Programming Integrated Surgical Operations and Preventive Maintenance Activities

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Abstract. The operating theatre (OT) represents a significant component of the technical means centre. This facility is the largest cost and revenue centre. To be efficient, it needs an optimal operational programme, which takes into account maintenance activities and not only surgical operations. To build such a programme, various methods have been used: mixed integer programming (MIP), three classic heuristics for Bin-Packing and a coupling of the first alternative with a stochastic descent (SD). Then we compare the obtained results from generated data.

Keywords: Surgical unit, operating planning, MIP, heuristics

1 Introduction

The renovation of the hospital centre: Laquintinie Hospital of Douala (LHD) in Cameroon has started for a few months with the aim to improve work conditions in the medical system environments. It was launched by the Cameroonian public authorities. Hospital team manager wants to reduce cost and to maximize the level of patient satisfaction. The OT was firstly chosen, to be optimized. Researchers having carried out works on the OT are unanimous: it is an important care provider, which generates large incomes and it is among the most important sources of expenditure. It is consuming between 10% and 15% of the hospital budget [1]. Hospital is generally organized in centres of responsibilities [2]. Each one is divided into functional units. Hospital is thus a complex structure, where various functions are provided by a multi-field corporation. Managing the OT is hard due to the conflicting priorities and the preferences of its stakeholders [3], but also due to highly stochastic OT activities, such as the breakdown of equipment in the operating rooms. The actual realization of the planning and scheduling cannot be perfectly predicted. To improve management of the OT, this randomness has, to be taken into account. The problems the OT are known for the greatest part, and researchers proposed tools of decision-making aid, based on modelling, simulation and optimization. In this paper, we propose a tool to help OT managers in LHD, to improve the realization of the directing programme of surgical operations (DPSO), which takes into account surgical operations but also preventive maintenance activities (MA).

The paper is organized as follow: in the next section, we review the related literature. The third section describes the problem to be handled. In the fourth section, we describe our model. The fifth section presents the generated data and the compared results, finally, we conclude and discuss extensions.

2 State of the art

The aim of this literature research is to guide the OT managers in programming (planning and scheduling) this facility, by taking into account the impact of equipment breakdowns, on functioning and the benefice of the equipment maintenance. In the 60 last years, researchers focused on the OT management. Regarding planning and scheduling within the OT, [4] present a substantive state of the art survey. What the planning concerns, its resolution is quite not easy considering the number of constraints, namely: the intervention duration, the emergencies, the material availability, etc. In this section, we focus on proposed models and methods to solve problems having stochastic aspects. In the related literature, we met the following approaches: mixed integer programming (MIP), heuristics, simulation and Markov theory.

MIP method has been applied in various OT studies, with the aim to optimize the management of this facility. Most of the studies are concerned with the optimization of costs. For instance, minimization of costs of overused or underused operating rooms [5], or with the maximization of the daily benefit [6]. Authors focus on the minimization of the allocated time slots of surgeons [7]. To build a stable and flexible operational programme, others [8] applied MIP method so as to maximize the use of operating rooms.

Heuristics are more and more used. To minimize the costs of the intervention hours, [9] designed a genetic algorithm coupled with a procedure implementing a taboo search. In [10], they used heuristics after they identified the problem as a two level Flow-Shop, they minimized the overtime costs in the recovery rooms.

The simulation approach has been used to investigate particular cases, taking advantage of its main asset, i.e., the ability to model specific systems in details. In [11], a Monte Carlo simulation was coupled with a heuristics to maximize the room occupation rate and to minimize the overtime. Authors proposed a planning method to solve emergency problem [12], they combined a Monte Carlo simulation with MIP, to minimize overtime costs and the operation day costs.

Markov chains have been applied to health care management in various studies too. In [13], they proposed an analytical approach to evaluate the risks in the OT, to determine the number of operations which must be planned, in order to limit overtime.

Concerning the equipment maintenance, industrial managers are unanimous: the zero risk does not exit unfortunately, because human and material failures ever occur.

We focus works that proposed methods for solving maintenance activity problem and its impact to production activities. Several approaches have been developed to address MA problems. In [14], they used mathematical models solved with LINGO and MATLAB, to optimize integrated planning, taking into account preventive MA in production. In industrial systems, production programme could not be designed without regarding MA. This reality must be regarded too in health care systems. We have not found any papers solving together OT optimization and MA. In the present work, we proposed a model that combines the flows of planned surgical operations (SO) and preventive MA.

