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Innovative Applications of O.R.

Coordinated lab-clinics: A tactical assignment problem in healthcare

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ABSTRACT

In some medical outpatient settings, it is desirable to perform patient diagnostic testing just before the appointment with the physician, effectively linking the testing to the clinic appointment. If testing resources are shared by several physicians, it becomes difficult to assure that testing is completed in time (with some probability) due to the variation in testing requirements across patients and types of clinics held concurrently. To address this tactical-level doctor–clinic assignment problem, we develop a mixed-integer programming (MIP)-based approach for assigning time slots to the physician clinics. The approach maximizes the minimum service level across blocks of time to reduce the likelihood of a patient not completing testing in time for their clinic appointment. A branch-and-price heuristic procedure is proposed to solve practical problem instances, and numerical examples are presented to show the efficiency of this model. Two mini-cases based on clinics' actual operations are provided. The results of the mini-cases suggest that the proposed scheduling method will bring important improvements to these systems.

1. Introduction

In some medical outpatient settings, it is desirable to perform diagnostic tests on a patient just before the patient's appointment with a physician, effectively linking the testing to the appointment. For example, a patient who has an appointment with a respirologist will undergo pulmonary function testing by a respiratory therapist in a pulmonary function laboratory. Ideally, the testing is performed only just prior to the patient's appointment with the respirologist, as the physician needs to have current test results in hand when seeing a patient, but patients should not have to arrive a long time before their appointment in order to have testing done.

Achieving this tight coordination of a patient's testing and his or her subsequent doctor's appointment may be difficult in a facility where many physicians share the same testing resources. During a week in such a facility, each physician holds one or more clinics, which are scheduled blocks of time during which a physician sees patients by appointment. The physical space available to see patients limits the number of clinics that can run at the same time at the facility, but since the weekly clinic schedule is based to some degree on physician preferences, there may be more clinics held on some half-days than on others. Some physicians may hold general clinics where they see any type of patient within their specialty, while other physicians hold clinics for patients with a particular condition that is in their subspecialty area of expertise. Physicians also vary on the number of new and follow-up patients they want to see during a clinic. Different physicians thus see different numbers and types of patients in a given half-day clinic. However, the variety in patient types can mean that each patient requires a different type of pre-appointment testing that takes a different amount of time to complete. The amount of, and variation in, the testing requirements generated by patient appointments across concurrently scheduled clinics may not be considered when the week's schedule of clinics is set up. A poor clinic schedule can yield an uneven workload on the testing facility, making it more difficult to complete testing in time for the patient's appointment. This can lead to lower quality of care as well as result in friction between physicians and testing staff. An approach to clinic scheduling that takes into account the varying testing requirements generated by concurrently scheduled clinics, as well as the limited availability of the resources required to complete that testing, is therefore needed.

This paper is motivated by the example of outpatient respirology facilities in hospitals that are part of Alberta Health Services in Alberta, Canada. Currently, administrators divide a period (usually a week) into blocks of time of a few hours each day (half-days) and within each block schedule clinics of particular types to be run by assigned physicians. For the sake of stability, these periods

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have similar assignments for each block for a relatively long time. Hence, decisions are made with a long horizon in mind. Although at the operational level there are adjustments with respect to the order in which physicians see patients and the type of patient (new or returning) a physician sees, administrators would like to have schedules set up in such way that there would be a high probability that the resulting mix of patients that have appointments in each block of time would be able to finish the required lab tests before their appointment. This is the problem we address.

It is important to stress that the problem under consideration is that of assigning doctors to clinics and clinics to blocks of time in a period (usually a week). The assignments are repeated period after period until there is a major reason for reviewing the assignments (possibly a new hire or the introduction of a new clinic). This is a tactical level problem and should not be confounded with the operational level problem of scheduling patients in a given block (ordering the patients to be treated).

More specifically, our research problem is the following: given the available testing time in each block of the period, what is the assignment of physicians' clinics to each block that will maximize the minimum service level over all blocks in a period while satisfying physicians' preferences for types and blocks for their clinics? Although there are different perceptions of service level, which will be reviewed in the next section, we define the service level for a block as the probability that the sum of all patients' testing times assigned to a block is less than or equal to the available testing time. This performance metric assures that the probability of not completing any given patient's testing prior to their appointment will be as similar, and as small, as possible.

