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Long term evaluation of operating theater planning policies

A. Agnetis [a], A. Coppi [a,d], M. Corsini [a], G. Dellino [b], C. Meloni [c,*], M. Pranzo [a]

[a] Dipartimento di Ingegneria dell'Informazione, Università di Siena, Italy
[b] Economics and Institutional Change, IMT Institute for Advanced Studies, Lucca, Italy
[c] Dipartimento di Elettrotecnica ed Elettronica, Politecnico di Bari, Italy
[d] Azienda Unità Sanitaria Locale 4 Prato, Italy

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ABSTRACT

This paper addresses Operating Room (OR) planning policies in elective surgery. In particular, we investigate long-term policies for determining the Master Surgical Schedule (MSS) throughout the year, analyzing the tradeoff between organizational simplicity, favored by an MSS that does not change completely every week, and quality of the service offered to the patients, favored by an MSS that dynamically adapts to the current state of waiting lists, the latter objective being related to a lean approach to hospital management. Surgical cases are selected from the waiting lists according to several parameters, including surgery duration, waiting time and priority class of the operations. We apply the proposed models to the operating theater of a public, medium-size hospital in Empoli, Italy, using Integer Linear Programming formulations, and analyze the scalability of the approach on larger hospitals. The simulations point out that introducing a very limited degree of variability in MSS in terms of OR sessions assignment can largely pay off in terms of resource efficiency and due date performance.

1. Introduction

The operating theater (OT) is one of the most critical resources in a hospital because it has a strong impact on the quality of health service and represents one of the main sources of costs (see Sobolev et al. [1], Cerda et al. [2]). The OT is the core resource of the patient's surgical pathway. The way such complex and costly resource is managed affects the quality of the whole process undergone by surgical patients. Several operating rooms (ORs), possibly with different characteristics, are managed in a single OT and may be shared among different surgical disciplines. An OR session is a time interval (e.g. Wednesday from 8 am to 2 pm) devoted to a surgical discipline in an OR. In this study we are concerned with elective surgeries. However, as described later, such allocation can also indirectly take into account possible emergencies.

In a given time period, the OT managers are faced with complex decision problems including:

(i) assigning surgical disciplines to operating room sessions over time,
(ii) assigning elective surgeries to operating room sessions,
(iii) sequencing surgeries within each operating room session.

Problem (i) is a tactical level problem, and it is often referred to as the Master Surgical Schedule Problem (MSSP) [3], its output being the Master Surgical Schedule (MSS). Problems (ii) and (iii) are operational problems. The former determines the Surgical Case Assignment (SCA) [4], and is therefore denoted as Surgical Case Assignment Problem (SCAP). The latter outputs the detailed timetable of elective surgeries for each day. We refer to this problem as Elective Surgery Sequencing Problem (ESSP). Given the patients' waiting lists and various information on OT characteristics and status, these problems aim at optimizing several performance measures including operating room utilization, throughput, surgeons' overtime, lateness etc.

In the last years, operating room planning and scheduling problems have been studied by several researchers, as reviewed in the comprehensive surveys by Cardoen et al. [3], Guerriero and Guido [5], Sier et al. [6]. Several papers address the above problems separately (e.g. Testi et al. [7], that use a sequential three-phase approach to determine the MSS, the SCA and the detailed surgery sequencing), or focus on a single problem (e.g. Blake et al. [8], Van Houdenhoven et al. [9], Sier et al. [6]).

In other studies, the problems are concurrently addressed, e.g. Testi and Tanfani [10] propose an Integer Linear Programming (ILP) model for concurrently solving MSSP and SCAP, and in a follow-up paper [4] they introduce a pre-assignment heuristic to reduce problem size. Dexter and Traub [11] address SCAP and ESSP on a number of pre-selected surgical cases, while Marques et al. [12] and Molina and Framinan [13] apply a similar approach

* Corresponding author.
E-mail addresses: agnetis@dii.unisi.it (A. Agnetis), coppi@dii.unisi.it (A. Coppi), matteo.corsini@unisi.it (M. Corsini), gabriella.dellino@imtlucca.it (G. Dellino), mail@carlomeloni.com, meloni@deemail.poliba.it (C. Meloni), pranzo@dii.unisi.it (M. Pranzo).

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to real cases. Herring and Herrmann [14] propose a surgery scheduling approach which re-assigns unused operating room time to account for new high priority cases and make more equitable waiting list decisions. Recently, a growing number of models relate surgical planning decisions to the broader patient pathway, including e.g. bed occupancy considerations in the wards (Vanberkel et al. [15,16], Evers et al. [17], Van Oostrum et al. [18]), or other issues such as surgeons and assistants training plans (Ghazalbash et al. [19]).

In this paper we investigate the effect of various MSS policies on the quality of the surgical plans that can be attained. We do this by simulating the system's behavior throughout one year, i.e., solving every week MSSP and SCAP, by means of a suitable model that reflects the MSS management strategy. In many hospitals, the same MSS is employed throughout several months, or a whole year. With a constant MSS, bed occupancy is more predictable and physicians' schedule is repetitive, which simplifies the overall organization. On the other hand, leaving more flexibility in defining the MSS expectedly results in more efficient resource utilization and allows to better follow the dynamics of the waiting lists. In recent years, as a growing number of hospitals re-engineer their processes according to the *lean* concept (see e.g. Graban [20]), much more attention has been paid to the fact that the patient flow should pull the delivery of services—surgical operations in this case. Ideally, therefore, all obstacles (such as getting stuck to a predetermined MSS) to a direct link between demand and service delivery should be removed. In our study we propose modeling and algorithmic tools for evaluating the benefits stemming from a dynamic MSS. We validate the model on data concerning San Giuseppe hospital, a medium-size Italian hospital, located in Empoli (Tuscany).

