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Abstract

Operating room (OR) is one of the most critical and expensive hospital resources, and it should be managed efficiently. shortening case duration by parallel processing, training of the resident surgeons, the choice of anesthetic methods, effective scheduling are important, because of increasing demand for surgical services, hospitals must provide high quality of care and work more efficiently with limited resources(Human , material).

In this context, we study the optimization of human and material resources in hospital,we focus on four critical resources(operating rooms and surgeons and recovery rooms and hospitalization beds).

Our goal is shortening surgical patient wait times in exception situation, and increasing patient admissions by optimizing the human and martial resources.

Our research consists on two phases:first, sizing the critical resources using integer programming with simulation, second, scheduling and assignment of operating rooms appointments based on deterministic data considering single-act surgery , we adopted workshop scheduling on operating block a two-stage flow shop hybrid and we proposed a scheduling algorithm.

Our proposed algorithm (modified ASC1) shows better results than original ASC1 proposed by (Nouaouri, 2010) , but we can not prove that our algorithm is better in every way because our limitation of implementing linear model.

The implementation of linear model considering the additional constraints can validate the optimization of the additional resources and then we can do a complete comparison that it can prove our algorithm better than original ASC1.

Keywords: *Help with the decision*, *Operating room scheduling*, *Linear programming*, *Hospital Management*, *operational programming*, *Human and Material Resources Management*, *flow shop hybrid*
.

Résumé

La salle d'opération est l'une des ressources hospitalières les plus critiques et les plus coûteuses, et elle devrait être gérée efficacement. Raccourcir la durée des cas par traitement parallèle, formation des chirurgiens résidents, choix des méthodes d'anesthésie, ordonnancement efficace sont importants, car les services chirurgicaux étant de plus en plus demandés, les hôpitaux doivent fournir des soins de haute qualité plus efficacement avec des ressources limitées (humaines, matérielles).

Dans ce contexte, nous étudions l'optimisation des ressources humaines et matérielles en milieu hospitalier, nous nous concentrons sur les ressources critiques (salles d'opération et chirurgiens et salles post-nterventionnelles et lits d'hospitalisation).

Notre objectif est de raccourcir les délais d'attente des patients en chirurgie en cas d'exception et d'augmenter les admissions des patients en optimisant les ressources humaines et martiales.

Nos recherches portent sur deux phases : d'une part, dimensionnement des ressources critiques en programmation entières avec une simulation, d'autre part, ordonnancement et affectation des rendez-vous en salles d'opération à partir de données déterministes pour la chirurgie d'une seule acte. Nous avons adopté l'ordonnancement de l'atelier sur le bloc opératoire "two-stage flow shop hybrid".

Notre algorithme proposé (ASC1 modifié) montre des meilleurs résultats que l'ASC1 original proposé par (Nouaouri, 2010), mais nous ne pouvons pas prouver que notre algorithme est meilleur dans tous les cas car on a limité de l'implémentation du modèle linéaire.

La mise en œuvre du modèle linéaire en tenant de compte des contraintes supplémentaires peut valider l'optimisation des ressources supplémentaires et ensuite nous pouvons faire une comparaison complète et cela peut prouver que notre algorithme est meilleur que l'ASCI original.

Mots clés: *Aide à la décision*, *ordonnancement des salles opératoire*, *Programmation linéaire*, *Gestion hospitalière*, *programmation opératoire* , *Gestion des ressources humaines et matérielles*, *flow shop hybrid*.

