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A stochastic model for operating room planning with elective and emergency demand for surgery

Mehdi Lamiri *, Xiaolan Xie, Alexandre Dolgui, Frédéric Grimaud

Ecole Nationale Supérieure des Mines de Saint Etienne, 158, Cours Fauriel, 42023 Saint Etienne cedex 2, France

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Abstract

This paper describes a stochastic model for Operating Room (OR) planning with two types of demand for surgery: elective surgery and emergency surgery. Elective cases can be planned ahead and have a patient-related cost depending on the surgery date. Emergency cases arrive randomly and have to be performed on the day of arrival. The planning problem consists in assigning elective cases to different periods over a planning horizon in order to minimize the sum of elective patient related costs and overtime costs of operating rooms. A new stochastic mathematical programming model is first proposed. We then propose a Monte Carlo optimization method combining Monte Carlo simulation and Mixed Integer Programming. The solution of this method is proved to converge to a real optimum as the computation budget increases. Numerical results show that important gains can be realized by using a stochastic OR planning model.

Keywords: Stochastic programming; Operating rooms; Surgery planning; Emergency patients; Monte Carlo optimisation

1. Introduction

Facing ever increasing health care demand, limited government support and increasing competition, hospitals are more and more aware of the need to use their resources as efficiently as possible. Operating Rooms (ORs) are among the most critical resources that generate highest costs for a hospital. For these reasons, planning and scheduling OR activities have become major priorities for hospitals.

In this paper, we focus on the planning of elective surgery when the OR capacity is shared between two competing patient classes: emergency patients and elective patients. These two patients groups have different characteristics. Emergency cases arrive randomly and must be served immediately on the same day. Electives cases can be delayed and planned for future dates.

The planning of surgical activities in ORs has been extensively addressed over the past three decades. Magerlein and Martin (1978) presented a review of surgical suite scheduling and discussed procedures for planning patients in advance of their surgical dates and techniques for the assignment of patients to operating rooms at

* Corresponding author. Tel.: +33 (0)4 77 42 66 45; fax: +33 (0)4 77 42 66 66.
E-mail addresses: Lamiri@emse.fr (M. Lamiri), Xie@emse.fr (X. Xie), Dolgui@emse.fr (A. Dolgui), Grimaud@emse.fr (F. Grimaud).

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specific times of day. Dexter et al. (1999a,b) used on-line and off-line bin-packing techniques to plan elective cases and evaluated their performances using simulation. Marcon et al. (2003) presented a tool to assist in the planning negotiation between the different participants in the surgical suite. Linear programming models were proposed for the planning and the scheduling of OR activities (Jebali et al., 2005; Guinet and Chaabane, 2003). A column generation approach was proposed in Fei et al. (2004) to plan elective surgeries in identical ORs. Ozkarahan (2000) proposed a goal-programming model to allocate surgeries to ORs.

Though a substantial body of work on OR planning has appeared in the literature, most of these papers assume that the total OR capacity is devoted to a single patient class. One exception is the work of Gerchak et al. (1996), which addressed the problem of reservation planning for elective patients when the capacity is shared between elective and emergency surgery. The focus of their work is on the characterization of the optimal policy that determines at the start of each day how many additional requests for elective surgery to assign for that day. Though similar to our problem, their model is mono-period and does not specify the intervention date for each elective case.

The goal of this paper is to develop an optimization model and algorithms for elective surgery planning in ORs with uncertain demand for emergency surgery. The problem consists of determining a plan that specifies the set of elective cases that would be performed in each period over a planning horizon (one or two weeks). The surgery plan should minimize costs related to the over-utilization of ORs and costs related to performing elective surgery.

Although numerous studies show the extreme importance of taking into account uncertainties such as emergency demand in OR planning, existing OR planning approaches all use deterministic optimization models and assume that the hospital use dedicated ORs to serve emergency patients, or devotes a fixed portion of OR capacity to perform only the emergency surgeries. The main contributions of this paper include (i) an original stochastic OR planning model that explicitly takes into account both elective and emergency patients, (ii) a Monte Carlo optimization method for effective OR planning with explicit consideration of uncertainties related to emergency demand. Numerical experiments further show importance of explicit modelling of uncertainties. Compared with a deterministic OR planning model that only considers the average emergency demand but neglects its uncertainty, our stochastic OR planning method yields about 4% reduction of overall cost.

The remainder of this paper is organized as follows: Section 2 presents the planning model, proposes a stochastic programming model of the problem and investigates its complexity. Section 3 proposes a Monte Carlo optimization method combining the Monte Carlo simulation and Mixed Integer Programming. Numerical results of the optimization method are presented in Section 4. Section 5 concludes the paper and discusses possible extensions of this work.

2. Problem setting

2.1. A stochastic programming model

This work concerns the planning of elective surgery at a hospital surgical suite over a planning horizon H. The surgical suite capacity is shared among two competing patient classes: elective cases, that are to be planned in advance; and emergency cases, that must be served on the day of arrival.

At the beginning of the horizon, there are N requests for elective surgery. Each elective case i ($i = 1..N$) has the following characteristics:

- p_i, the time needed for performing elective case i , which we call operating time, and includes not only the surgery time but also set-up time, cleaning, etc.;
- B_i, the release period.

Accurate estimates of operating times are necessary to have efficient OR planning. Shukla et al. (1990) recommend using historical information to estimate the operating time of elective cases. Zhou and Dexter (1998) advocate the use of log–normal distributions to approximate surgery durations. Surgeons and OR managers can also provide good estimations of operating times. In this work, we assume that operating times of all elective cases are known and deterministic.

The release date B_i ($i = 1..N$) is the earliest perioid at which elective case i can be performed, it may represent hospitalization date, date of medical test delivery, etc.