3 Problem to be handled

The research originates from collaboration with a Cameroonian hospital in the Douala area, from which we will receive real data that can be used to evaluate the reliability of our approach and illustrate its application. This hospital is composed of three surgical units: a gynaecologist-obstetrics unit, an emergencies unit and an OT, this OT is the object of our study. In this hospital, the OT is open five days a week (except for emergencies), for 8 hours a day. It can happen that the duration of an operation overflows closing time. The OT comprises six operating rooms (OR). Four rooms are dedicated to visceral surgery and urology, orthopaedic surgery, orthopaedic surgery and neurosurgery, and endoscopic surgery; the two other rooms are reserved for emergency cases. They are open 24 hours a day. But in this present work, we consider that all those as versatile rooms (able to accommodate any type of surgery). Each OR has his team consists of: 2 nurses, 1 instrumentalist, 1 anesthetist nurse, 1 team leader, 1 health care assistant, 1 anaesthetist doctor who supervises two OR. If the OR is not in service, the team is going to serve in other units. According to the operation, the team is supplemented by a surgeon and his assistant. The number of operations per OR and day does not exceed 4 (except for emergencies). After one operation, the staff has 30 minutes rest. The average time of decontamination is 25 minutes. To realize a daily scheduling in the OR, some criteria are applied: medical or clinical ones and availability of equipment.

4 Approach

In order to construct the DPSO model, some hypotheses are made: the open strategic planning and scheduling are used, DPSO is focusing only on the OR, the operation day is communicated to each patient, there is the possibility to postpone one planned operation, no criterion is considered to appointing patients, the equipment in the OR is only taken into account, emergencies are not regarded, the operation duration is estimated; health care units, induction and recovery rooms are well sized. We propose a tool to help OT managers in assessing the impact of equipment breakdown by planning DPSO. The aim is to help them, by guiding their decisions at an operational tactical level. We have to assign of MA and SO, it is a similar problem to that of Bin-Packing. It is a NP-hard problem. This problem is solved by three heuristics, a

MIP model and the first heuristic variant coupled with a stochastic descent. We established first the algorithms First Fit (FT), Next Fit (NF) and Best Fit (BF). An MA can be planned at the opening time, either just before closing or in midday. So the day of medical use of a room can be cut in one or two periods. The approach is described as follows:

- Insert the MA on the weekly schedule: indicate the day, the room, the starting hour and the end hour of every MA
- For every day

– Operating day planning: indicate the day, the room and the period 1 or 2;
– Daily sequencing of the SO and the appointment of the surgeons: indicate the room and the time slot, postpone the SO in conflict the next day.

- Publishing of the weekly schedule and the untreated SO

The heuristics principle ones is to affect MA and SO respecting various constraints. We applied followings heuristic variants:

– Heuristics 1 (H1) affects SO in arrival order, according to the ascending order of the compatible rooms, days and period duration, without exceeding the maximum period use (First Fit Decreasing).
– Heuristics 2 (H2) proceeds initially by sorting SO in decreasing order of duration, then to their assignment (Next Fit Decreasing).
– Heuristics 3 (H3) proceeds by sorting SO in decreasing order of duration. Every day and before assignment, rooms are maintained sorted in ascending order of the remaining period duration. It assigns an SO to a compatible room period having the smallest availability duration (Best Fit).

4.1 Mathematical formalization

Only one mathematical model is presented, because various mathematical formalizations of the Bin-Packing problem, in one dimension are similar.

Data, parameter and variable used in the model for the main problem are

NR	number of operating rooms
ND	number of days
NSO	number of surgical operations
NMA	number of maintenance activities
DC_c	duration of SO c (including decontamination)
DM_m	duration of MA m (including cleaning-up time)
Q	duration of the room opening (8 h)
c	index of surgical operations
r	index of operating rooms
d	index of working days of the horizon
m	index of maintenance activities
Z_{mrd}	1 if MA m is allocated the d day in room r; otherwise = 0

X_{crd} 1 if SO c is allocated the d day in room r; otherwise = 0

Constraints

Respect of the room opening duration

$$(\sum_{c=1}^{NSO} DC_c * X_{crd} + \sum_{m=1}^{NMA} DM_m * Z_{mrd}) \leq Q; r = 1 \dots NR, d = 1 \dots ND \quad (1)$$

SO c is allocated in only one room and in only one day

$$\sum_{r=1}^{NR} \sum_{d=1}^{ND} X_{crd} \leq 1 ; c = 1 \dots NSO \quad (2)$$

Parameter verifier

MA m is allocated in only one room and in only one day

$$\sum_{r=1}^{NR} \sum_{d}^{ND} Z_{mrd} ; m = 1 \dots NMA \quad (3)$$

Integrity constraints

$$X_{crd},\ Z_{mrd} \in \{0, 1\}; c = 1 \dots NSO, r = 1 \dots NR, d = 1 \dots ND, m = 1 \dots NMA \quad (4)$$

Multi-objectives function

We have first to minimize the number of not allocated SO (*NNASO*), then the number of used room-day couples (*NURDC*) and finally, the minimum activity time (*MAT*)

$$NNASO = NSO - \sum_{c=1}^{NSO} \sum_{r=1}^{NR} \sum_{d=1}^{ND} X_{crd} \quad (5)$$

A Boolean function

$$Y_{rd} = (\sum_{c=1}^{NSO} X_{crd} > 0) \in \{0, 1\}, r = 1 \dots NR, d = 1 \dots ND \quad (6)$$

$$NURDC = \sum_{r=1}^{NR} \sum_{d=1}^{ND} Y_{rd} \quad (7)$$

$$MAT = \min_{r,d}(\sum_{c=1}^{NSO} X_{crd} * DC_c + (1 - Y_{rd}) * 10) \quad (8)$$

The following multi-criterion objective results from the three ones (*MCO*)

$$MCO = (NNASO * 100 + NURDC) * 10 + MAT \quad (9)$$

5 Results

5.1 Generated data

We illustrate the obtained results from generated data. It is composed of 15 preventive MA and 80 SO. Table 1 indicates following information: for the MA (number, type, start hour, end hour, room, day and the worker). Table 2 contains the data of SO: number, type and duration (Du). The decontamination time is 25 minutes. All durations are given in minutes.

