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Scheduling elective patient admissions considering room assignment and operating theatre capacity constraints

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Abstract. The present contribution studies an elective patient admission scheduling problem considering both operating theatre capacity and room assignment constraints. The aim of the study is to determine how scheduling surgical and non-surgical admissions impacts room assignment issues at hospital wards, and how these can be avoided. We present a problem setting and the corresponding mathematical formulation as the basis of our study. First results will be presented at the conference.

Keywords: patient scheduling; room assignments; operating theatre planning

Introduction

Several issues following from poor elective admission scheduling can be identified at hospital wards: insufficient bed capacity to accommodate all patients, variability in the number of patients in a ward over a certain period, long waiting times for patients before being admitted, etc. The main causes for these concerns can be attributed to a lack of overview of current and planned admissions during scheduling, uncoordinated planning between inpatient and surgical care services, the variability in patients' length of stay, and of course, the inability to plan urgent and emergency admissions. Much research has been done to support decision making for admission scheduling in order to alleviate these issues, particularly in the context of surgery planning. Decisions impacting the process of admission scheduling can be identified at the strategic, tactical and operational decision levels (see e.g. Hulshof et al. 2012 for an extensive overview). The present contribution is situated at the operational decision level and deals with the assignment of admission dates to individual patients. From the perspective of surgery planning, such a setting has already been studied to improve utilization of available operating theatre capacity and to reduce operating overtime (see e.g. Jebali et al., 2006, Hans et al., 2008, Riise and Burke, 2011). Another main concern is to reduce/avoid undercapacity of beds, especially in the presence of emergency arrivals and uncertainty in the length of stay in patients (see e.g Mazier et al., 2010).

Less obvious, but nevertheless important, is that organizational issues related to the admission scheduling at hospital wards can also be found. For example, many hospitals impose a gender separation policy that requires male and female patients to be assigned to separate rooms. Thus, when all rooms are occupied by (at least one) female patient, no more male patients can be admitted to the ward unless the patients are reassigned. Another example following from medical necessity is the requirement of assigning certain patients to single rooms for medical reasons (e.g. isolation for infectious diseases). In the event of no single room being available, a double/communal room may be reserved for a single patient. Finally, an issue applicable to at least the Belgian hospital admission system is the preference a patient may have concerning his or her room type (single or double/communal room) and the availability thereof. There is a significant financial incentive for hospitals and physicians to meet these preferences. Room supplements and physician honorarium supplements may be charged, making the final cost for a patient preferring a single room as high as 400% of a double/communal room (Crommelynck et al., 2012). The issues concerning patient-to-room assignments have already been studied by Demeester et al. (2010), Bilgin et al. (2011) and Ceschia and Schaerf (2011), who develop local search based methods to improve the room assignments, taking into consideration room equipment and specialization, gender conflicts, age restrictions, room preferences, etc. Dynamic aspects of the problem, encountered when performing room assignments in an online context, are studied by Ceschia and Schaerf (2012a) and Vancroonenburg et al. (2012). The present contribution aims at studying how these room assignments can already be considered during admission scheduling.

Problem setting

We consider a set of patients P that are to be admitted over a certain time period of length T. Each patient has to be admitted at some point $t \in \{1, \dots, T\}$ and requires an assignment to a room $r \in R$ during her or his respective stay. Each room $r \in R$

has a specific capacity $c(r)$, which cannot be exceeded at any time. Some patient admissions may also require a surgical procedure to be performed. This procedure requires some estimated surgical time $esd(p)$ that must be available in the operating theatre at the patient's admission (or after some preoperative testing has been performed, see further). There is however, only a limited amount of operating theatre surgery time OT_t available at each t.

Patients $p \in P$ are further characterized by the following attributes:

- an *expected* length of stay $los(p)$;
- a release date $rd(p)$, which is the earliest time a patient may be admitted;
- an admission due date $add(p)$ (with $add(p) + los(p) \leq T$) before which the patient should be admitted;
- a preoperative time $preop(t)$, that specifies the number of time units that is required for preoperative tests before surgery;
- an *estimated* surgery duration $esd(p)$ that specifies how much surgery time is required for a patient's procedure (= 0 if it is not a surgical case);
- gender, M(ale) or F(emale);
- a room preference (single, double, any).

The problem is to assign to all patients $p \in P$ both an admission date $\in \{1, \ldots, T\}$ as well as a room $r \in R$ for the length of their stay. This assignment must take into account the following considerations:

- Room capacity should never be exceeded.
- Available surgery time in the operating theatre should never be exceeded.
- Male and female patients should not be admitted to the same room, at the same time.

Several objectives can be identified when scheduling elective patients:

- Maximizing occupancy and throughput in wards: given that the set of patients is fixed, it follows that the currently expected occupancy averaged over the horizon is thus also fixed. However, it is most important that the distribution of occupancy over the time period is skewed to the *left*. New registrations will occur at later planning 'sessions' and thus will fill up the right tail of the planning horizon.
- Maximizing operating theatre utilization and throughput;
- Maximizing patient comfort by meeting patient preferences, and minimizing patient discomfort (e.g. by being assigned to a room with a patient of the same gender).