ملخص

غرفة العمليات هي واحدة من موارد المستشفى الأكثر أهمية وكلفة، ويجب أن تدار على نحو فعال. تقصير المدة الكلية لإجراء العمليات الجراحية عن طريق العلاج المتوازي ، تدريب الجراحين ، اختيار طرق التخدير ، الجدولة الفعالة مهمة ، بسبب الطلب المتزايد على الخدمات الجراحية ، يجب على المستشفيات توفير رعاية عالية الجودة بشكل أكثر فعالية مع مراعاة الموارد المحدودة (البشرية والمادية). في هذا السياق ، نركز على تحسين الموارد البشرية والمادية في المستشفى ، ونحن نركز على الموارد الحيوية (غرف العمليات والجراحين وغرف ما بعد التدخل وأسرّة الاستشفاء) هدفنا هو تقصير أوقات الانتظار الجراحية للمرضى ، وزيادة قبول المرضى من خلال تحسين الموارد البشرية والمادية ، ونأخذ بعين الإعتبار حالات الإستثنائية وهي وقوع الكوارث. يتكون بحثنا على مرحلتين: أولاً ، تحديد حجم الموارد الحيوية الأساسية لإجراء العمليات باستخدام البرمجة الخطية والمحاكاة ، ثانيا، تحديد مواعيد وتخصيص غرف العمليات وغرف الإنعاش ثم أسرة الإستشفاء استنادًا إلى بيانات حتمية مع مراعاة ظروف إجراء الجراحة، واعتمدنا جدولة ورشة العمل على غرف العمليات الجراحية ذات طابقين ($hyprid\ shop\ Flow$)، الخوارزمية المقترحة $ASC1$ المعدلة تظهر نتائج أفضل من $ASC1$ الخوارزمية الأصلية من قبل ($Nouaouri, 2010$) ، ولكننا لا نستطيع أن نثبت أن خوارزميتنا أفضل في كل شيء لأن لدينا حدود لتطبيق النموذج الخطي. إن تطبيق النموذج الخطي بالنظر إلى القيود الإضافية قد يثبت صحة اختلاف الموارد الإضافية وبعد ذلك يمكننا إجراء مقارنة كاملة وقد يثبت أن خوارزمياتنا أفضل من $ASC1$ الأصلية.

كلمات مفتاحية

مساعدة في القرار، جدولة غرفة العمليات، البرمجة الخطية، إدارة المستشفيات، برمجة العمليات إدارة تدفق الموارد المادية والموارد البشرية

Acknowledgment

It is not by tradition that this page appears in the preamble of this thesis, but it is rather a moral duty and a sincere recognition that we are driven to do it.

We will indeed be ungrateful if we do not express my gratitude and we are grateful to all those, from near or far,

We have the immense honor of thanking "ALLAH" for helping us and giving us patience and courage during these long years of study.

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Introduction

An operating theater also known as an operating room or operating suite is a facility within a hospital where surgical operations are carried out in a sterile environment , the increasing demand for surgical services faces the need to improve the efficiency, while the OR schedule causes high peak requirements for beds on surgical wards, waiting lists for surgery remain long and OR-planners deal with increasing workloads due to a multitude of equipment related constraints.All activities in the OR are centered around the best possible care of the patient.

The peculiarity of the hospital system necessitates making decisions and executing quick actions,faced with the optimization of the human and material resources necessary to be able to treat the maximum of patients and give the patients appointments soon as possible.

There is a lot of work dealing with problems of organization and optimization of hospital systems They are generally based on methods and tools from the manufacturing sector, Most of this work focuses on the optimization of the two critical resources operating rooms and surgeons .

Our study is on the optimization of the operating rooms and surgeons with two additional resources, Recovery rooms and hospitalization beds. Our goal is shortening surgical patient wait times in exception situation, and increasing patient admissions by optimizing the human and martial resources.

We present our study with a presentation of the context in which our memoir works .In Chapter 1, we describe the functionality of the operating theater which constitutes one of the most important sectors ,we present operating programming , the existing activities, resources and flows of the operational process.

In Chapter 2, we present a related work dealing with our problematics. we distinguish three headlines (1) problems of sizing human and material resources,(2)appointment programming , (3) Operating rooms scheduling .

Chapter 3 presents the resolution methods and the results of the experimental phase that was conducted. we present the production system with main terms and the adaptation of workshop scheduling on operating theater then sizing the critical resources existing in the literature, whose objective is to minimize only the completion date of jobs (make-span), without taking into account the uncertainties on execution times. finally the results of scheduling and assignment predictive interventions in the operating rooms.

