ISORAP 2013
May 08-10, 2013
Marrakech, Morocco

Surgical team rostering taking into account affinities

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Abstract

The paper focuses on the building of nurses' timetabling and surgical teams knowing the weekly schedule. The objective of the sequential approach adopted is to be able to do teams with high affinities while using the nurses efficiently. The problem is modeled as a mixed integer program and offers flexibility to consider any work pattern. The model is tested on real hospital data.

1. Introduction

An operating theatre is composed of several operating rooms and a recovery room. It is an extremely important sector of the hospital. According to the researchers studying operating theatre problems, the latter is also known to be one of the most expensive units of a hospital. Indeed, expenses of the operating theatre accounts for almost 33% of the estimated hospital budget [8] because it involves expensive labor costs (surgeons, anesthetists, nurses) and material costs (beds, surgical equipment, etc.).

Operating theatre managers have to plan and schedule surgical interventions over a time horizon taking into account constraints related to the availability of materials, human resources and financial resources. In the present economic context, hospital managers are interested in finding effective ways of running the operating theatre so as to improve the efficiency and quality of its services.

The objective of the paper is to create surgical teams with high level of affinities. The surgical teams scheduled have to take into account availabilities of personnel and hard constraints of scheduling (non preemption, days-offs, etc.).

The originality of this research is the integration of personnel affinities in the rostering. Indeed, it has been proven that when members of a surgical team have high affinities, it creates synergies and improves safety and quality of the care provided to the patient [10].

We propose a sequential decision-making framework using mixed-integer programs to build a nurse schedule over one week while assigning them to surgical interventions. The approach is then tested on real data of a Belgian hospital.

The rest of the paper is organized as follows: in section 2, we briefly review the relevant literature to our problem and present the context of the paper. In section 3, we propose a mixed-integer program to build the nurses timetabling. The model is then tested on real data and the results are discussed in section 4. We finish with conclusion and future work.

2. Literature review

Numerous research papers deal with the planning and scheduling of the operating rooms [2]. The planning phase assigns a patient a day. Then, the scheduling phase determines the detailed timing of each surgical intervention [4, 5]. The constraints on resources (surgeons, nurses, anesthesiologists, room) are usually taken into account at the planning level.

This approach leads to a major problem: there is no guarantee to obtain a feasible schedule in terms of resources because the interactions between the planning and scheduling phases are not considered [1]. Indeed, each surgical intervention requires a number of nurses. While there might be enough nurses to cover the surgical planning, the timely variations of the schedule might require more nurses. Also, the schedule obtained does not take into account the affinities between the surgical team members. A growing number of studies [6, 7, 10] has however underlined the role of interpersonal skills and team cohesion on the quality of the surgical performance.

Some research papers address partially that problem. Di Martinelly et al. [3] integrate the planning and scheduling of the surgical interventions under constraints of resources. The horizon considered is a week. Meskens et al. [9] schedule daily the surgeries while maximizing the affinities and desiderata of the surgical team.

The framework we propose builds up on those two research papers. The objective of the framework is to provide the decision maker with a tool to obtain a surgical schedule that both satisfy human and managerial constraints. It uses a holistic view of the problem.

Figure 1 describes the sequential decision-making framework that uses mixed-integer programs. The first part consisted in a model developed by Di Martinelly et al. [3]. It considered the planning and scheduling of surgical interventions over 5 days. Each surgical intervention is done by a surgeon, which has availabilities over the week. It requires a number of resources (rooms, anesthesiologists, nurses) to be available. At every time period, the suggested planning must satisfy the constraints in terms of number of nurses available. The results of this model indicate the starting time on a day of each surgical intervention in a specific room.

The detailed surgical schedule over the week is the workload pattern used to build the nurses' timetabling and the surgical teams while taking into account the working rules.