Table 1. The MA data

MAnum	MAtype	Sh	Eh	Room	Day	Worker
1	2	0	45	1	1	X1
2	1	180	240	2	1	X2
3	4	450	480	3	1	X3
4	5	0	60	2	2	X4
5	7	240	300	4	2	X1
6	3	0	30	3	2	X2
7	6	90	140	4	3	X3
8	6	90	140	1	3	X1
9	3	0	30	3	3	X4
10	2	429	474	1	4	X3
11	1	0	60	2	4	X2
12	7	420	480	4	4	X1
13	5	120	180	2	5	X4
14	5	0	60	3	5	Y1
15	4	300	350	4	5	Y2

5.2 Mixed integer programming

Firstly, we generalized the mathematical model so as to deal with room-day-periods. Then we used two tools [15] (Gl and Gu) and [16] (Lp). Gl (Glpsol) and Gu (Gusek) used different solving options. Table 3 presents results with 60 seconds limited resolution duration. It indicates the number of allocated SO (Naso) and the room utilization duration (Rud). The first objective is studied using a MIP model solved with [15] and [16]. The multi-criterion objective is studied using a classic stochastic descent meta-heuristic coupled with a heuristic variant.

Table 2. The SO data

Sonum	Sotype	Du	Sonum	Sotype	Du	Sonum	Sotype	Du	Sonum	Sotype	Du
1	3	90	21	10	90	41	3	90	61	8	120
2	1	120	22	8	120	42	5	150	62	5	150
3	2	90	23	9	120	43	7	90	63	4	120
4	4	120	24	5	150	44	4	120	64	9	120
5	5	150	25	6	90	45	2	90	65	9	120
6	10	90	26	2	90	46	1	120	66	1	120
7	8	120	27	1	120	47	8	120	67	1	120
8	6	90	28	4	120	48	9	120	68	2	90
9	7	90	29	3	90	49	10	90	69	3	90
10	9	120	30	7	90	50	6	90	70	10	90
11	1	120	31	5	150	51	4	120	71	2	90
12	2	90	32	1	90	52	1	120	72	5	150
13	8	120	33	4	120	53	8	120	73	4	120
14	9	120	34	2	90	54	3	90	74	8	120
15	3	90	35	3	90	55	5	150	75	10	90
16	5	150	36	6	90	56	6	90	76	3	90
17	4	120	37	7	90	57	6	90	77	2	90
18	10	90	38	10	90	58	8	120	78	6	90
19	7	90	39	8	120	59	7	90	79	4	120
20	6	90	40	9	120	60	7	90	80	5	150

Table 3. MIP results

Horizon	Gl		Gu		Lp	
Day	Naso	Rud	Naso	Rud	Naso	Rud
1	21	2415	21	2505	21	2415
2	38	4550	42	5010	38	4580
3	57	7155	58	7390	55	7075
4	71	9335	74	9890	72	9570
5	80	10700	80	10700	80	10700

5.3 Heuristics results

Table 4 presents obtained results with the three heuristics. It gives Naso, the number of used room-days (Nurd) and the number of room day periods Nrdp).

Table 4. Heuristics results

Horizon	H1			H2			H3			SD
Day	Naso	Nurd	Nrdp	Naso	Nurd	Nrdp	Naso	Nurd	Nrdp	Naso
1	15	6	7	17	6	7	17	6	7	**21**
2	32	12	14	35	12	14	34	12	14	**40**
3	49	18	20	51	18	20	51	18	20	**57**
4	70	24	26	72	24	27	68	24	26	**75**
5	80	27	30	80	27	31	80	29	33	**80**

H1 does not affect SO better than H3 and H2. H2 affects more and uses in less Nurd than H3. When all SO are allocated, horizon 5, H1 uses less Nurd and less Nrdp than the other heuristics. In MIP, the options used for Gu allocate more SO than Gl, Lp and the three heuristics. The meta-heuristic SD generates scheduling and optimizes the criteria. H1 evaluates them for the tested scheduling. SD gives the best results.

6 Conclusion and extensions

We proposed a mathematical model for our problem and we implemented and applied exact methods and estimations on generated data. The obtained results are satisfying, especially the multi-criterion stochastic descent. Our tool of decision-making aid will be used in the hospital on real data. The prospects concern the surgical unit programming, the SO planning, the allocation of material resources and the management of the curative maintenance activities.

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