Chapter 1

Context & Problematics

1.1 Introduction

The operating block is an essential element of a hospital's , because of its high technicality, the financial investment that it represents, the importance of the human resource it mobilizes, the stakes in terms of patient safety. In the context of activity pricing, it is also a source of revenue for institutions. The operating block is a highly strategic place for hospitals, the fact that it involves human resources such as surgeons, anesthesiologists, specialized nurses and various material resources, in this chapter we present operating programming and the scheduling approaches of operating block and patient flow process taking into account exceptional situation.

1.2 Hospital Information System

HIS is a special case of information system.The information system of a health facility can be defined as the set of information, their circulation and treatment rules necessary for daily operation, its management and evaluation methods. and its strategic decision-making process. **HIS** is one of the components of the health information system The **HIS** is inserted in the hospital organization in perpetual evolution; it is able, according to predefined rules and operating procedures, to acquire data, to evaluate them, to process them by computer or organizational tools, to distribute information containing a strong added value to all internal or external partners of the establishment, collaborating in a common goal-oriented work, namely the care of a patient and recovery.

1.3 Operating Block

1.3.1 Definition

An operating room is a very specific part of the hospital. It is an essential element of the technical platform of a hospital. It is in this structure that the surgical operations take place. It is a clean and secure space that only health professionals have access to. Generally located in the center of a hospital or department, the operating theater is accessible to surgeons, doctors, anesthetists, nurses, caregivers, radiologists and stretcher bearers. Operating theaters are subject to strict regulations and many controls.

There are two types of operating theater: mono and multidisciplinary. A mono-disciplinary operating theater is dedicated to the surgical activities of a given department (Orthopedics, Ophthalmology, etc . . .). This type of block is generally characterized by a low level of standardization. However, nowadays hospitals tend more and more towards the sizing of resources and opt for multidisciplinary blocks able to treat patients from different departments.

1.3.2 Description of the Operating Block

The operating block is at the interface of many activities with limited resources: surgery, anesthesia, radiology and biology.The operating block, consisting of human and material resources.

Material resources : contains operating rooms and recovery rooms , the operating theater represents a universe in which appointments are performed (Cuvillier and Breack, 1997).
-The operating rooms are where the surgical procedures, properly speaking, are performed. They must be equipped with the surgical and anesthetic equipment necessary for the proper course of the surgical procedure.
-The recovery room contains beds to accommodate patients operated in the wake phase, and medical devices to monitor the patient's condition.

Human resources : The operating block is also a place of high concentration of human skills. Indeed, a surgical appointment requires the involvement of a large number of actors from different specialties (surgeons, anesthetists, nurses, stretcher bearers ...) who intervene in the same place, in a sequential or parallel way, to achieve a set of activities using medical equipment.

1.4 Management of Operating Block

The management of the operating block should be able to evolve rapidly towards centers of responsibility in the public establishments "A more efficient organization of operating theaters is needed to make better use of available human and technical resources and improve their productivity. ", by (Kharraja, 2003).

In order to show the interaction of the operating theater with the rest of the sectors of the hospital, we present the different phases of the operating process. This process can be broken down into three major phases:

The pre-operative phase : Extends from the care of the patient until its transfer to the operating block for the intervention. During this phase, the patient undergoes surgical and anesthetic consultations. During this phase, a "provisional" intervention date is proposed to the patient. This date may or may not be modifiable according to the operating block policy.

The intra-operative phase : Corresponds to the patient's stay in the operating block. It covers the time the patient enters the block until he leaves the recovery room. The day of the procedure, the patient is first carried by stretcher bearers from his room in the hospital to the operating room, he will then be anesthetized and finally operated by a surgical team. Note that various sterilization and consumables preparation activities are performed just before and after the procedure. Once the surgery is over, the patient is transferred to the recovery room. He stays there until the anesthetist authorizes him to return to his room where he is transferred to the intensive care and resuscitation unit.

