Int. J. Production Economics 141 (2013) 646–658

Contents lists available at SciVerse ScienceDirect

Int. J. Production Economics

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

Appointment scheduling of outpatient surgical services in a multistage operating room department

Alireza Saremi [a], Payman Jula [b,*], Tarek ElMekkawy [c], G. Gary Wang [d]

[a] Department of Mechanical and Manufacturing Eng., University of Manitoba, Winnipeg, MB, Canada R3T 2N2
[b] Beedie School of Business, Simon Fraser University, 8888 University drive, Vancouver, BC, Canada V5A1S6
[c] Department of Mechanical and Manufacturing Eng., University of Manitoba, Winnipeg, MB, Canada R3T 2N2
[d] Mechatronic Systems Engineering, Simon Fraser University, Surrey, BC, Canada V3T 0A3

ARTICLE INFO

Article history:
Received 14 August 2011
Accepted 6 October 2012
Available online 13 October 2012

Keywords:
Outpatient surgery scheduling
Simulation-based optimization
Mathematical programming
Tabu search

ABSTRACT

This article addresses the appointment scheduling of outpatient surgeries in a multistage operating room (OR) department with stochastic service times serving multiple patient types. We discuss many challenges, such as the limited availability of multiple resources (e.g., staff, operating rooms, surgeons, and recovery beds), and the compatibility of patient and surgeon types. In addition, availability of surgeons is restricted by time window constraints. Three simulation-based optimization methods have been proposed to minimize the patients' wait time, patients' completion time, and number of surgery cancellations. The first method is simulation-based tabu search (STS). It combines discrete-event simulation and tabu search to schedule surgery cases. The second and third methods are integer programming enhanced tabu search (IPETS) and binary programming enhanced tabu search (BPETS). IPETS and BPETS improve on STS by incorporating integer programming and binary programming models, respectively. This article includes a case study of an OR department in a major Canadian hospital. We further expand the actual data obtained in the case study to cover a wide range of parameters in sets of test problems, and provide analysis on the efficiency and effectiveness of the proposed methods in comparison with several scheduling rules. Finally, comments on the applications of the proposed methods are provided.

1. Introduction

Operating room (OR) departments are in a constant battle to use their limited resources in order to serve a maximum number of patients. Appointment scheduling plays an important role in this context, by providing a smooth flow of patients while minimizing the patient waiting time, completion time, and number of cancellations in OR departments. In this research, appointment scheduling refers to the determination of the time at which each patient should arrive at the OR department, and waiting time is the time that a patient spends in the facility waiting to be served. Completion time refers to the time that the last patient leaves the OR department. Case cancellations, simply called cancellations here, refer to scheduled surgery cases that are cancelled due to the lack of time or resources. Scheduling in this environment is a challenging task due to the stochastic service times and constrained resources. Surgery scheduling is not only restricted by the availability of resources, but also constrained by the compatibility requirements (e.g., only a specific surgeon type can serve a patient type). In this study, we focus on outpatient surgeries, in which patients leave the system on the same day after receiving the service.

This research focuses on minimizing the waiting time of patients, and the completion time of OR department while monitoring the cancellation of scheduled cases. As reported by several studies such as Gül et al. (2011), and Klassen and Yoogalingam (2009), in this environment, improving one measure often leads to the deterioration of other criteria. For example, minimizing waiting time may decrease the utilization, or increase the completion time and number of cancellations in the OR department.

Previous studies have applied optimization or simulation methods to schedule surgery cases. Typically, optimization methods use analytical approaches to achieve optimal (or near optimal) solutions. These approaches have difficulty addressing large-complex systems and, therefore, have often focused on elements of the system, or have overly simplified the system. For instance, many optimization methods consider only single stage systems with Exponential or Erlang distributions for service

* Corresponding author. Tel.: +778 782 3564; fax: +778 782 4920.
E-mail addresses: umsaremi@cc.umanitoba.ca (A. Saremi), pjula@sfu.ca (P. Jula), tmekkawy@cc.umanitoba.ca (T. ElMekkawy), gary_wang@sfu.ca (G.G. Wang).

0925-5273/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijpe.2012.10.004

times. On the other hand, simulation methods are capable of addressing complexities of large systems. Hence, simulation literature has considered detailed multistage systems with constraints on resources, accounting for several environmental factors such as patient priorities, unpunctual patients, and different service time distributions. However, simulation approaches are time-consuming and often do not deliver a competitive optimization strategy. Therefore, a gap exists in the literature questing for efficient and effective methods to address the challenges in outpatient surgery scheduling. The *efficiency* of a method refers to the amount of computation time required by the method to produce meaningful results, while *effectiveness* addresses the quality of solutions generated.

In this study, we integrate the *discrete-event simulation* model, hereafter called simulation model, with metaheuristics, propose three simulation-based optimization methods, and further improve the performance of the proposed methods using mathematical programming (MP). The proposed methods address the problem of appointment scheduling of a predetermined number of patients of different types with stochastic durations in a multistage OR department. We consider the availability of several resources including ORs, recovery beds, and human resources such as surgeons. Furthermore, other constraints are considered in our model, such as the compatibility of resources and the number of available surgeons for each surgeon type. In addition, each surgeon is constrained by a time window, which indicates his/her availability in the scheduling horizon.

