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Maximizing the efficiency of use of nurses under uncertain surgery durations: A case study

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ABSTRACT

This paper studies a nurse scheduling problem of assigning a set of nurses to surgeries scheduled on each workday in an operating room (OR) suite. This problem plays a decisive role in utilizing nurses efficiently, which is of paramount importance for OR suites to provide high-quality service at ever reduced cost. Due to significant uncertainty in surgery durations, designing schedules that achieve high nurse efficiency is complicated by the competing objective of ensuring on-time starts of surgeries. For trading off between the two performance criteria, we formulate the problem as a mixed integer programming (MIP) model with explicit probability modeling of uncertainty. We are concerned about improving nurse efficiency in terms of overtime and idle time of nurses while mastering the risk of delay of surgeries. The MIP model is applied in a large size Chinese hospital, and the results are compared with the actual performance of the OR suite. The comparisons reveal that through examining the trade-off between the performance criteria, important nurse efficiency improvements can be achieved with good on-time start performance. Moreover, the applicability of the MIP model in various problem settings is also investigated.

1. Introduction

The operating room scheduling problem has been the focus of increasing attention from operations researchers and management scientists during the last decades (Cardoen, Demeulemeester, & Beliën, 2010; Guerriero & Guido, 2011; May, Spangler, Strum, & Vargas, 2011). However, the growth in this research area is mainly motivated by cost containment with respect to facilities such as operating rooms (ORs) and ward beds, and little effort is made to improve the efficiency and welfare of nursing staff. Nurses are among the most critical human resources in delivering surgical services. Because salaries of nurses account for nearly 37% of OR suite costs (National Health Services Survey in China, 2012), it is important for OR suites to minimize overtime and idle time of nurses. Moreover, scheduling of nurses plays a decisive role in ensuring on-time starts of surgeries, which is strongly related to the service quality perceived by patients as well as medical staff (Denton, Viapiano, & Vogl, 2007).

In this paper, we focus on the nurse scheduling problem of assigning a set of nurses to surgeries scheduled on each workday, functioning in scrub and circulating roles. The nurse scheduling problem can be complicated because of the competing performance measures involved regarding multiple stakeholders (i.e., patients, surgeons, nurses). First, nurses should be used as efficiently as possible. The efficiency of use of nurses is maximized by minimizing both nurse overtime and idle time. Overtime stresses nurses and thus decreases the quality of care, while idleness causes waste (Maenhout & Vanhoucke, 2010; Welton, 2006). Second, due to significant uncertainty in surgery durations, scheduling of nurses highly affects on-time surgery starts. For example, consider a situation when a nurse is assigned to two non-overlapping surgeries in two ORs. If the former surgery finishes later than scheduled, the latter surgery could be delayed only because of the absence of the nurse. On-time surgery starts are important in practice since late starts increase the likelihood of overtime which results in higher direct surgery costs, patient and surgeon fatigue (Denton, Miller, Balasubramanian, & Huschka, 2010; Marcon, Kharraja, & Simonnet, 2003). Given uncertain surgery durations, there is a trade-off between nurse efficiency and on-time surgery start performance: assigning nurses to surgeries in different ORs provides more flexibility for nurse scheduling and thus allows more efficient use of nurses. However, this may result in poor on-time surgery start performance as illustrated by the example above (see Section 2.1 for a graphic illustration of the trade-off).

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To the best of our knowledge, most previous studies on OR scheduling only consider the aggregated capacity of nurses, and neglect the detailed scheduling of nurses for a workday (in which nurses are assigned to surgeries), which is a fundamental element of OR scheduling in practice. Consequently, OR suite performance measures such as nurse efficiency, on-time surgery start performance and especially their inherent trade-off has not been addressed. Sier, Tobin, and McGurk (1997) propose a simulated annealing approach to find feasible OR schedules according to predefined constraints, which consider availability of nurses and surgeons. Guinet and Chaabane (2003) propose an assignment model with nurse capacity constraint for assigning surgeries to ORs over a planning horizon. Jebali, Hadj Alouane, and Ladet (2006) also study the problem of assigning surgeries to ORs with the objective of improving OR utilization. The availabilities of nurses are considered. Pham and Klinkert (2008) treat the OR scheduling problem as a multi-mode job shop problem. A mode is defined as a possible choice of resource set that considers both personnel as well as facilities. Roland, Di Martinelly, Riane, and Pochet (2010) apply the resource constrained project scheduling model to formulate the OR scheduling problem. Several constraints regarding human resources' availabilities and preferences are included in their model. Fei, Meskens, and Chu (2010) formulate the surgery assignment problem as a set partitioning problem, taking into account the maximal working hours of nursing staff. Marques, Captivo, and Vaz Pato (2011) develop an integer linear programming model for scheduling surgeries on a weekly time horizon with the objective of maximizing OR utilization. Nurses' regular working hours are considered in the model.