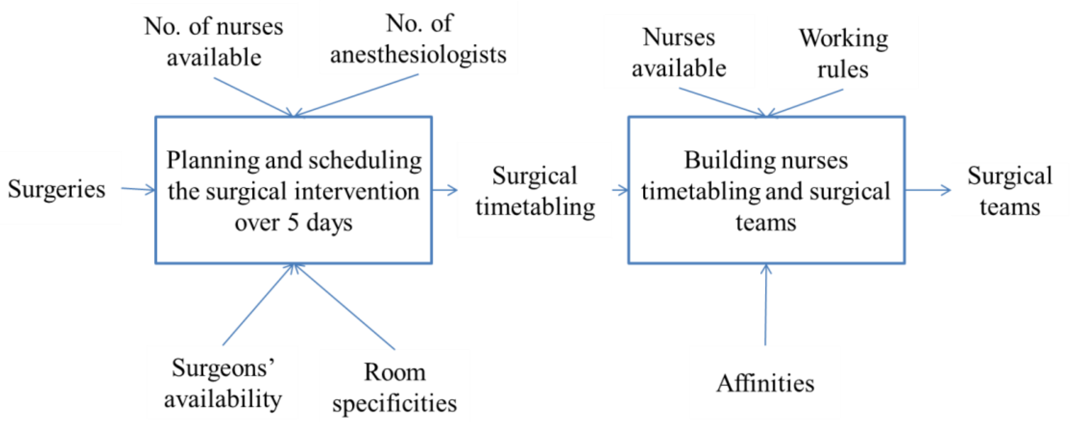

Figure 1. General framework

The remainder of the paper focuses on the second part of the framework. The surgical rooms are of no concern in our second model and, in order to keep the model simple, we don't consider the surgical rooms anymore.

3. Methodology

In this section, we propose a mixed-integer programs that establishes surgical team maximizing the affinities between the nurses and the surgeon while making the schedule efficient for nurses. While both objectives are opposite, we test 2 scenarios and do a sensitivity analysis on data from a Belgian hospital.

3.1. Problem description

Each surgical intervention k requires a number of nurses (n_k), which are attending during the entire surgical time (l_k). A surgical intervention is done by one specific surgeon. Each nurse has a degree of affinity with the operating surgeon. This gives us the degree of affinity between the surgery k and the nurse i (s_{ki}).

While a nurse i can be available for working at a specific time period t on day d ($p_{td}^{i} = 1$), she can only work a maximum number of time periods over a day d (t_{id}). Also, based on her working contract, she can work up to a maximum number of time periods over the week (z_i). Nurses can start working at different time periods ($r_{i,d}$), with $r_{i,d} = \min_t p_{td}^{i}\ \forall i, \forall d$. This modeling technique allows us to take into account any nurse' requirements (half-day working, 35 hours or 40 hours, etc.).

We determine which nurse i will attend the surgery k (y_{ik}). The quality of the nurse schedule is evaluated either by the waiting time of each nurse i on day d (w_{id}) or by the affinities of the surgical team.

3.2. Mathematical model

Sets

- d set of operating days , $d = 1, .., D$
- t set of time periods per day , $t = 1, .., T$
- k set of surgical interventions over the period , $k = 1, .., K$
- i set of nurses , $i = 1, .., I$

Parameters

- s_{ki} : degree of affinity between the surgeon (related to surgery k) and the nurse i
- p_{td}^{i} : presence of nurse i in period t on day d {0,1}
- $r_{i,d}$: time period at witch nurse i starts working on day d
- n_k : number of nurses required to perform surgical intervention k
- x_{td}^{k} : starting time of surgical intervention k in period t on day d {0,1}
- l_k : duration of surgical intervention k in time periods
- t_{id} : available working time in time periods for nurse i on day d
- z_i : available working time in time periods for nurse i over the horizon

Variables

- y_{ik} :binary variable represents the nurse i affected to surgical intervention k
- m_{id}: time period at which nurse i finishes her surgical interventions for day d
- w_{id}: total waiting time in periods of nurse i over day d

Model

Minimize waiting time		Maximize affinities	
$MIN\ w = \sum_i \sum_d w_{id}$	(1)	$MAX\ a = \sum_k \sum_i y_{ik} * s_{ki}$	(2)
$\sum_k (y_{ik} \sum_{\tau=t-l_k+1}^{t} x_{td}^k) \leq 1\ \forall i, \forall t, \forall d$			(3)
$\sum_k (y_{ik} \sum_{\tau=t-l_k+1}^{t} x_{td}^k) \leq p_{td}^i\ \ \forall i, \forall t, \forall d$			(4)
$\sum_i y_{ik} = n_k\ \forall k$			(5)
$\sum_k (y_{ik} * l_k) \leq z_i\ \ \forall i$			(6)
$\sum_k \sum_t (y_{ik} * l_k * x_{td}^k) \leq t_{id}\ \ \forall i, \forall d$			(7)
$\sum_t (y_{ik} * (l_k + t) * x_{td}^k) \leq m_{id} \forall i, \forall d, \forall k$	(8)		
$m_{id} - r_{i,d} - \sum_k \sum_t (y_{ik} * l_k * x_{td}^k) \leq w_{id} \forall i, \forall d$	(9)		
$m_{id}, w_{id} \geq 0\ , \forall i, \forall d$	(10)		
$y_{ik}\ \in \{0,1\}$			(11)

Objective (1) is intended to give the nurses a schedule that minimizes waiting times. Objective (2) maximizes the affinities between the nurses and the surgeon leading the intervention.

