Local Search for the Patient Admission Scheduling Problem under Uncertainty

Sara Ceschia, Andrea Schaerf
DIEGM, Università degli Studi di Udine
via delle Scienze 206 – I-33100, Udine, Italy
sara.ceschia@uniud.it, schaerf@uniud.it

Abstract

We propose an extension of the Patient Admission Scheduling (PAS) problem that includes, among others, uncertainty in arrival times and stay lengths. We propose the use of a Simulated Annealing approach for both the long- and short-term versions of the new problem, along the lines of the one employed successfully for the original PAS problem in [2].

1 The Patient Admission Scheduling Problem

The Patient Admission Scheduling (PAS) problem consists in assigning patients to hospital rooms in such a way to maximize both medical treatment effectiveness and patients’ comfort. PAS has been defined by Demeester et al [4], and further studied by the same research group [9].

In the proposed PAS formulation, each patient has fixed admission and discharge dates and one or more treatments to undergo. Each room is characterized by its equipments and location and may be more or less suitable for a specific patient; and this results in a matrix of patient/room compatibility costs that contributes to the objective function. In addition, there is a room gender policy that forbids, for normal rooms, the simultaneous presence of male and female patients. Finally, patients should possibly not change the room during their stay; a room change is called a transfer and is penalized in the objective function. The problem then consists in assigning patients to rooms for each day of their stay in hospital, minimizing all the mentioned costs and respecting the capacity constraint and the gender policies of the rooms. The planning horizon $h$ is expressed in days and varies from 2 weeks ($h = 14$) up to 3 months ($h \approx 90$).

Unfortunately, this long-term version of the problem has little usefulness for most practical cases where patients might arrive at unpredictable times (urgent and emergency patients) [7, 8]. Furthermore, it is also frequent that the discharge date of the patients is unknown, because it might depend of the progress of the gradual recovery [5, 6]. In these cases, the long-term solution of the problem can provide only a provisional assignment that needs to be subsequently modified several times.

In [2] we introduce a short-term (daily) version in which the admission dates become known to the solver only a fixed number of days (called forecast level) before the patient arrivals. In this setting, the scheduling is repeated iteratively each day $d$, starting with $d = 0$ and by increasing $d$ by one at every step. For each day $d$, the system schedules all the patients known at time $d$, treating those that arrived before $d$ as preassigned (because they cannot be moved anymore). The process continues up to the point in which all patients are eventually registered and thus scheduled. The assignment generated by the last invocation provides the final schedule and thus the final cost of the solution.

We have solved both versions (long- and short-term) of the problem by local search in [2]. For the long-term case, we have obtained the best known solutions on all the available PAS benchmarks [3]. For the short-term one, we have analyzed the behavior of the solver as a function of the forecast level.

The short-term version of the solver is surely closer than the long-term one to real dynamic situations that normally happen in hospitals. Nevertheless, following [7] we believe that some further steps have to be made to design a problem formulation that captures most of the real situations.

In this work, we define a new version of PAS (both short- and long-term) and we propose a solution approach based on local search built upon the one used in [2].
2 New PAS Formulation under Uncertainty

In order to adapt the original PAS problem to the typical functioning of a hospital, we introduce three new features for the patients, namely the registration day, the uncertain stay length, and the admission shifting possibility.

Patient registration day: The registration day is the day in which the presence of the patient becomes known to the hospital. This can vary from patient to patient, and thus needs to be specified independently for each one. For emergency patients, this coincides with the admission day, whereas for the elective ones it can be also several days in advance. For the short-term solver, only patients registered before the current day \( d \) are included in the planning.

Uncertain stay length: The stay length of the patients is supposed to be fixed in PAS. On the contrary, we consider it as a probabilistic value, expressed in terms of average and deviation. This extension is complemented by an additional cost component in the objective function that accounts for the risk that a room is overcrowded in some specific day, due to the probability of the over-length stay of some patients assigned to the room.

Patient admission shifting: In the PAS problem, admission dates are fixed and the scheduling regards only the assignment of a room in the specified days. However, it is normally possible to delay or anticipate the entrance of a (non-urgent) patient, if it helps to improve the overall quality of service for the hospital. This extension prescribes that for each patient we are given in the input data the maximum anticipation and maximum delay that his/her conditions can afford, without risking complications.

The latter extension leads to a new search space of the problem, in which the admission day of the patients is an additional decision variable. In addition, we include a new cost component that takes into account the discomfort of the change of the admission day for the patient.

3 Solution Technique

The solution technique adopted in [2] is based on Simulated Annealing (SA). In particular, the neighborhood used is the composition of two basic moves, which are the change of the room assigned to a patient for a subset of his/her stay length (called PCR, for Partial Change Room) and the swap of the assigned room between two patients (SP, for Swap Patients).

In order to explore the larger search space in which admissions of patients can be delayed or anticipated, we consider also the additional neighborhood (called S, for Shift) that shifts forward or backward the admission of a patient by one day.

The neighborhood considered is thus PCR ⊕ SP ⊕ S, from which a random move is selected at each step of the SA procedure. The random selection prescribed by SA is performed selecting first the neighborhood used, and then the specific move. Regarding the selection of the neighborhood, the probability is not uniform (i.e. 1/3 each), but set to three given values \( p_{\text{PCR}}, p_{\text{SP}}, \) and \( p_{\text{S}} \) (with \( p_{\text{S}} = 1 - p_{\text{PCR}} - p_{\text{SP}} \)). The values of \( p_{\text{PCR}} \) and \( p_{\text{SP}} \) are subject of tuning, along with the main SA parameters (starting temperature, cooling rate, . . . ).

The cost function includes the cost components of the PAS problem, namely RG (room gender), PRC (patient-room cost), and Tr (transfer). To these components we add two additional ones, OR (overbooking risk) and SD (shift discomfort). The relative weights of the cost components are still under investigation.

4 Current Work

The project is ongoing and the computational results are preliminary and will be presented in the forthcoming long version of the paper. The project road-map includes the following steps:

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**Instance generation:** We are going to produce an instance generator which can be easily parametrized in order to create instances for both the original PAS problem and the revised one. Given that only a few PAS cases are available, the use of a generator removes the opportunity to hand-tune algorithms to the particular set of instances, therefore allowing a larger fairness when comparing algorithms.

**Parameter tuning:** Metaheuristics, such as SA, have a number of configurable parameters, and their performance depends on the particular setting of these parameters. In this work, differently from [2], we plan to test new automatic configuration tools, e.g. the iterated racing procedure recently introduced by Birattari et al [1], which can allow us to explore more effectively the space of parameters on a large set of instances, and to verify the robustness of our algorithm.

**Multi-objective analysis:** The problem considered includes very diverse objectives that range from medical effectiveness, to hospital policies, to patient comfort and/or risk management. It is clear that finding a good balance between all these components is extremely difficult. For this reason, we believe that a multi-objective formulation of the problem and a deep analysis on the relative influence and correlation between objectives would be very useful to understand the behavior of the problem in practical cases.

**References**


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