The post-operative phase : from the recovery room, the patient is transferred either to his / her room or to the intensive care and resuscitation unit if there are any complications. This phase covers all the necessary care following the intervention. For a more detailed description of the different phases of the operational process as well as the different resources (human and material) involved in the realization of each of these phases. we are referring to the work of (Chaabane et al., 2003). According to the description of the operating process, it is clear that the operating theater also represents an interface between several other sectors of the hospital, such as hospitalization services, the intensive care unit, sterilization activities, stretcher and logistics (supply of consumables and various materials).

1.5 Operating Programming

The operating block is not only the largest and most expensive sector in most hospitals, but it is also the most complex service to manage, the large number of actors, the difficulty in standardizing and coordinating surgical procedures.
In order to manage and coordinate the various activities of the operating block, hospitals use a management tool called "operating programming" (Kharraja, 2003; Chaabane et al., 2003; Jebali, 2004).

Therefore, it consists of constructing a provisional schedule of surgical appointments to be performed during a period, based on the patients' requests. In the same vein, also requests from surgical services, the period is usually one week, (Kharraja, 2003).

More specifically, the operating program is a kind of agenda specifying for each operating room the patients who will be operated, their order and their hours of passage. The time horizon can range from one day to several weeks. The programmed appointments can come from one or more surgical services depending on the type of mono or multidisciplinary block. Intervention requests may be known one or more months in advance, as in the hour preceding the establishment of the operating program according to the policy adopted in the block.

In general, we can say that the operating planning activity consists in organizing the activity of the various operating rooms in the best possible way so as to use the operating theaters as efficiently as possible (minimizing the periods of idle time and the use of overtime), to effectively use the recovery rooms and achieve a low level of cancellation.

So it can be said that the operating program represents not only an internal management tool in the operating room, but also a source of information for other activities of the hospital, such as hospitalization services, sterilization activities, stretcher, etc ...

1.5.1 Elements of the Operating Program

Important elements for an operating program

1. Number of operating rooms.
2. Number of specialized surgical equipment.
3. Availability of time slots reserved for surgeons.
4. Estimated operating times.
5. Limitation of rooms related to surgical equipment.
6. Approach of operating programming in a hospital.
7. Normal opening and closing time of the operating theaters.

1.5.2 Operating Programming Approaches

The development of the operating program is a complex task, the process of which varies considerably from one hospital to another. However, the literature reports three approaches to program construction (Patterson, 1996; Kharraja, 2003): block scheduling ,open scheduling , and programming by allocation and adjustment of ranges ("modified block scheduling").

1.5.2.1 Block Scheduling

Programming by allocation of time slots is an operating program corresponding to an assignment of an operating room during a period fixed to one and only one surgeon. The problem to be treated for this type of operating programming consists of two parts:
- Prior allocation of time slots to each surgeon (or surgical units) according to their availability and preferences (Magerlein and Martin, 1978; Przasnyski, 1986; Blake and Carter, 1997).
- Filling of time slots: planning and scheduling of appointments according to the surgeon in their reserved time slots.

During this period, only the surgeons in question can plan and schedule their appointments within the time slots of the rooms that have been assigned to them.
As soon as these time slots are assigned to a surgeon for a given period, they can not be changed

except during negotiations and redeployments of time slots by the management of the hospital (every three months or annually). Fig.1.1 shows an example of a time table assignment schedule from Tuesdays and Wednesday for two operating rooms and four surgeons.