Mathematical formulation

We present the following mathematical formulation for this problem setting. The main decision variables are as follows:

- x_{prt} = binary variable indicating (=1) whether patient p is admitted at time t and is assigned to room r, 0 otherwise.
- y_{rt}= binary aid variable indicating (=1) whether room r is occupied by more $male$ patients than $female$ patients at time t, 0 otherwise.
- v_{rt}= variable representing (≥0) the minimum of the number of male patients and the number of female patients in room r at time t. That is $v_{rt} = \min\{male\ patients, female\ patients\}$ assigned to room r at time t.

We can thus formulate the objectives presented in the previous section by:

$$min \sum_{t\prime=1}^{T} \sum_{\substack{p\in P: \\ rd(p)\leq t\prime}} \sum_{r\in R} \sum_{t=t\prime-los(p)+1}^{t\prime} t' \cdot x_{prt} \tag{1}$$

$$max \sum_{t\prime=1}^{T} \sum_{\substack{p\in P: \\ rd(p)+preop(p)\leq t\prime}} \sum_{r\in R} (T-t'+1) \cdot \frac{esd(p)}{OT_{t\prime}} \cdot x_{pr(t'-preop(p))} \tag{2}$$

$$min \sum_{p\in P} \sum_{r\in R} \sum_{t=rd(p)}^{add(p)-1} C(p,r) \cdot x_{prt} + \sum_{t=1}^{T} \sum_{r\in R} w_G \cdot v_{rt} \tag{3}$$

Expression (1) minimizes the *mean occupancy day* over the planning horizon. Given the distribution of occupancy over the planning horizon, this expression entails to have high occupancy in the beginning of the planning period (occupancy skewed to the left). Expression (2) considers the utilization of the operating theatre, maximizing the sum of (weighted) daily usage of the operating theatre. By weighing the daily usage by the (negated) date, the expression prefers usage of the OT in the beginning of the planning horizon, leaving room for future usage. Finally, Expression (3) is concerned with both patient comfort and discomfort, minimizing the total patient-room assignment cost (with $C(p,r)$ denoting the suitability of assigning patient p to room r, higher values meaning less suitable), as well as the (weighted) total number of gender conflicts (number of occurrences where patients of different gender are assigned to the same room).

The model is subject to the following constraints:

$$\sum_{r\in R} \sum_{t=rd(p)}^{add(p)-1} x_{prt} = 1 \qquad \forall p \in P \tag{4}$$

$$\sum_{p\in P} \sum_{t=t'-los(p)+1}^{t\prime} x_{prt} \leq c(r) \qquad \forall r \in R, t' = 1, \dots, T \tag{5}$$

$$\sum_{p\in P} \sum_{r\in R} esd(p)\, x_{pr(t'-preop(p))} \leq OT_{t\prime} \qquad \forall t' = 1, \dots, T \tag{6}$$

$$\sum_{\substack{p\in P:\\ p\ is\ male}} \sum_{t=t'-los(p)+1}^{t'} x_{prt} \le v_{rt'} + c(r)y_{rt'} \qquad \forall r \in R, t' = 1, \dots, T \tag{7}$$

$$\sum_{\substack{p\in P:\\ p\ is\ female}} \sum_{t=t'-los(p)+1}^{t'} x_{prt} \le v_{rt'} + c(r)(1 - y_{rt'}) \qquad \forall r \in R, t' = 1, \dots, T \tag{8}$$

$$\sum_{\substack{p\in P:\\ p\ is\ male}} \sum_{t=t'-los(p)+1}^{t'} x_{prt} \ge v_{rt'} \qquad \forall r \in R, t' = 1, \dots, T \tag{9}$$

$$\sum_{\substack{p\in P:\\ p\ is\ female}} \sum_{t=t'-los(p)+1}^{t'} x_{prt} \ge v_{rt'} \qquad \forall r \in R, t' = 1, \dots, T \tag{10}$$

$$x_{prt} \in \{0,1\} \qquad \forall p \in P, r \in R, t = 1, \dots, T: rd(p) \le t < add(p) \tag{11}$$

$$y_{rt} \in \{0,1\} \qquad \forall r \in R, t = 1, \dots, T \tag{12}$$

$$v_{rt} \ge 0 \qquad \forall r \in R, t = 1, \dots, T \tag{13}$$

Expressions (4) – (6) enforce the basic assumptions of the model, namely that each patient should be assigned one specific admission date and room over the planning horizon; that room capacity should be respected for each room $r \in R$ and at each time $t' = 1, \dots, T$; and that the planned elective surgery should not exceed the operating theatre time at any time t'.

Expressions (7) – (10) model the relation $v_{rt} = \min\{male\ patients, female\ patients\}$ assigned to room r at time t. Thus, the variable v_{rt} models the number of female or male patients that need to be relocated from room r at time t to resolve the mixed gender conflict.

Conclusion

Following the earlier work of the authors on patient-to-room assignments, the aim of the study is to determine how scheduling surgical and non-surgical admissions impacts room assignment issues at hospital wards, and how these can be avoided. Computational results for the mathematical formulation will be presented at the conference.

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