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SIZING OPERATING ROOMS IN CASE OF A DISASTER PLAN

In case of a disaster, the need for medical and surgical treatments overwhelms hospitals' capabilities with respect to standard operating procedures. In this paper, we deal with the preparation phase of the disaster management plan. We focus on the sizing activity of emergency resources, more precisely on operating rooms. So, we propose integer linear programming model. This model provides the optimal number of operating rooms that best respond to mass casualty events such that all victims are treated. Computational experiments performed by the Cplex solver show that a substantial aid is proposed by using this model in hospital disaster management.

Integer programmingж Disaster plan, Sizing; operating rooms.

1. Introduction. The annual report of the International Federation of Red Cross and Red Crescent Societies proves that the national societies were impacted by 429 different disasters or crises in 2006. This shows an increase of 22 % from 2005 and 47 % from 2003 (Ghezail and *al.*, 2007). Such an incident, affects hospitals of all sizes and geographic locations. Different countries require that their hospitals have plans for emergency preparation and disaster preparedness. For example, in the USA, the Joint Commission on the Accreditation of Healthcare Organizations requires US hospitals to have a disaster management plan (DMP). In other countries, like in France and in Tunisia, state requirements or laws impose each hospital to have a disaster plan so called white plan (Ministère de la santé et de la solidarité, 2006) (Ministère de la santé publique, 2002).

Any emergency management plan must address the following phases: preparation, response, and recovery (Kimberly and *al.*, 2003). The preparation phase is considered as the driving force behind a successful response. Indeed, it is vital to have a strong framework to activate in case of a disaster (Lipp and *al.*, 1998). It includes all emergency preparedness activities such as defining medical and technical supplies, maintaining accurate contact lists of the involved actors and conducting regular exercises with various disaster scenarios. This phase allows the hospital to be able to estimate the additional resources that may be needed in a given disaster situation, to keep adequate supplies on hand and to establish employees' emergency planning. This is not an easy undertaking in any hospital setting (Kimberly and *al.*, 2003) (Lipp and *al.*, 1998).

Sizing problems are frequently encountered in hospitals, in order to optimize critical resources (operating rooms, medical staffs, beds,…) (Kusters and Groot, 1996) (Wang and *al.*, 2008) and to satisfy health care requirements. Different works exist in the literature. They are based on four solving approaches: Markov chains, mathematical programming, queuing theory and simulation. Markov chains have been used by (Kao, 1974) to analyse the flows of patients among the different care units and therefore to assess their stay time in the hospital. The requirement on resources such as nurses' staff and hospital beds are then determined. Several works based on mathematical programming models have been also proposed (Vissers, 1994). (Teow and Tan, 2007) presents a two-stage programming model. The first stage involves the sizing of beds by room configurations while the second stage assigns beds to physical locations with respect to operational considerations such as physical spanning and nurses' training. (Lapierre and *al.*, 1999) and (Murray, 2005) deal with bed sizing and planning according to the number of admitted patients. (Kusters and Groot, 1996) uses the dynamic programming for the sizing of hospital beds while taking into account the operating room planning, the availability of nurses' staff, the arrival and exit patterns of patients. (Gorunescu and *al.,* 2002) (Kao and Tung, 1981) and (Mackay, 2001) address the bed sizing problem with respect to different room configurations. The authors use queuing theory. Simulation has been employed in health care systems (Dumas, 1984) (Harper and Shahani, 2002) (Kim and Horowitz, 2002) (Ridge and *al.*, 1998) with the purpose of a better understanding and analysis of care activities to evaluate the decisions that will be taken.

In this paper, we deal with resources optimisation in emergency preparedness. We focus more precisely on operating rooms and surgical staffs. Our purpose here is to find the optimal schedule of surgical cares that minimises the number of operating rooms needed to treat all persons injured by the disaster. To achieve this, we propose an integer-programming model.

The remainder of this paper is organized as follows. Section 2 describes the sizing problem we address. Section 3 details the integer-programming model we propose. Section 4 discusses the obtained numerical results. Section 5 concludes the paper and presents possible extensions of this work.

