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Waiting list management through master surgical schedules: A case study

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ABSTRACT

In this paper we address the problem of generating master surgical schedules (**MSS**s) that adhere to staff and equipment restrictions whilst ensuring patients are treated in a timely manner. We simultaneously address the master surgical scheduling problem (**MSSP**) and the surgical case assignment problem (**SCAP**). Stochastic surgical durations are considered in order to produce more robust schedules and reduce unexpected overtime. Also incorporated into the model are several constraints regarding patient wait targets that are set by the Australian government. The problem is formulated using a mixed integer nonlinear programming (**MINLP**) approach and solved using a variety of hybrid metaheuristics. The metaheuristics implemented are inspired by simulated annealing (**SA**) and reduced variable neighbourhood search (**RVNS**). In particular, we present an adaptive SA and hybridise SA and RVNS to greatly improve solution quality. The solution neighbourhoods used by the metaheuristics are based on the hierarchical structure present in the combined MSSP SCAP. We consider a case study of an Australian public hospital with a large surgical department and compare the performance of our model to historical data.

1. Introduction

The surgical department is often one of the largest sources of hospital costs and patient flow. Inefficient use of the operating theatres (**OT**s) and related resources can result in increased costs and a decrease in patient and staff welfare. The schedule used by hospital administrators can have a massive impact on patient outcomes. Although the scheduling of surgical procedures is a complex process, many surgical departments still rely on simple heuristics and general intuition to produce weekly or fortnightly OT schedules and some daily updates. Such simple techniques can result in overtime, bed shortages, unused resources or large waiting lists due to unnecessary improper utilisation of operating rooms (**OR**s).

The administrative practices of surgical departments can have a large impact on hospital costs, patient outcomes and the overall efficiency of a hospital. As such, a large number of papers exist which investigate and analyse some of the most significant issues in OT planning. For a thorough review of the existing literature see [1–3].

Van Riet and Demeulemeester [1] review efforts to plan ORs in the case of both elective and emergency surgeries with an emphasis on the trade-offs encountered between costs and waiting times. Ferrand et al. [2] also consider both elective and emergency cases in their survey of methodologies used to ensure ORs are both responsive and efficient. In their literature survey, Guerriero and Guido [3] discuss both optimisation and simulation models used for OT planning and scheduling problems. OT planning problems can exist at the strategic, tactical or operational levels.

Decisions at the strategic level include determining how much time to allocate to each surgical specialty in order to optimise the mix of patients processed [4]. Tactical problems include the development of a MSS [5], or determining which time blocks to allocate to a particular surgeon [6] or surgical specialty [7]. Problems at the operational level are advanced and allocation scheduling of elective patients. Advanced scheduling is the assignment of a patient to a time block on a particular day. This is also known as the SCAP. Allocation scheduling is the scheduling of patients within those time blocks, also known as the surgical case sequencing problem (**SCSP**).

There are three main policies used in OT scheduling at the tactical level. These are open scheduling, block scheduling and modified block scheduling [6]. An open scheduling policy allows surgeons to assign a surgical case to any day in the planning horizon. Block scheduling allocates time blocks to surgeons or

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surgical specialties. These time blocks may only be used by the surgeon or surgical specialty that they are assigned to. In a modified block scheduling policy, time blocks may be left open for use or unused time can be reallocated to a different surgeon or specialty.

A MSS is often used under a block scheduling strategy in order to assign time blocks to surgical specialties. There are many benefits that arise from the implementation of a MSS [8]. The cyclic nature of the schedule allows the coordination of staff and resources and can improve patient flow and throughput. The predictability of a repeated MSS can be incredibly useful when planning admissions and can help stabilise bed occupancy. It is possible to generate an optimal or near optimal MSS for a hospital, based on their particular requirements and goals, using a variety of different operations research techniques.

Many hospitals repeat the same MSS over a period of several months. Agnetis et al. [9] analyse the trade-off between the organisational benefits of repeating a single weekly MSS against a schedule updated weekly to adapt to the current state of the surgical waiting lists. The authors consider three policies for the development of MSSs, each permitting different levels of variability from an original schedule. The authors found that allowing even a small number of deviations from a reference schedule greatly improves the performance of the MSS in terms of lateness and waiting time.

Throughout the literature, it is common to incorporate constraints on the suitability of the ORs for each specialty, the availability of surgical teams, and post-surgical capacity (e.g. [7]). Other authors include constraints on the patient mix to match hospital requirements. Most of the models used to solve the MSSP have a single objective which is usually related to maximising throughput or utilisation. Some models throughout the literature have multiple objectives, commonly incorporated in a single weighted objective function.