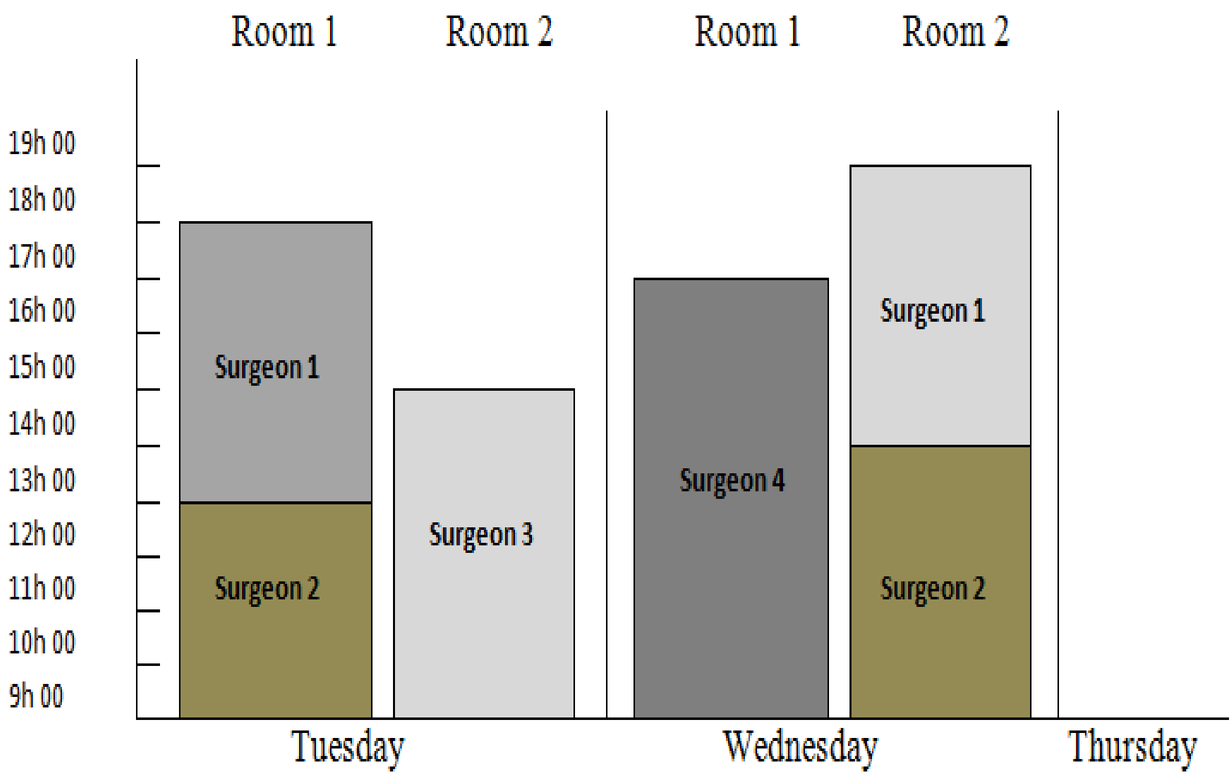

Figure 1.1: An example of a schedule Tuesdays and Wednesday for the 2 operating rooms of the block operating (block scheduling) by (Kharraja, 2003)

This type of operative programming is becoming more and more common in hospitals. It has its advantages and disadvantages. As soon as the time slots have been established, the planning of the appointments is easier than other types of operative programming and moreover, there is no risk for a surgeon to operate two patients at the same time or in two rooms. Moreover, the disadvantages are:

1. The difficulty of constructing the master plan for the allocation of time slots. The placement and the size of the time slots are in fact the determining factors of the quality of allocation of the time slots. Over sized beaches will bring comfort for surgeons but lead to poor performance and just undersized beaches risk, in case of hazards, to cause tension between surgeons when changing ranges.

2. The rigidity of the program requires surgeons to work at a constant volume. At the risk of seeing the productive performance of the block crumble, it is the surgeons "responsibility" to optimally fill the ranges reserved for them and to respect the duration of planned appointments.

3. The loss of flexibility and the degradation of the block's productive performance. Because time slots are fixed, some surgeons may have to refuse appointments while others do not fill in their

time slots.