The paper is organized as follows. In Section 2 the problem is described in detail. In Section 3 the mathematical formulations are introduced. Computational experiments concerning the case study are illustrated and discussed in Section 4. Finally, in Section 5 some conclusions are drawn.

2. Problem description

This study focuses on the evaluation of various approaches to defining the MSS over time. OT managers are typically interested in long-term planning *stability* and *flexibility*. Stability refers to personnel having a repetitive, predictable schedule, which is typically preferred since it allows a simpler scheduling of personal engagements. Also, a stable schedule allows a more predictable pattern of bed occupancy in the pre- and post-operative rooms as well as in the wards. Flexibility concerns the ability to dynamically adapt the weekly plan to the evolution of the waiting lists, which may avoid imbalances among the quality of service perceived by the patients of various disciplines, and may also allow for a more efficient utilization of the operating rooms. Stability and flexibility are potentially conflicting, since the former pushes towards having a constant MSS, while the latter might benefit from changing the MSS over time. Different organizations may have different capabilities of adjustment to a changing MSS, therefore the right *tradeoff* between flexibility and stability has to be found.

From the viewpoint of this tradeoff, the two extreme policies consist of keeping the MSS fixed throughout the year or, respectively, recomputing it every week from scratch. In between these two policies, one may allow periodic but limited changes in the structure of the MSS. Let the *distance* between two given MSSs be the number of operating rooms, for each OR session, which are assigned to different surgical disciplines across the two MSSs. For instance, let us assume that, for a given MSS, surgical discipline s_1 will be performed in operating room j on Wednesday morning (i.e., 8 am–2 pm); then, a new MSS having distance 1 from the original MSS can be obtained by assigning a different surgical discipline s_2 to the same operating room j on Wednesday morning, and leaving the rest of the MSS unchanged.

Hence, we can define an *MSS change policy* as the policy of keeping the same MSS for blocks of b weeks, and allowing changes only with respect to a *reference MSS*. When the MSS changes, we require that the distance between the new MSS and the reference MSS does not exceed a value Δ, providing a trade-off between stability and flexibility. OT managers will identify a suitable value for the maximum distance Δ, based on their attitude towards either higher stability (corresponding to smaller Δ-values) or higher flexibility (supported by higher Δ-values). Actually, we consider two possibilities for the reference MSS. It can be either the MSS of the previous block (*dynamic change policy*) or a given MSS which does not change over time (*static change policy*). We refer to a dynamic (static) change policy as $D(b, \Delta)(S(b, \Delta))$.

We next describe the distinctive features of the problems we deal with.

All elective surgeries are grouped into *surgical disciplines*. The main input to the overall problem is the *waiting list* of each discipline, containing all the case surgeries that currently need to be performed. Besides the patient personal record, for each case surgery, the following information is specified in the waiting list:

- Surgery code—identifies the specific type of surgery.
- Processing time—expected duration of the surgery (including setup times due to cleaning and OR preparation for the next surgery). We assume all these times to be deterministic.
- Decision date—date when the surgery enters the waiting list, based on physician's prescription.
- Waiting time—days currently elapsed since the decision date.
- Priority class—surgeries are classified in three priority classes A, B or C (A having the highest priority), according to the regulatory essential assistance levels. As dictated by regional policies for waiting list management, this is a static classification which only depends on surgery type, not on the current waiting time.
- Due date—date within which the surgery should be performed. It is obtained by adding a quantity W to the decision date. W represents a maximum waiting time, and it only depends on the priority class.

Elective surgeries are not performed on Saturday and Sunday, therefore weekly schedules span five days. OR sessions are of three types, lasting either half a day (*morning* and *afternoon* sessions) or the whole day (*full-day* session). During one day, an OR can be either assigned one morning session and one afternoon session, or a single full-day session. All sessions of the same type have the same duration, which must not be exceeded by the total processing time of the surgeries allocated to that session.

In general, a MSS may be subject to various types of restrictions:

- *Discipline-to-OR restrictions*. Certain disciplines can only be performed in a restricted set of ORs, due to size and/or equipment constraints.
- *Limits on discipline parallelism*. Typically, no more than k OR sessions of a certain discipline can take place at the same time, e.g. because only k surgical teams for that discipline are available.
- *OR sessions-per-discipline restrictions*. Lower and upper limits on the number of OR sessions assigned to each discipline throughout one week can be specified. These restrictions may arise from workload balancing goals as well as from considerations on the number of available beds in the various wards.
- *OR reservation*. The hospital management may decide that there must be one or more OR sessions reserved for certain disciplines every day. (Note that this can also be used to reserve OR sessions to non-elective surgeries.)

The main management objectives are:

- Maximize the utilization of ORs, without resorting to overtime;
- As far as possible, perform each case surgery within the respective due date.