The extreme importance of optimal use of nurses has been emphasized by several researchers. Beliën and Demeulemeester (2008) formulate the nurse rostering problem using a branch and price approach combined with different surgery workload patterns. He, Dexter, Macario, and Zenios (2012) propose a newsvendor framework to determine the optimal nurse staffing levels for an OR suite with different information sets: no information, information on surgery number, and information on surgery number and type. Altamirano et al. (2012) propose a particle swarm optimization algorithm to determine the shifts assignment of nurses (i.e., Day shift, Emergency day shift, Emergency night shift) at a French public hospital. Unfortunately, these studies fall into the category of tactical nurse rostering problem at medium term (1 or 2 weeks), in which collective agreement requirements such as legal regulations, personnel policies are the major concerns (Cheang, Li, Lim, & Rodrigues, 2003). In contrast, the nurse scheduling problem concerned in this paper lies at an operational level at short term (one workday), whose distinctive feature is the trade-off between nurse efficiency and on-time surgery start performance given uncertain surgery durations.

The goal of this paper is to develop a methodology for nurse scheduling under uncertain surgery durations. The primary contributions of this paper include: (1) a mixed integer programming model that explores the trade-off between the two competing performance criteria (i.e., nurse efficiency, on-time surgery start performance) with respect to nurses, patients and surgeons; (2) an explicit probability modeling of uncertain surgery durations that can be used for mastering on-time surgery start performance. Our work is based on a real world case study of an OR suite that frequently receives complaints about unbalanced nurses' workload and poor on-time surgery start performance. By applying the present MIP model to the OR suite, significantly improved nurse efficiency can be achieved with good on-time surgery start performance. We also investigate the applicability of the MIP model in various problem settings.

The rest of the paper is organized as follows. In Section 2, we first illustrate the trade-off between nurse efficiency and on-time surgery start performance. Then we propose the probability modeling of uncertainty in surgery durations and the MIP formulation of nurse scheduling. Section 3 presents the case study of applying the MIP model to the OR suite of interest. The results of the case study are discussed in Section 4, followed by the conclusion in Section 5.

2. Problem statement and formulation

2.1. Trade-off between performance criteria

Due to significant uncertainty in surgery durations, nurse scheduling in practice is complicated by the trade-off between the performance criteria regarding nurses, patients and surgeons. In this paper, we focus on *nurse efficiency* in terms of overtime and idle time of nurses and *on-time surgery start performance*. The two performance measures are in conflict that can be illustrated by the following example: Consider a simple illustrative surgery schedule, which have 6 surgeries allocated in 2 ORs (Fig. 1).

Given the surgery schedule in Fig. 1, Table 1 presents two possible nurses schedules. It is easy to see that nurse schedule #1 produces less overtime and idle time of nurses, compared with nurse schedule #2. However, this nurse efficiency increase should be carefully weighed against the risk imposed to the on-time start of surgery #6. Observe that nurse #2 is assigned to surgeries #1, #2, and #6 in nurse schedule #1, and this raises the risk that surgery #6 will be delayed as a result of the absence of nurse #2, if

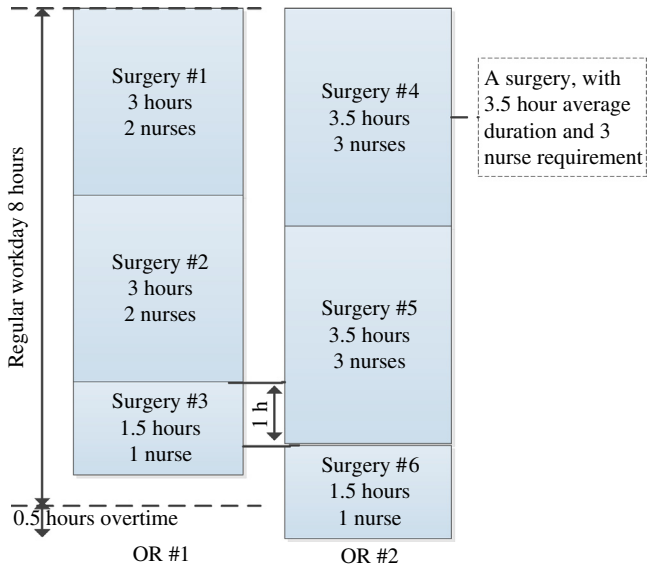

Fig. 1. Example – surgery schedule.

Table 1
Example – nurse schedules.

Nurse No.	Nurse schedule #1		Nurse schedule #2	
	Set of assigned surgeries	Workload (h)	Set of assigned surgeries	Workload (h)
#1	{#1, #2, #3}	7.5	{#1, #2, #3}	7.5
#2	{#1, #2, #6}	7.5	{#1, #2}	6.0
#3	{#4, #5}	7.0	{#4, #5, #6}	8.5
#4	{#4, #5}	7.0	{#4, #5}	7.0
#5	{#4, #5}	7.0	{#4, #5}	7.0
Overtime/idle time		0.0/4.0		0.5/4.5