Although this study is motivated by the problems that we have observed at respirology lab-clinics, and for ease of exposition and consistency we will continue with that example throughout, more generally our paper provides an approach for assigning servers in any type of demand centers that share a predetermined amount of a service resource that provides a time-sensitive activity to those demanders, who send independent requests for varying amounts of service. Outside the healthcare setting there are several variations of the problem, for example, cold temperatures and deicing problems can cause delays in airports. A limited amount of deicing equipment is available for airfield pavement and aircraft anti-icing operations. To avoid or reduce delays due to the need for anti-icing, it would be valuable to assign flights to runways, taxiways, and time slots such that all planes can be anti-iced prior to their scheduled departure time. The human resources (HR) department of a particular business school assigns blocks for dealing with specific tasks (e.g., safety and ergonomic related concerns are only dealt with from Tuesday to Thursday during morning times, while paycheck related issues are dealt with every afternoon) and the HR department wants to choose what specific tasks should be assigned to each block in order to minimize the chance that requests are not met within the block allotted time – the backroom of the HR department is analogous to a testing-lab in the respirology clinic case. In some tax revenue agencies in France, different types of "tax-payer requests" are assigned to different blocks where the tax-payer deals first with a general administrative worker who proceeds with assessment, organization of documents, checking basic validity of claims, etc., and then, when the general pre-work is done, sends the client to talk to the particular field expert related to the request. Back to the healthcare setting, for small surgical interventions and some MRI exams where recovery is relatively fast compared to the length of a block, the problem of assigning doctors-clinics to particular blocks of time will create needs for recovery rooms.

In this paper, we address a tactical-level problem for assigning time slots to the physician clinics. First, we propose a MILP with the objective of maximizing the minimum service level across blocks of time. As a second step, a branch-and-price heuristic procedure is proposed to solve practical problem instances.

This study has three key contributions. Firstly, it shows the potential of operations research (OR)-based studies as helpful decision making tools for real-world healthcare problems. Secondly, it demonstrates and evaluates the implementation of the branch-and-price algorithm for the doctors' assignment problem or any assignment problems in any type of demand centers that share a predetermined amount of a service resource. The third contribution is a method for facility managers to decide on the required lab capacity or the common resource at the strategic level.

The rest of this paper is organized as follows. In Section 2, we define more precisely the coordinated lab-clinics problem and review the relevant literature. In Section 3, we describe the properties of the problem. In Section 4, the mathematical formulation for the model is first developed, and then the complexity of the problem is discussed. A branch-and-price heuristic is proposed to solve practical examples in Section 5. In Section 6, two mini-case studies from two respirology clinics within the Alberta Health Services (AHS) are provided. Finally, we conclude in Section 7 with a discussion and further research suggestions.

2. The coordinated lab-clinics problem and related literature

In healthcare, many scheduling studies are focused on outpatient appointment scheduling, with the goal of finding an appointment system for which a particular measure of performance is optimized (e.g., Baron, Berman, Krass, & Wang, 2016; Kucukyazici, Verter, & Mayo, 2011; Samorani & LaGanga, 2015; White, Craig, & Klassen, 2011; Zacharias & Pinedo, 2013). The lateness and interruption level of doctors are two doctor-related parameters studied (see, e.g., Cayirli & Veral, 2003; Klassen & Yoogalingam, 2008). However, the outpatient appointment scheduling problem is focused on the operational level of scheduling, whereas the coordinated lab-clinics problem addresses the tactical level. A problem that is more closely related to the lab-clinics scheduling problem is medium-term surgical block scheduling, where a cyclic schedule is determined to assign doctors to blocks over a time period (see e.g., Fei, Chu, & Meskens, 2009; Guerriero & Guido, 2011; Gupta, 2008). In both problems, the strategic level decision acts as a constraint, as the number of physicians and the available time in each block has already been decided. The operational level of both scheduling problems, where the sequence of patients will be determined, occurs after the tactical level. Fig. 1 summarizes the main problems on each decision level in the surgical block and the lab-clinics scheduling processes.

Van Houdenhoven, Van Oostrum, Hans, Wullink, and Kazemier (2007) applied bin-packing and portfolio techniques to assign surgeries to blocks with the objective of minimizing the probability of overtime. The bin-packing algorithm suggested in Van Houdenhoven, Van Oostrum, Hans, Wullink, and Kazemier (2007) can also be used to solve heuristically our assignment problem for a given service level. Although real-sized problems are solvable when applying the exact solution proposed herein, the heuristic approach can be, with minor modification, used after applying our method for obtaining the time distribution. Latorre-Núñez et al. (2016) proposed an integer linear programming model to address the surgery scheduling problem considering not only the assignment of surgeries to operating rooms, but all the resources required for each surgery (human and material), and the recovery beds. They then developed a metaheuristic based on a genetic algorithm to deal with larger-sized instances. Silva, De Souza, Saldanha, and Burke (2015) addressed surgery scheduling and resources assignment in an operating room. They applied an integer model and integer programming based heuristics to maximize the use of the operating rooms. Min and Yih (2010) proposed a stochastic optimization