Whilst a large number of mathematical formulations and solution techniques exist to produce optimal OT schedules with respect to a variety of objectives, it is necessary to make these solutions applicable and accessible to hospital administration staff. In order to allow surgical staff and scheduling nurses to utilise schedules generated using operations research techniques, a number of decision support systems are presented in the literature (e.g. [10]).

The advanced scheduling problem (the OT planning problem or SCAP) is the problem of assigning patients to time blocks over a one to two week time period. This can be done using an open scheduling, block scheduling, or modified block scheduling policy [11]. Advanced scheduling is frequently addressed in the literature and solved using a variety of both exact and heuristic approaches.

Whilst some authors rely on exact approaches to solve small test instances, as the problem is NP-hard [12] it is necessary to use heuristics, meta-heuristics and hybrid heuristics to provide good feasible solutions in reasonable amounts of computational time. Column-generation based heuristics are often used to solve OT scheduling problems at the operational level (cf. Wang et al. [13] and Fei et al. [14]) Fei et al. [15] apply a branch-and-price approach to solve the SCAP. Many authors rely on simulation based models to investigate OT planning problems (e.g. [16,17]).

The constraints and objective functions used to define OT practice can differ significantly between models. Many models present in the literature minimise expenses related to OT use. Other models prioritise patient welfare over expenses. Roland et al. [18] places particular significance on human resource constraints.

The tactical and operational levels of OT planning and scheduling are often treated separately. A more effective procedure involves scheduling the tactical and operational levels simultaneously. Agnetis et al. [19] integrate the two levels of planning and compare an integrated approach to the use of a decomposition approach. Whilst the decomposition approach allowed the authors to produce comparable solutions in far less time, the model had several simplifying assumptions that make this method unsuitable here. The authors did not consider specific surgeon availability or suitability, and incorporated uncertainty in surgical durations using added slack time in conjunction with expected durations. These assumptions make this approach unsuitable for implementation on the case study considered in Section 2.

Aringhieri et al. [20] solve a binary integer programming (**BIP**) formulation of the MSSP and the advanced scheduling problem (SCAP) simultaneously by making use of the hierarchical structure present in OT schedules in a metaheuristic. We also consider the hierarchical structure when solving the MINLP formulation presented in Section 3. The model presented by Aringhieri et al. [20] considers deterministic surgical durations, whereas we consider stochastic durations. Aringhieri et al. [20] assume that the strategic decisions can be used as an input to the problem, particularly the number of time blocks assigned to each surgical specialty. We implicitly consider the surgical case mix planning problem when solving the combined MSSP SCAP to allow for variations in the MSS based on the current state of waiting lists.

One of the major concerns currently facing Australian hospitals is the length of elective surgery waiting lists. The longer a patient waits for surgery, the more their quality of life is reduced. Long surgery waits can also worsen patient outcomes. Occasionally, patients are not seen on time as they are not fit for surgery at that stage, however most overdue patients are late for surgery due to insufficient resources or poor planning. A limited number of operations research techniques have been used to manage waiting lists and improve patient outcomes whilst adhering to resource availability constraints.

Everett [21] provides a decision support tool based on a simulation model of elective surgery waiting lists for Australian public hospitals. The model developed by the author can be used in order to monitor the system, assist in strategic decisions or even surgical scheduling at the tactical and operational levels. The simulation model is quite simplistic to allow for the results to be interpreted by hospital staff with ease and does not include as much detail as we incorporate into the model presented in Section 3.

Patient priority is considered by Min and Yih [22] whilst assigning elective patients to available surgical capacity. In their model, the authors assign appropriate patients in order of urgency. A common issue identified in waiting list management is the discrepancy in waiting times between urgency categories which often leads to excessive waiting for non-urgent elective patients. Min and Yih [23] use a patient priority which is a combination of urgency category and waiting time by formulating the problem as an infinite horizon Markov decision process.

Marques et al. [24] address the SCAP for a small Portuguese public hospital under an open scheduling strategy. The authors aim to maximise surgical suite utilisation and the number of surgeries scheduled. The authors ensure that all deferred urgent and high priority surgeries are scheduled within the planning horizon and use the remainder of the time to schedule priority and normal surgeries according to a weighted objective function.

In this paper we provide a MINLP formulation of the combined MSSP SCAP that maximises the number of surgeries scheduled. Whilst the above waiting list management policies are worth considering, in this paper we consider the policies imposed by the Australian government to ensure the model presented is applicable to Australian public hospitals. We ensure that certain government dictated patient-wait targets are satisfied on the final day of the planning horizon and adhere to resource availability and suitability