2. Problem description. In case of a disaster, victims are evacuated from the damaged zone to the nearby hospital. The triage allows classifying victims according to the urgency of the medical and/or surgical cares they need. In this paper, we consider victims that require surgical cares with predefined processing times and different ready dates in the operating theatre. Each victim is characterized by an emergency level, which is defined by the latest starting time of its surgical care. Therefore, the surgical care must be planned before the vital prognosis of the victim is being overtaken (Dhahri, 1999) (Ministère de la santé et de la solidarité, 2006).

Each hospital has a maximum of human resources that should be requested in a disaster situation. Therefore, surgical staffs, their number, configurations and ready dates in the operating theatre are detailed in a pre-established emergency planning. Each surgical staff (composed by a surgeon, an anaesthetist and nurses) is assigned to an operating room. In such a situation, all operating rooms are considered to be polyvalent. The hospital have to forecast the minimal number of operating rooms that ensure facing a given disaster situation.

The sizing problem we address is stated as follows: given a set of surgical staffs, find a schedule of surgical cares to be realized, so as all victims are treated, while minimizing the number of required operating rooms and satisfying some given constraints such as the ready dates of victims and surgical staffs.

3. Problem modelling. We propose a mathematical model. So, an integer linear programming model is developed using ILOG OPL 5.5 Studio.

Before presenting our model, we will first introduce the following notations:

N – Number of victims;

C – Number of staffs;

T – Time horizon;

p_i – Processing time of surgical care *i*;

dl_i – Latest starting time of surgical care *i*;

dar_i – Ready date of victim *i*;

r_c – Ready date of surgical staff *c* with respect to the hospital emergency planning;

M – Very big positive number.

Besides, we define the following decision variables:

t_i – Starting time of surgical care *i*;

$$X_{itc} = \begin{cases} 1 & \text{if victim } i \text{ is assigned to staff } c \text{ at time } t \\ 0 & \text{otherwise.} \end{cases}$$

$$y_{ijc} = \begin{cases} 1 & \text{if victim } i \text{ is treated before victim } j \text{ by staff } c \\ 0 & \text{otherwise.} \end{cases}$$

$$NO_c = \begin{cases} 1 & \text{if staff } c \text{ is assigned to an operating room} \\ 0 & \text{otherwise.} \end{cases}$$

Using the notations listed above, we propose the following integer linear programming:

$$Minimize \sum_{c}^{C} NO_c. \tag{1}$$

$$\sum_{t}^{T}\sum_{c}^{C} X_{itc} = 1 \qquad \forall i \in \{1..N\}. \tag{2}$$

$$\sum_{i}^{N} X_{itc} \le 1 \qquad \forall t \in \{0..T\} \qquad \forall c \in \{1..C\}. \tag{3}$$

$$t_i \le dl_i \quad \forall i \in \{1..N\}. \tag{4}$$

$$t_i \ge dar_i \qquad \forall i \in \{1..N\}. \tag{5}$$

$$t_i - r_c \sum_{t}^{T} X_{itc} - M\left(1 - \sum_{t}^{T} X_{itc}\right) \ge 0, \quad \forall i \in \{1..N\}, \qquad \forall c \in \{1..C\}. \tag{6}$$

$$\sum_{j \ne i}^{N} y_{ijc} \le 1, \qquad \forall i \in \{1..N\}, \quad \forall c \in \{1..C\}. \tag{7a}$$

$$\sum_{j\neq i}^{N} y_{jic} \leq 1, \qquad \forall i \in \{1..N\}, \qquad \forall c \in \{1..C\} \tag{7b}$$

$$\sum_{i}^{N}\sum_{j\neq i}^{N} y_{ijc} = \sum_{i}^{N}\sum_{t}^{T} X_{itc} - 1, \qquad \forall c \in \{1..C\} \tag{8}$$

$$t_i = \sum_{t}^{T}\sum_{c}^{C} tX_{itc} \qquad \forall i \in \{1..N\}. \tag{9}$$

$$t_j \geq t_i + y_{ijc} p_i - M(1 - y_{ijc}), \qquad \forall i,j \in \{1..N\}, \qquad \forall c \in \{1..C\}. \tag{10}$$

