Surgery Allocation and Scheduling

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1 Introduction

Operation rooms are significant cost drivers in hospitals. This is because of the expensive resources that are directly involved in surgery, and the indirect impact that operating room activities have on related activities and resources throughout the hospital. Surgery planning on different levels and time scales are thus central planning problems with strong interactions with other planning processes. An effective resolution of these problems is crucial to an efficient utilisation of hospital resources. As an example, consider the tactical planning problem of assigning blocks of operating time in operating rooms to groups of surgeons (See e.g. [1,11,4]). The result is a "Master Surgery Schedule", which will typically influence, or be influenced by, other resource planning processes that happen on a similar time scale. For example, this master schedule influences the variation of demand for surgeons and nurses (see e.g. [5] about physician scheduling and [2] about nurse rostering). In turn, at an operational level, the personnel rosters that are based on this demand will constrain the detailed surgery scheduling. This exemplifies the close connections between activity and resource planning processes at different time scales in a hospital.

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2 Problem description

At the operational level, we find the Surgery Scheduling Problem, which can be loosely defined as aiming to find the optimal allocation of surgeries to operating rooms and days, and their optimal sequence for each day. Objectives are typically tardiness costs (over time), hospitalisation costs, intervention costs, operating room utilisation, patient's waiting time, patient or personnel preferences, etc. This problem is solved on different time scales, ranging from month-scale admission planning to daily detailed surgery scheduling, using different objectives and constraints.

Formally, the basic surgery scheduling problem can be modelled as follows. Let N be the number of interventions to be planned, D be the number of days in the planning period, S the number of surgeon groups, and R the number of operating rooms that are considered. We use a discrete time model, where P is the number of time periods in which an intervention may be performed during a day.

The basic problem is then to:

$$Minimize \;\; O = \sum_{i=1}^{N} \left(\sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{r=1}^{R} x_{ipdr} C_{ipdr} + \left(1 - \sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{r=1}^{R} x_{ipdr} \right) \Psi_i \right) \quad (1)$$

subject to the following

$$\sum_{p=1}^{P} \sum_{d=1}^{D} \sum_{r=1}^{R} x_{ipdr} \leq 1, \forall i \in [1, N] \quad (2)$$

$$\sum_{i=1}^{N} y_{ipdr} \leq 1, \forall p \in [1, P], d \in [1, D], r \in [1, R] \quad (3)$$

$$\sum_{p=1}^{P} y_{ipdr} = \Delta_i \sum_{p=1}^{P} x_{ipdr}, \forall i \in [1, N], r \in [1, R], s \in [1, S], d \in [1, D] \quad (4)$$

$$\sum_{i=1}^{N} \sum_{r=1}^{R} y_{ipdr} \; z_{is} \leq |SG_s| \,, \forall s \in [1, S], p \in [1, P], d \in [1, D] \quad (5)$$

where

$$x_{ipdr} = \begin{cases} 1, \; \textit{if intervention i starts in period p on day d in room r} \\ 0, \; \textit{otherwise} \end{cases} \quad (6)$$

$$y_{ipdr} = \sum_{p'=\max(p-\Delta_i+1,1)}^{p} x_{ip'dr} \quad (7)$$

$$z_{is} = \begin{cases} 1, \; \textit{if intervention i is allocated to surgeon group s} \\ 0, \; \textit{otherwise} \end{cases} \quad (8)$$

Now, (1) defines the objective. C_{ipdr} is the total cost of performing intervention i in operating room r, on day d, starting in period p. Ψ_i represents a penalty of not performing intervention i. The relation in (2) says that each intervention happens at most once, and it happens in exactly one operating room. In (3), we state that at most one intervention can happen simultaneously in any operating room. Here, we have introduced a temporary variable y_{ipdr}, which, as can be seen from (7), is 1 if intervention i occupies period p in room r on day d. Δ_i is the duration of intervention i, given in a number of time periods. The duration is (in this basic formulation) considered to be deterministic. In (4) we say that no surgery can start too late to be completed within the operation room opening hours. The relation in (5) states that the number of simultaneous interventions performed by surgeons from surgeon group s, SG_s, cannot exceed the number of surgeons in that group ($|SG_s| \geq 1$).

In some hospitals, surgery scheduling is done under constraints given by a master surgery schedule (block scheduling). In our simple model above, this corresponds to replacing (4) with the following:

$$\sum_{p=1}^{P} y_{ipdr}\ M_{rpds} = \Delta_i\ z_{is}\ \sum_{p=1}^{P} x_{ipdr}, \forall i \in [1, N], r \in [1, R], s \in [1, S], d \in [1, D] \tag{9}$$

where

$$M_{rpds} = \begin{cases} 1, \textit{ if the master surgery schedule allocates} \\ \quad \textit{operating room } r \textit{ to SG } s \textit{ on day } d \textit{ and period } p \\ 0, \textit{ otherwise} \end{cases} \tag{10}$$

Various other extensions and specialisations of this basic surgery scheduling problem are treated in the literature, including the use of post-operative resources (see e.g. [8] or [6]), use of stationary or mobile equipment [8], employee preferences and work regulations, operating room cleaning time, equipment sterilisation time, stochastic surgery and recovery durations [10,8,3,7], and stochastic demand (e.g. because of emergency care). Actually, it is difficult to find two papers that address the exact same version of this problem. The surgery scheduling problem is typically multi-objective, as one often finds criteria that are not directly comparable with each other. E.g. quality of treatment is not easily measurable along the same dimension as, say, costs. It would therefore be useful to aggregate only criteria that are comparable, and then treat these aggregates as separate objectives during optimization. This would provide the user with information about the range of available compromises. Even so, we have yet to see any literature that addresses this issue other than through aggregation or hierarchical evaluation of all criteria, which only gives one solution.

3 Algorithmic approach

The current literature on optimisation in surgery scheduling includes the use of integer programming, column generation techniques, meta-heuristic optimisation methods and simple assignment heuristics. Our problem definition above is similar to the one-step job shop scheduling problem with multiple identical machines, which for general objective functions is NP-hard. Due to this computational complexity, which is found for many variations of the surgery scheduling problem, most authors decompose the problem into an allocation step (assigning surgeries to operating rooms and days), and a scheduling step (scheduling surgeries within each operating room and day). Here, we present a meta-heuristic local-search based algorithm for solving a typical version of the complete problem. The algorithm uses simple relocate and swap neighbourhoods, governed by an iterated local search meta heuristic [9]. The choice of method is motivated by the complexity of the real world problem instances that we would like to solve, and the need for easy adaptation to future problem modifications and extensions. We present an analysis of the search space associated with our neighbourhood operators, and show how an adaptive filtering of neighbourhoods based on solution features may increase efficiency. The algorithm is tested on synthetic data, and on real data from selected Norwegian hospitals. Benchmark problems will be made available to other researchers. We present and discuss preliminary results.

4 Conclusions and future work

We show to what degree the proposed algorithm is suitable for solving realistic instances of the surgery scheduling problem. We also show how an adaptive neighbourhood filtering based on solution features may be applied to reduce unwanted neighbourhood exploration. Our main focus has so far been on long term admission planning. For future work, we will address more detailed short term surgery scheduling, with the addition of all relevant real world constraints and preferences. We also wish to optimise explicitly for independent objectives, which we believe will facilitate better decision support for surgery planners.

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[1] See www.sintef.no/hospital

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