The first method, termed simulation-based tabu search (STS), integrates simulation with tabu search. The second method, integer programming enhanced tabu search (IPETS), improves the tabu search by incorporating an integer programming model. The third method, binary programming enhanced tabu search (BPETS) uses a binary programming model along with a heuristic and simulation-based tabu search to solve the problem.

In order to evaluate the performance of our methods, a number of test problems have been developed based on our findings in the OR department under study over an extended range of three major factors, namely, the number of patients, number of ORs, and coefficient of variability (CV) of service time. We then analyze the proposed methods based on their performance in terms of solution quality and the computation time. Furthermore, we examine the application of several scheduling rules (such as shortest/longest processing time, etc.) in comparison with the proposed methods. Based on this study, we provide insight into the applications of the proposed scheduling approaches to assist practitioners. Additionally, we study the application of BPETS in a case study of an OR department in a major Canadian hospital and compare the results with those of the actual schedules used in the OR department for several days.

The remainder of the paper is organized as follows: Section 2 discusses the relevant literature of outpatient surgery scheduling problem. Section 3 states the problem definition. Section 4 depicts the architecture of the proposed methods. Section 5 describes the design of experiments for testing and presents analysis of the test results. Section 6 presents the case study of an OR department. Finally, Section 7 discusses the conclusions and future work.

2. Literature review

In this section, we divide the relevant articles into two categories, optimization and simulation. Few articles combine simulation and optimization for patient appointment scheduling (e.g., Klassen and Yoogalingam, 2009). The existing literature can further be categorized based on their applications in clinics, or OR departments. For a comprehensive review of literature, readers are encouraged to refer to Cayirli and Veral (2003) for appointment scheduling of outpatient clinics, and to Blake and Carter (1997) and Cardoen et al. (2010) for surgery scheduling.

Many works in the optimization category use analytical methods to schedule appointments in healthcare. Although analytical methods can propose optimal schedules, they cannot easily model all the details and constraints in a complex environment. Therefore, they have focused on elements of the system, or have overly simplified the system. For instance, many optimization methods considered only single stage systems with Exponential or Erlang distributions for service times (Cayirli and Veral, 2003). Klassen and Yoogalingam (2009) pointed out that most of the proposed analytical methods are only valid for problems dealing with a small number of patients.

Within the optimization category, queuing theory has been widely used to solve clinic appointment scheduling problems. Most articles in this domain assume steady state behavior for the system, which is hardly achievable in healthcare environments (Cayirli and Veral, 2003).

In addition to the queuing theory, researchers have used mathematical programming (MP) as an analytical method to tackle the appointment scheduling problem. Hsu et al. (2003) developed a deterministic two-stage no-wait flow shop model for appointment scheduling of an ambulatory surgery clinic. Guinet and Chaabane (2003) developed a no-wait flow shop method for scheduling surgery cases. Pham and Klinkert (2008) proposed a deterministic MP model based on a multi-blocking job shop scheduling problem with the goal of minimizing makespan in surgery-case scheduling. Min and Yih (2010) proposed a stochastic programming model for case scheduling. They considered OR and surgical intensive care units that include several specialties. However, the model did not consider the intake procedure and other resources such as nurses, surgeons and equipment. They solved their model using a sample average approximation method.

Lamiri et al. (2009) developed a stochastic programming model for surgery planning to minimize elective patients' assignment costs and expected overtime costs. They considered elective and emergency cases and presented an "almost-exact" Monte Carlo simulation method. They studied the performance of their method in comparison with several heuristic and metaheuristic approaches (such as simulated annealing and tabu search). They reported that although for small to medium size test problems, their method has a better performance than the heuristic and metaheuristics methods, the computation time was significantly higher. For large problems, however, tabu search provided better solutions than those provided by the almost-exact method with a reasonable amount of time.

In brief, although MP has been used in several studies and delivered promising results, most MP methods (except for stochastic programming) do not address the stochastic nature of service times in outpatient clinic scheduling. Although stochastic programming can accommodate stochastic service time, they are usually analytically intractable, and suffer from long computation time. Similar to other analytical methods, MP lacks the capabilities required to capture all the intricacies that arise in complex-large systems.

Simulation is another approach that has been used to study the appointment scheduling problem. In contrast to analytical methods, simulation has the flexibility to model large and complex systems. Dexter et al. (1999) used simulation to address general surgery scheduling. They proposed a method to assign a time block to the surgeons and schedule patients to improve utilization of operating rooms. Marcon and Dexter (2006) used simulation to analyze the impact of different sequencing rules on OR utilization and workload of post anesthesia care units (PACU). Lowery and Davis (1999) used a simulation model to examine the effects of the surgery schedule and variability in surgery durations on the number of required beds. Overall, simulation does