$$X_{itc} \leq NO_c, \quad \forall i \in \{1..N\}, \quad \forall c \in \{1..C\}, \qquad \forall t \in \{0..T\}. \tag{11}$$

$$y_{ijc} \in \{0,1\}, \quad \forall i,j \in \{1..N\}, \quad \forall c \in \{1..C\}. \tag{12}$$

$$X_{itc} \in \{0,1\}, \qquad \forall i,j \in \{1..N\}, \quad \forall t \in \{0..T\}, \qquad \forall c \in \{1..C\}. \tag{13}$$

$$NO_c \in \{0,1\}, \qquad \forall c \in \{1..C\}. \tag{14}$$

The objective function (1) minimises the number of operating rooms used in a given disaster situation. Constraints (2) ensure that each victim must be treated only once during the horizon *T*. In case these constraints can not be satisfied, so the available human resources are not sufficient enough to face the disaster. The hospital is then aware of this important information and should reinforce its staffs. Constraints (3) grantee that every staff makes one surgical care at most at each time *t*. Constraints (4) impose to satisfy the emergency degree of each victim. Equations (5) and (6) express the availability dates of respectively victims and staffs to begin surgical cares. Constraints (7a), (7b) and (8) are disjunctive precedence constraints. Equations (9) give the starting times of surgical cares. Constraints (10) impose no overlapping between two successive cares made by the same staff. Equations (11) guarantee that an operating room is used by a staff that is assigned at least one surgical care.

4. Computational experiments. In this section, we present the computational experiments that are performed using the Cplex solver 10.1 on a pentium® 4 of 3.00 GHz processor and 504 Mo RAM. We assess the performances of the proposed two-stage optimization model in different situations described on the following.

4.1. Problem tests. Different disaster situations are considered by varying the number of victims (*N*=25, 50 and 70) and the durations of surgical cares (given between 30 minutes and 2 hours). Moreover, 10 staffs are available with different ready dates ($R = (r_1, \ldots r_C)$, $C = 10$) according to the hospital emergency planning. The different data are reported in tables 1, 2 and 3 of the appendix. The instance label *PN.R* means the problem *P* involves *N* victims and ready dates *R* of staffs. For example $P50.R_1$ denotes a problem of 50 victims and 10 staffs which ready dates in minutes are given by R_1, thus $r_1 = 0$, $r_2 = 0$, $r_3 = 0$, $r_4 = 30$, $r_5 = 30$, $r_6 = 30$, $r_7 = 60$, $r_8 = 60$, $r_9 = 120$, $r_{10} = 120$.

The computational experiments are performed while fixing the time horizon $T = \max_{i=1,\ldots,N} (dl_i + p_i)$. Indeed, after this date, no victim can be treated.

4.2. Results. The results presented in Tables 4 obtained by solving the proposed integer program. For each instance, we report the CPU time, the number of constraints (*N.Cont.*), the number of variables (*N.Var.*), the number of iterations (*N.Iter.*) and the optimal values of objective functions denoted by NO_c^* .

Table 4

Results

Instances	NO_c^*	CPU(s)	N.Cont.	N.Var.
P25.R_1	3	3.4	63148	2104
P25.R_2	3	3.5	63148	2104
P25.R_3	3	5.87	63148	2104
P25.R_4	3	3.04	63148	2104
P25.R_5	3	3.50	63148	2104
P50.R_1	5	16.26	572845	7006
P50.R_2	5	32.26	572845	7006
P50.R_3	5	29.06	572845	7006
P50.R_4	5	29.70	572845	7006
P50.R_5	5	33.42	572845	7006
P70.R_1	6	310	1409158	13027
P70.R_2	6	167	1409158	13027
P70.R_3	6	163	1409158	13027
P70.R_4	6	185	1409158	13027
P70.R_5	6	162	1409158	13027

Table 4 shows the minimal number of operating rooms needed to treat all victims requiring surgical cares with respect to staffs' ready dates given by the hospital emergency planning (Table 3). This sizing allows an optimal use of available resources. For example, to treat 70 victims in time with different staffs' ready dates, we need six operating rooms. Therefore, if the hospital possesses a greater number of operating rooms, only six rooms will be used. Consequently, the remaining rooms can be kept on hand as safety rooms more particularly in case the disaster is much more important than forecasted. Otherwise, the minimal number of needed operating rooms exceeds the number of operating rooms possessed by the hospital. In this context, the proposed model allows the hospital to estimate how many modulated operating rooms are required to be kept on hand and to update the emergency planning of its employees. As a result, the hospital can extend, if possible, its resources, to avoid the evacuation of victims to farther hospitals, thus decreasing the risk of loss of lives.

