Computers & Industrial Engineering 90 (2015) 429–443

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

New heuristics for planning operating rooms

Jose M. Molina-Pariente [a,*], Erwin W. Hans [b], Jose M. Framinan [a], Tomas Gomez-Cia [c]

[a] Industrial Management, School of Engineering, University of Seville, Spain
[b] Center for Healthcare Operations Improvement and Research (CHOIR), School of Management and Governance, University of Twente, The Netherlands
[c] Head of Plastic Surgery and Major Burns Specialty, University Hospital Virgen del Rocio, Seville, Spain

A R T I C L E I N F O

Article history:
Received 15 March 2015
Received in revised form 19 August 2015
Accepted 7 October 2015
Available online 27 October 2015

Keywords:
Operations research in health services
Operating room planning
Surgery scheduling
Heuristics
Managerial implications

A B S T R A C T

We tackle the operating room planning problem of the Plastic Surgery and Major Burns Specialty of the University Hospital "Virgen del Rocio" in Seville (Spain). The decision problem is to assign an intervention date and an operating room to a set of surgeries on the waiting list, minimizing access time for patients with diverse clinical priority values. This problem has been previously addressed in the literature considering different objective functions. The clinical priority depends on the surgery priority and the number of days spent on the waiting list. We propose a set of 83 heuristics (81 constructive heuristics, a composite heuristic, and a meta-heuristic) based on a new solution encoding, and we compare these methods against existing heuristics from the literature for solving operating room planning problems. The heuristics are adapted to the problem under consideration (i.e. considering all constraints and the new objective function), being re-implemented using the information provided by the authors. In total, after a calibration procedure, we compare 17 heuristics. The computational experiments show that our proposed meta-heuristic is the best for the problem under consideration. Finally, the proposed heuristics are tested using data from the Plastic Surgery and Major Burns Specialty. The results show significant improvements on several key performance indicators (number of scheduled surgeries, quality of surgical plan, resources utilization, etc.) when comparing with the actual results obtained by the specialty in the current practice. The aforementioned hospital is currently implementing the heuristic methods.

1. Introduction

Nowadays health care organizations experience increasing pressure in order to provide their services at the lowest possible costs (Fei, Meskens, & Chu, 2010) as a response to the combination of restrictive budgets, increasing waiting lists, and the aging of the population (Roland, Di Martinelly, Riane, & Pochet, 2010). In this context, adequate decision-making in health care, particularly in the operating room (OR), which is the most budget-consuming facility (Macario, Vitez, Dunn, & McDonald, 1995), may greatly impact the quality and costs of healthcare provision.

This study was motivated by the analysis of the operational decision level in the Plastic Surgery and Major Burns Specialty of the University Hospital "Virgen del Rocio" in Seville (Spain), in which surgery planning decisions are made without the support of any optimization based decision-support tool. We have observed that the current surgery assignment approach based on the decision maker's experience leads to underperformance in terms of access time for patients, and inefficient OR utilization. The importance of providing the decision maker with decision models and heuristics to evaluate the impact of management strategies on management indicators (number of scheduled surgeries, quality of surgical plan, resources utilization, etc.), to reduce/remove surgery cancelations in different ways (expired or not performed surgical tests, no-shows on the day of the surgery, etc.), and to quickly perform what-if analyses over several possible scenarios is evident.

The operational decision level consists of the off-line and the on-line levels (Hans, van Houdenhoven, & Hulshof, 2012). The off-line operational level is traditionally solved into two steps (Cardoen, Demeulemeester, & Beliën, 2010): the first step (called advance scheduling), involves the determination of the OR and the day in which each surgery will be performed, while in the second step (called allocation scheduling), a sequence of surgeries for each OR within each day in the planning horizon is obtained. The on-line operational level involves control mechanisms that dealing with monitoring the process and reacting to unforeseen or unanticipated events (Hans et al., 2012), such as the large discrepancies between the scheduled duration and the real duration of the surgeries (Min & Yih, 2010), and/or the availability of the resources reserved for uncertain arrivals (see e.g. Lamiri, Grimaud, & Xie, 2009).

* Corresponding author. Tel.: +34 95 4487220; fax: +34 95 4487329.
E-mail address: jmolina1@us.es (J.M. Molina-Pariente).

http://dx.doi.org/10.1016/j.cie.2015.10.002
0360-8352/

The advance OR scheduling of surgeries on the offline operational decision level is a popular topic of research (see the literature reviews by Cardoen et al., 2010; Guerriero & Guido, 2011; May, Spangler, Strum, & Vargas, 2011). In Table 1 we have classified the literature contributions on advance OR scheduling, and have indicated for all these contributions the type of surgical resources are taken into account, the block scheduling strategy, as well as the modeling approach, decision types, objective functions, and solution approach. The aforementioned approaches are not suitable for solving the advance OR scheduling problem in the Plastic Surgery and Major Burns Specialty under consideration, due to the following reasons:

- Most references propose decision models to tackle the problem assuming that surgeons have no limits on the number of ORs where they could be assigned for performing surgeries on a given day. However, a maximum number of ORs is defined to each surgeon in the specialty depending on the surgeon's specialty and the surgeon's workload, trying to reduce the surgeon idle time and to avoid the overlapping of consecutive surgeries performed by the same surgeon.
- Regarding the objective function, the Plastic Surgery and Major Burns Specialty considers an objective derived from the performance indicators employed by the Regional Healthcare System in Andalusia (Spain), and it is related to minimizing patients' access time, prioritizing who have higher clinical priority values. The access time of a patient is defined as the period of time between the surgical procedure is diagnosed (i.e. when the patient is included in the waiting list) and the execution date of the surgery. A clinical priority objective has only been only considered by Ozkarahan (2000) in a goal programming approach. The priority is determined in a straightforward way, being the rank of each surgery the ordinal ranking on the waiting list. In our case, we consider that the clinical priority is defined as a linear combination of the surgery's urgency and the number of days spent on the waiting list at the time of planning, as occurred in practice at the specialty.