Equations (3) state that a nurse can only attend a surgical intervention at a time. Equations (4) ensure that a nurse will be affected at a surgical intervention only if she is available. Equations (5) ensure that there is the required number of nurses to perform the surgery. Equations (6) ensure that a nurse doesn't work more than the authorized time over the week. Equally, equations (7) ensure that the daily working time of a nurse is respected. Equations (10) define binary variables for the allocation of a nurse to a surgical intervention.

Equations (8) and (9) are related to the model minimizing the waiting time. Equations (8) determine when the last surgical intervention of a nurse finishes each day (Makespan of a nurse *i* activity on day *d*). Equations (9) determine the daily waiting time of a nurse. Equations (10) define the variables as positive.

3.3. Scenarios

The two mixed-integer models suggested have contradictory objectives. In order to investigate the relations existing between those objectives, we use a sequential decision-making framework presented in Figure 2. Two scenarios were tested.

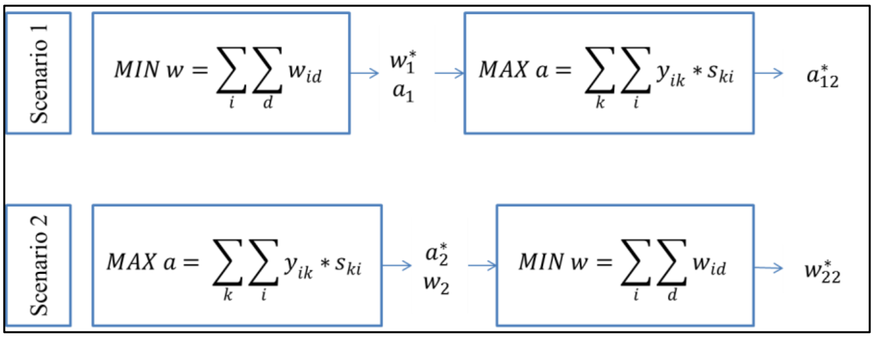

Figure 2. Sequential decision-making framework

The result of minimization problem serves as an upper bound on the waiting time in the maximization problem. In the same way, the result of the maximization problem serves as a lower bound on the affinities in the minimization problem.

A sensitivity analysis is then performed by relaxing the bounds by 10%.

4. Results and discussion

4.1. Test instances

We tested our model on a data set obtained from a Belgian hospital. The surgical interventions take place between 8 AM and 6 PM at the latest. Each hour is divided in quarter (for a total of 40 quarters a day). There are 8 instances in the set (8 weeks). The number of planned and scheduled surgeries varies between 49 and 90 surgeries. Each week, between 22 and 38 different surgeons operate.

The affinity matrix is built by asking each surgeon to assess his affinity with each nurse using a scale between 1 and 9 (9 being the highest affinity).

There is a pool of 15 nurses allotted to the operating theatre. Every day, at every time, there is a maximum of 12 concurrent nurses, having different working hours.

4.2. Results and discussion

The model was developed and solved using FICO Xpress-Optimizer. It was tested on a computer with 2.2 GHz CPU and 8 GB of RAM.

The results of the hospital data set are presented in Table 1. The left part presents the sequential scenario first minimizing the waiting time and then maximizing the affinities. The right part of Table 1 displays the results of the second scenario that first maximizes the affinities and then minimizes the waiting time. For each scenario, we keep track at each step of the waiting time and the affinities. Regarding the first scenario, minimizing the waiting time, the second column displays the optimum waiting time (w_1^*) and the affinities obtained (a_1). The optimum waiting time becomes the upper bound on the second step, maximizing the affinities, which results are provided in the fourth column (a_{12}^*). The fifth column computes the increase in affinities compared to the initial situation. The sixth column computes the improvement in affinities compared to the optimum situation.