Another observation stemming from Tables 4 is that if the number of victims gets more important, the computational time increases.

5. Conclusion. In this paper, we have addressed an emergency preparedness activity tied to the dimensioning of operating rooms. The suggested approach is based on integer linear programming model.

This model yields the minimal number of operating rooms needed to treat all injured persons, while satisfying the availability of surgical staffs in the operating theatre once they are requested by the hospital. The proposed approach allows the hospital to estimate the additional supplies to be kept on hand by updating their number and configuration. Another interesting advantage is that it proposes a scheduling program for the involved surgical cares with respect to the obtained optimal sizing.

This approach has been tested on various disaster situations for which we have shown that we can find the optimal solutions. Future research works should consider this important issue and deal with auxiliary services as well as sharing critical resources.

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Appendix

Table 1. Data about victims

i	p_i (mn)	dl_i (mn)	dar_i (mn)	i	p_i (mn)	dl_i (mn)	dar_i (mn)
1	60	510	0	36	30	330	180
2	30	270	0	37	90	330	120
3	30	420	240	38	60	810	240
4	30	150	30	39	30	450	300
5	90	630	120	40	60	570	330
6	30	750	420	41	60	600	420
7	30	300	120	42	30	450	360
8	30	630	450	43	30	600	270
9	60	450	60	44	60	900	450
10	60	480	150	45	30	660	240
11	60	660	210	46	90	630	480
12	120	630	390	47	60	480	150
13	30	660	240	48	30	630	180
14	30	630	300	49	90	600	270
15	90	630	30	50	30	510	210
16	30	660	330	51	90	510	420
17	30	600	330	52	30	450	270
18	30	660	300	53	60	60	0
19	60	630	420	54	60	720	360
20	30	660	60	55	30	480	120
21	30	270	30	56	120	330	30
22	120	270	180	57	30	450	360
23	30	270	30	58	30	540	180
24	90	180	90	59	60	510	0
25	120	540	0	60	120	240	120
26	60	510	270	61	30	30	0
27	60	600	300	62	90	450	210
28	60	480	120	63	30	330	180
29	90	630	450	64	60	120	0
30	30	540	300	65	30	450	270
31	120	630	450	66	30	240	120
32	60	420	360	67	60	360	30
33	30	360	30	68	30	540	300
34	90	570	330	69	60	360	180
35	120	510	420	70	30	270	150

Table 2. Victims of the different instances

N	Victims
25	2; 3; 5; 8; 10; 12; 15; 16; 20; 30; 33; 35; 37; 39; 41; 43; 46; 48; 50; 52; 54; 58; 61; 65; 68
50	18; 23; 25; 2; 3; 27; 29; 5; 8; 31; 36; 38; 10; 12; 15; 16; 20; 69; 30; 33; 35; 37; 39; 40; 41; 44; 47; 49; 51; 53; 55; 43; 46; 48; 50; 56; 57; 59; 60; 52; 54; 62; 63; 64; 58; 61; 65; 66; 67; 68
70	1 to 70

Table 3. Ready dates of surgical staffs according to hospital emergency planning

R	r_1 (mn)	r_2 (mn)	r_3 (mn)	r_4 (mn)	r_5 (mn)	r_6 (mn)	r_7 (mn)	r_8 (mn)	r_9 (mn)	r_{10} (mn)
R_1	0	0	0	30	30	30	60	60	120	120
R_2	0	0	0	30	30	30	60	60	60	120
R_3	0	0	0	30	30	60	60	60	120	120
R_4	0	0	30	30	30	60	60	60	120	120
R_5	0	0	30	30	60	60	60	120	120	120

mn : minutes.

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