This paper contributes twofold to improve quality of care and OR efficiency even further on the target surgical specialty. First, we propose a set of heuristics based on a new encoding scheme for solving real size instances in a reasonable time in order to reduce the negative effects of unforeseen events (rescheduling scheduled surgeries), and to allow the decision maker to quickly perform long-term what-if analyses for determining the best management strategy. We evaluate the performance of the most efficient proposed heuristics and existing heuristics from the literature for solving operating room planning problems, using a test bed we have developed based on the literature. The existing heuristics are adapted for solving the advance OR scheduling problem on the Plastic Surgery and Major Burns Specialty, being re-implemented using the information provided by the authors. In total we have compared 17 efficient methods (i.e. the best parameters of any method have been selected by a calibration procedure). Second, we aim to assess the impact of the best proposed method on the real life case of the Plastic Surgery and Major Burns Specialty. Quantitative results have been obtained comparing the impact on several key performance indicators, several objective functions, several resource management strategies and several planning horizons.

The paper is organized as follows. In Section 2 we formally define the advance OR scheduling problem for the Plastic Surgery and Major Burns Specialty, and present an integer linear programming (ILP) decision model. Section 3 presents the heuristics for solving the problem in an approximate way. The generation of the test bed and the computational results are presented in Sections 4 and 5 respectively. The calibration of the heuristics is presented in Appendix A. Section 6 presents the managerial implications of implementing the proposed heuristics in the Plastic Surgery and Major Burns Specialty of the University Hospital "Virgen del Rocio" in Seville (Spain). Finally, in Section 7, we give our conclusions and outline directions for further work.

2. Problem description

The Plastic Surgery and Major Burns Specialty performs around 3000 surgeries per year, including emergency, deferred urgency, elective and ambulatory surgeries. More specifically, the specialty has 14 surgeons and 4 multifunctional ORs to perform deferred urgency, elective and ambulatory surgeries. Emergency surgeries do not fall within the scope of the paper, since these surgeries are performed using additional resources (called urgent surgical resources). Currently, on each day, 3 ORs are available for performing deferred urgency and elective surgeries from 8.30 a.m. to 3 p.m., and 1 OR is reserved for performing ambulatory surgeries from 3 p.m. to 8 p.m. On each day, each surgeon has a maximum available time for performing surgeries, being either 0 (not available for surgery) or 6.5 h (i.e. they could perform surgeries from 8.30 to 3 p.m.). The number of ORs where a surgeon could be allocated (u_s) is limited in order to reduce surgeon idle time and overlapping of consecutive surgeries by the same surgeon. Finally, the remaining human and instrumental perioperative resources and recovery facilities are assumed to be available whenever needed, not representing bottlenecks for the problem under consideration.

The modified block scheduling strategy is used by the decision maker to manage ORs. Burn surgeries (i.e. deferred urgency surgeries) have two reserved OR-days (i.e. a tuple of an OR and a day) every week because of their unpredictable arrivals and their high priority (they have to be operated as soon as possible), and because they can only be operated by only few surgeons. Most plastic surgeries can be performed in any available OR by any available surgeon, with the exception of microsurgeries which have two reserved OR-days every week because of the complexity, the special surgical equipment required, and the 10-h estimated length of the surgery.

At the consultation stage, each patient on the waiting list is assigned to a surgeon who is the responsible for performing the surgery. This assignment is made by the decision maker based on the surgeon's specialty (i.e. types of surgery which could be performed by the surgeon), his/her skills and workload. The expected surgery duration is forecasted by the decision maker based on the historical data and the patient's characteristics. Each surgery must be scheduled within a time period defined by its release and due dates. The release date defines the earliest date in which the patient could be operated (i.e. once all medical tests are completed). The due date (i.e. the latest date for performing the surgery) depends on the maximum time before treatment (in days) established by the patient's urgency-related group, which are defined by National Healthcare Services based on a set of explicit clinical and social criteria. The maximum times considered in the Specialty are 45, 180 and 365 days.

Finally, the objective function is derived from the performance indicators employed by the Regional Healthcare System in Andalusia (Spain), and it is related to minimizing access time for patients with higher clinical weight values. The clinical weight depends on a linear combination of the priority of the surgery (so a higher urgency of the surgery leads to a greater weight) and the number of days per patient spent on the waiting list at the time (patients with longer stays on the waiting list have higher weights and thus it aims to reduce access time).

Below, we present the ILP model to solve the OR planning problem of the Plastic Surgery and Major Burns Specialty. Table 2 summarizes sets, data, and variables used in the decision model.