatics tools, such as using mathematical programming/mathematical software [10,11,14–16], using meta-heuristics algorithms [13,17–21], and using simulation methods [22,23].

Most researchers consider the amount of the required physical and human resources to perform several sequential operations of a surgery [3,18,24–33], but few researchers have considered the dependence of

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required human resources [34–39]. However, performing surgery does not require all human resources simultaneously, especially in terms of anesthesiologists. In some cases, an anesthesiologist can administer general anesthesia for more than two surgeries during a single scheduled time slot. This is an important relaxed constraint when scheduling surgeries, especially for those hospitals with a limited number of anesthesiologists. As anesthesiologists play an important role in addressing ORS problems, designing a good anesthesiologist schedule can help hospital managers improve the operating rooms' utilization. However, the papers cited thus far did not deal with stochastic medical resources. Thus, the current research focuses on the dynamic configuration scheduling problem for stochastic medical resources. This is the motivation of this research. This study separates the medical resources into four types (i.e., nurse anesthetist, anesthesiologist, surgeon, and surgical nurse); the surgery operating room is limited, and the arriving calls (i.e., number of patients) are dynamic. When a patient arrives, the nurse anesthetist and anesthesiologist are limited, but the medical service duration per patient is random.

The main focus of the study is to solve the dynamic configuration scheduling problem. We introduce the drum-buffer-rope (DBR) scheduling approach to analyze which types of medical resources are bottleneck resources that can maximize the serviced patient's critical medical resources optimized for the ORS. The background information for the DBR scheduling approach is as follows. DBR is a bottleneck-oriented methodology of theory of constraint (TOC) proposed by Goldratt and Cox [40] to identify the bottlenecks of the entire production processes through the analysis of capacity load [41,42]. As the capacity of bottlenecks determines the maximum throughput of the production processes, the control and management of bottlenecks facilitate an increased output (i.e., utilization rate of medical resources) and decreased inventory (i.e., waiting patients) and operation expense (i.e., idle recovery beds). Due to its simplification and ease of implementation in different industries, it is the rationale of DBR we have chosen. We use the DBR to calculate the loads of the surgical process to confirm the bottleneck resources and rationalize the human resource distribution for surgeons and nurses in the surgical process. In addition, a Monte Carlo simulation is conducted to reveal the circumstances of stochastic medical resources in which medical call, service duration, and bottleneck buffer time are uncertainties.

The remainder of this paper is organized as follows. Section 2 provides the DBR approach for analyzing bottleneck resources. In Section 3, we model a conventional ORS problem and provide an example demonstrating the DBR. This paper describes the processes and results of the Monte Carlo simulation in Section 4. Section 5 summarizes the results.

2. Methodology

This section introduces the surgical process for Hospital A, whose goal was to maximize the daily utilization rate of the operating rooms. To this end, the idle time of the operating rooms must be reduced to increase the number of serviced patients. Thus, the applicability of the DBR method to the scheduling model for Hospital A is introduced.

2.1. The surgical process for Hospital A

This study employed Hospital A as an example. Fig. 1 provides a graphical representation of surgical processes for Hospital A. We give a synthetic illustration of the situation. First, a nurse anesthetist prepares the anesthesia and related equipment for the surgical treatment. The patient is then transferred to the operating room to wait for the anesthesia treatment. The anesthesiologist uses a monitoring device to monitor the depth of anesthesia (DOA) and determines the depth required for the specific type of surgical operation. After an adequate DOA level is achieved, the surgeons are called to perform the operation. The nurse anesthetist also monitors the patient's DOA stability. If the DOA is inadequate, the nurse anesthetist reports the abnormal anesthetic status. After the entire surgical operation process is completed, the patient is sent to a recovery room. Common approaches are followed to determine the level of the patient's consciousness (i.e., examining the patient's abilities to swallow and blink and asking the patient questions to judge whether he or she can answer the questions correctly). Finally, the attending physician determines whether the patient requires further observation or can leave the hospital.

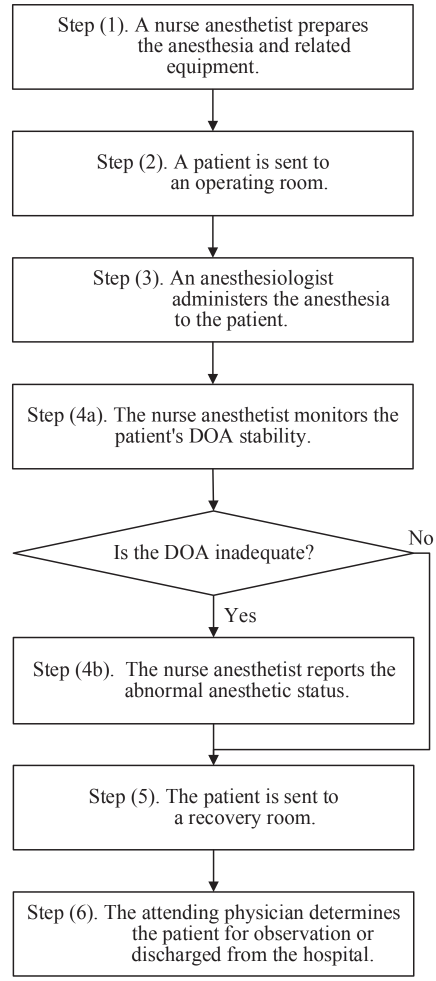

Fig. 1. Flowchart of a surgical process in Hospital A.

2.2. The DBR method to establish a dynamic configuration scheduling

The objective of this paper is to introduce the DBR scheduling approach to analyze which types of medical resources are bottleneck resources that can optimize the ORS. Watson et al. [43] indicated that the drum, or bottleneck resource, determined the pace of operations (referred as a surgical process in this study). The rope referred to a task-releasing mechanism; the pace at which the task was released to the first operation was determined by the drum. The rope acted to keep the minimal and constant patient levels in the operating rooms. The buffers were strategically placed to prevent the bottleneck resources of operating rooms from starvation due to a lack of patients.

Because patients must be anesthetized by anesthesiologists before surgical operations, a sufficient number of surgeons and operating rooms with a shortage of anesthesiologists may require several patients to wait for the anesthesia administration, lead to an increase in the operating room's idle time and a decreased throughput efficiency (reflected by the number of patients who have undergone surgery in each operating room per day). Hospital A's goal was to maximize the daily