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Planning problem in Healthcare domain*

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1 Introduction

The complexity of planning in healthcare domain is an issue that is increasingly being highlighted by hospitals. This kind of problem belongs to the Resource Constrained Project Scheduling Problem (RCPSP) family that is NP-Hard (M.R. Garey and D.S. Johnson 1979) (P. Baptiste *et al.* 2006). The RCPSP problem consists in finding the best assignment of resources and start times to a set of appointments. Scheduling problems have been the subject of many studies for decades in various fields (R.N. Anthony 1965) (J. Blazewicz *et al.* 2019), and they are of increasing interest in healthcare domain (B. Shnits *et al.* 2019). Through better patient care and better management of staff time schedules, health facilities want to reduce their costs while improving patient care. Nowadays, schedules are mostly designed by hand, a difficult and time-consuming task that can be challenged by various kind of unexpected events. The structure of the considered problems differs according to the institutions, their size and the number of resources taken into account. The institutions' needs are differents, and the criteria for evaluating a schedule may also change from one institution to another or from one department to another within the same institution. In this paper we present an efficient 0-1 linear programming model for various concrete scenarios in healthcare.

The rest of this article is structured as follows. In section 2, we describe and formalize our scheduling problem. In section 3 we present some instances and the corresponding results obtained by the CPLEX solver. In section 4, we conclude with some remarks and perspectives.

2 0-1 Linear programming model

The horizon H is decomposed into timeslots. We have a finite set of resources R. Each resource $r \in R$ is characterised by a set of properties Π_r that determines which roles a resource will be able to hold in an appointment. To each resource $r \in R$ is also associated a set of timeslot t such that $Available_t^r = 1$ if resource r is available at timeslot t. For example, an orthopedic surgeon who is available the first hour over $H =< t_1, t_2, t_3, t_4 >$ will be represented as ressource r with properties *orthopedic surgeon* and *orthopaedist* and with the set of available timeslots $< 1, 1, 0, 0 >$. He will be able to perform surgical operations and medical consultations. A is a set of appointments, such that each appointment $a \in A$ is characterized by its duration $duration_a$, a feasibility interval ES_a and LS_a, $qtreq_a^\pi$ the amount of resources with property π required by a. $Essential_a$ and $Emergency_a$ are two coefficients used to respectivly quantify the importance and the urgency of appointment a. They both occur as penalties in the objective function. Each appointment a is also

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defined by a set of resources R_a having one of the properties required by a and Π_a the set of properties required by a. $PreAssigned_a$ is a set of couples $(resource, property)$ pre-assigned to a.

We define decision variables x and y, with $x_a^{r,\pi} = 1$ if resource r with the property π is assigned to appointment a and $y_a^t = 1$ if appointment a starts at the timeslot t. We now present the hard constraints mentioned above.

A resource may have multiple properties, and thus be able to perform multiple roles. However, resource r can only be allocated to appointment a with exactly one of its properties π if a is scheduled:

$$\forall\, a \in A, \forall\, r \in R_a, \sum_{\pi \in \Pi_r} x_a^{r,\pi} \leq 1 \tag{1}$$

If resource r does not have property π, it cannot be allocated to appointment a with this property π:

$$\forall\, r \in R, \sum_{\pi \in \Pi \setminus \Pi_r} \sum_{a} x_a^{r,\pi} = 0 \tag{2}$$

If resource r does not have any of the properties π required by appointment a, it cannot be allocated to a:

$$\forall\, a \in A, \sum_{r \in R \setminus R_a} \sum_{\pi \in \Pi} x_a^{r,\pi} = 0 \tag{3}$$

Each appointment a must be planned into feasibilty interval determined by ES_a and LS_a:

$$\forall a \in A, \sum_{t \in H} y_a^t \times ES_a \leq \sum_{t \in H} y_a^t \times t \leq LS_a \tag{4}$$

If appointment a is planned, it is necessary to allocate the required quantity of resource with property π:

$$\forall\, a \in A, \forall\, \pi \in \Pi_a, \sum_{r \in R_a} x_a^{r,\pi} = qtreq_a^{\pi} \times \sum_{t \in [ES_a; LS_a]} y_a^t \tag{5}$$

Each resource r, allocated to appointment a, must be available for the complete duration of a:

$$\forall\, a \in A, \forall\, r \in R_a, \forall\, t \in [ES_a; LS_a],$$
$$duration_a \times \sum_{\pi \in \Pi_a} x_a^{r,\pi} - y_a^t \times \sum_{t'=t}^{t+duration_a-1} dispo_t^r \leq (1 - y_a^t) \times H \tag{6}$$

An appointment a is at most scheduled once:

$$\forall\, a, \in A \sum_{t \in [ES_a; LS_a]} y_a^t \leq 1 \tag{7}$$

Resources are not allocated if the appointment a is not scheduled:

$$\forall\, a \in A, |R| \times |\Pi| \times \sum_{t \in [ES_a; LS_a]} y_a^t \geq \sum_{r \in R_a} \sum_{\pi \in \Pi_a} x_a^{r,\pi} \tag{8}$$