Table 1. Results of scenarios 1 and 2

week	Scenario 1					Scenario 2				
	w_1^*	a_1	a_{12}^*	$(a_{12}^* - a_1)/a_1$	$(a_{12}^* - a_2^*)/a_2^*$	a_2^*	w_2	w_{22}^*	$(w_{22}^* - w_2)/w_2$	$(w_{22}^* - w_1^*)/w_1^*$
1	0	342	592	73,099%	-9,342%	653	293	263	-10,239%	/
2	40	732	1021	39,481%	-11,372%	1152	332	257	-22,590%	542,500%
3	4	675	1007	49,185%	-7,868%	1093	271	208	-23,247%	5100,000%
4	50	436	600	37,615%	-24,433%	794	390	295	-24,359%	490,000%
5	47	621	821	32,206%	-24,748%	1091	441	338	-23,356%	619,149%
6	71	441	845	91,610%	-6,007%	899	466	378	-18,884%	417,808%
7	75	438	708	61,644%	-8,763%	776	405	376	-7,160%	394,737%
8	64	476	745	56,513%	-23,668%	976	529	357	-32,514%	457,813%

In the first scenario (minimize waiting time and then maximize affinities), there is a significant improvement of the degree of affinity of the surgical team. Affinities are improved by an average of 52% while, in the second scenario, the waiting time is only decreased by 20% on average. Also, if comparisons are made with the initial situation (minimizing waiting time or maximizing affinities), the second scenario degrades much more the results. Indeed the waiting time for nurses is at least 3.9 times more important than in the first scenario. In the worst case, it reaches 51 times. Those results are limited to maximum 24.8% in the case of scenario 1.

Table 2 presents the results of the scenarios when the upper bound on waiting time is increased by 10% (left part of the table) and when the lower bound on affinities is decreased by 10%. If the bound on waiting time is relaxed by 10%, affinities increase by an average of 7% with respect to the initial situation (when the bound is not relaxed). In the same way, if the bound on affinities is relaxed by 10%, the waiting time will decrease by an average of 13%. In some cases, we will even reach the optimum values of the waiting time (w_1^*).

Table 2. Result of scenarios 1 and 2 when relaxing the bound by 10%

week	Scenario 1 – bound relaxed by 10%					Scenario 2 – bound relaxed by 10%				
	w_1^*	a_1	a_{12}^*	$(a_{12}^* - a_1)/a_1$	$(a_{12}^* - a_2^*)/a_2^*$	a_2^*	w_2	w_{22}^*	$(w_{22}^* - w_2)/w_2$	$(w_{22}^* - w_1^*)/w_1^*$
1	0	342	592	73,099%	-9,342%	653	293	0	-100,000%	/
2	40	732	1064	45,355%	-7,639%	1152	332	52	-84,337%	30,000%
3	4	675	1009	49,481%	-7,685%	1093	271	4	-98,524%	0,000%
4	50	436	740	69,725%	-6,801%	794	390	58	-85,128%	16,000%
5	47	621	928	49,436%	-14,940%	1091	441	65	-85,261%	38,298%
6	71	441	848	92,290%	-5,673%	899	466	71	-84,764%	0,000%
7	75	438	712	62,557%	-8,247%	776	405	75	-81,481%	0,000%
8	64	476	856	79,832%	-12,295%	976	529	70	-86,767%	9,375%

From a managerial point of view, if the affinities between the surgical team members are not a concern for the patient safety, the operating room manager has interest in adopting scenario 1 to build surgical team. Indeed while providing the nurses with a schedule that minimizes the waiting time, he can, by relaxing slightly the constraint on waiting time, increase the affinities closed to their optimum value.

5. Conclusion

Planning and scheduling the operating theatre is a difficult task that involves resources having different management schemes: the surgical interventions and the nurses. The ultimate goal of our research is to provide the decision maker a tool that gives a surgical schedule satisfying both human and managerial requirements, using a holistic approach.

The present paper focused on the building of the nurses' timetabling and surgical teams knowing the weekly schedule. The objective of the sequential approach adopted was to be able to do teams with high affinities while using the nurses efficiently. The problem was modeled as a mixed integer program and offered flexibility to consider any work pattern. The model has been tested on real hospital data.

The results have shown that the waiting time criterion is predominant. If we relaxed a little bit the waiting time, we could obtain a schedule that was close to optimality in terms of affinities.

Future work deals with assessing how those conclusions are robust to variations in the work availabilities of nurses and to the affinity matrix.

Since the model is flexible, the model could be easily adapted to take into account affinities between all the surgical teams or to consider their competences.

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