Resource r cannot be allocated to different appointments on same timeslot t:

$$\forall\, a \in A, \forall\, b \in A, \forall\, r \in R_a \cap R_b, \forall\, t \in [\max(duration_a; duration_b); |H|],$$
$$\sum_{\pi \in \Pi_r} x_a^{r,\pi} + \sum_{t'=t}^{t-duration_a} y_a^{t'} + \sum_{\pi \in \Pi_r} x_b^{r,\pi} + \sum_{t'=t}^{t-duration_b} y_b^{t'} \leq 3 \quad (9)$$

In most cases, an appointment is associated to a specific resource. The following constraint ensures that the resources r with their property π in $PreAssigned_a$ are allocated to appointment a:

$$\forall a \in A, \forall (r, \pi) \in PreAssigned_a,\ x_a^{r,\pi} = 1 \quad (10)$$

The quality of a solution is evaluated by an objective function f that computes the sum of the unplanned appointments $a \in A$, weighted by the importance factor $Essential_a$ and the sum of the differences between the start date of an appointment a and ES_a, weighted by the emergency factor $Emergency_a$. The objective is to find a valid solution while minimizing objective function defined in equation 11.

$$f = \sum_{a \in A} (1 - \sum_{t \in [ES_a; LS_a]} y_a^t) \times Essential_a + \sum_{a \in A} \sum_{t \in [ES_a; LS_a]} y_a^t \times \frac{t - ES_a}{LS_a - ES_a} \times Emergency_a \quad (11)$$

3 Experimentations and results

We generated instances from four different scenarios with the help of various planners from different health care facilities in France who face daily concrete problems.

The first scenario *SurgDep* concerns a surgical department and involves 16 patients, 2 orthopedic surgeons, 2 gastric surgeons and 4 operating rooms. Each patient needs one operation (with a duration from 3 to 7 timeslots), either an orthopedic or a gastric one, for a total of 16 appointments. The horizon is represented by 23 timeslots (*i.e.* 1 day). Every patient is available over the horizon, surgeons and rooms are available from timeslots 2 to 21.

The second scenario *RehabCenter* concerns a follow-up care and rehabilitation facility and involves 24 patients, 12 doctors and 12 specialists (6 of each speciality). Each patient requires 2 medical consultations and 2 sessions of each speciality for a total of 96 appointments. The duration of all appointments is 4 timeslots. The horizon is represented by 20 timeslots (*i.e.* 1 day). All resources have a lunch break of 4 timeslots and are available during 16 timeslots.

The next scenario *Admission* represents the admission of 8 patients into a hospital and involves 5 differents specialists. Each patient has a care program and needs 9 appointments (one appointment with a duration of 2 timeslots, others with a duration of 1 timeslot), for a total of 72 appointments. The horizon is represented by 120 timeslots (*i.e.* 5 days). All resources have a lunch break of 4 timeslots and are available during 18 timeslots each day.

The last scenario *CardioRehab* concerns a cardiovascular rehabilitation facility and involves 16 patients and 10 specialists (2 of each speciality). Each patient follows a care program and needs 8 appointments (with a duration of 2 timeslots), for a total of 128 appointments. The horizon is represented by 104 timeslots (*i.e.* 5 days). All resources have a lunch break of 4 timeslots and are available during 16 timeslots each day. Medical staff has in addition 2×8 timeslots off.

From each of these four scenarios, we generated three instances, starting with no important nor urgent appointments and then increasing the number of essential (Ess) and

urgent appointments (Em). We implemented the model under CPLEX and we run tests on Intel i5-8350U processor. We limit the computation time to two hours, and we report the results in Table 1.

Table 1. CPLEX results on scenario benchmarks

Instance name	Time	Objective value
$SurgDep_Ess_0Em_0$	797	0
$SurgDep_Ess_1Em_1$	2737	5.8160
$SurgDep_Ess_2Em_2$	2085	19.4235
$CardioRehab_Ess_0Em_0$	>7200	0-4
$CardioRehab_Ess_1Em_1$	>7200	12.7059-16.7059
$CardioRehab_Ess_2Em_2$	>7200	18.8015-23.0589
$Admission_Ess_0Em_0$	246	0
$Admission_Ess_1Em_1$	659	4.5098
$Admission_Ess_2Em_2$	671	9.1734
$RehabCenter_Ess_0Em_0$	1117	0
$RehabCenter_Ess_1Em_1$	3015	36
$RehabCenter_Ess_2Em_2$	6956	72

Objective value column corresponds to the objective function in equation 11. If CPLEX is unable to find an optimal solution within the time limit, we report the upper and lower bound. Time column is the running time in seconds that CPLEX needs to work out the optimal solution. For all scenarios other than the *CardioRehab* scenario, CPLEX finds an optimal solution before the computation time limit. We notice that the increased number of important and urgent appointments implies an increase in computing time, exept for the scenario *SurgDep*. The calculation time also increases with the number of appointments involved in the scenario.

4 Conclusion & perspectives

In this paper we have described and formalized concrete scheduling prolems. We proposed a 0-1 linear programming model able to solve various scenarios in healthcare. We implemented this model under CPLEX and generated some instances in order to test it. The optimality has been reached for most instances and this model has proven to be effective on various scheduling issues in the medical domain. This will be a reliable benchmark to compare different approaches addressing these problems. We plan to develop a genetic algorithm to solve larger instances.

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