1.5.2.2 Open Scheduling

Contrary to the block scheduling strategy, open scheduling is an operating program consisting of constructing appointments allocation schedules for a planning period without taking into account the preferences of the surgeons. Two approaches (Kharraja, 2003) are applied in hospitals this type of

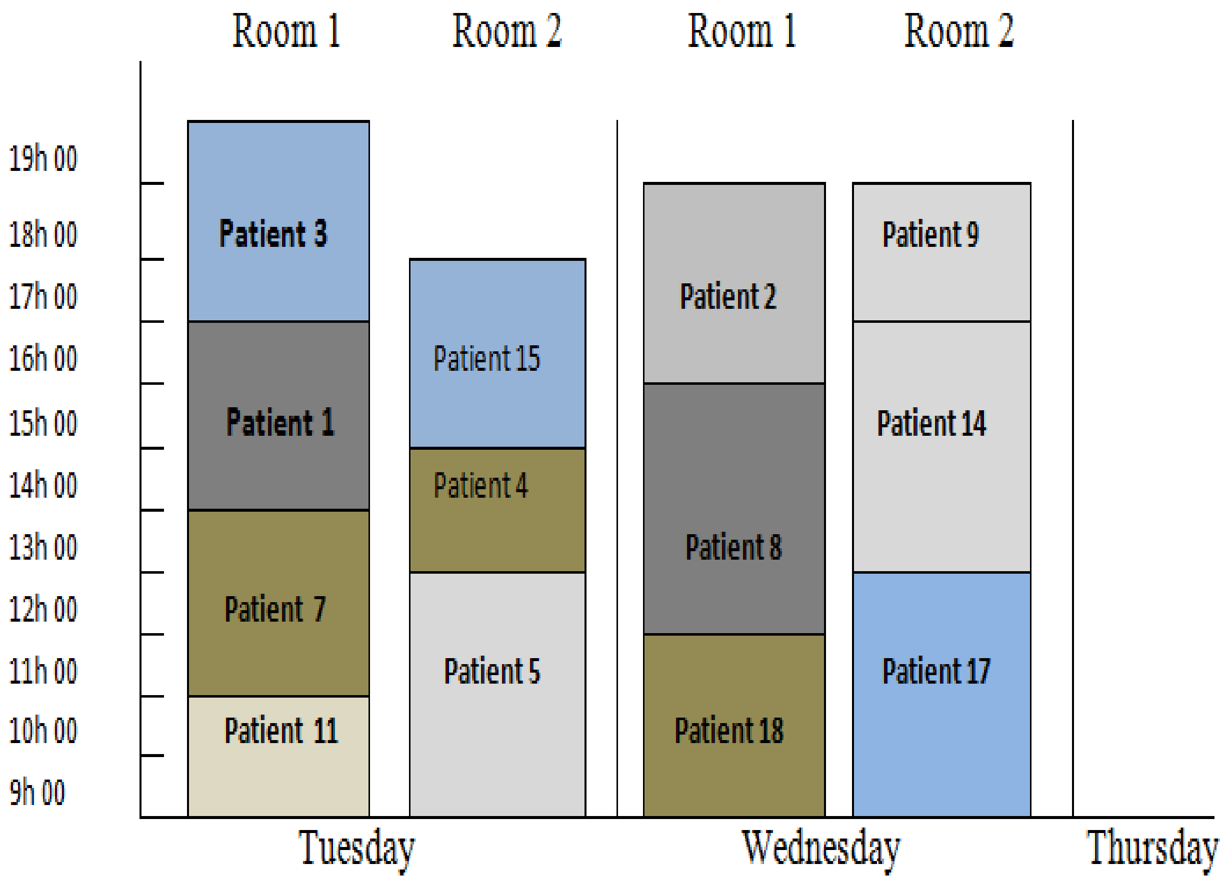

Figure 1.2: An example of a schedule for Tuesdays and Wednesday for the 2 operating rooms of the block (open scheduling) (Kharraja, 2003)

programming to manage the planning of allocation of appointments in a hospital: The Patterson First Come First Serve (FCFS) and the negotiation between actors.

a) **First Come First Served :**

This rule applies throughout the planning period. It is a "collective agenda" linked to an information system that allows to estimate the duration of appointments and to insert new appointments in the operating program.

This agenda can be managed by the secretariats of the different surgical services. In case of the placement of an appointment in an overtime, the block manager is alerted, which triggers a regulatory process whose objective is to obtain a negotiated resolution solution. This technique has the advantage of being extremely simple to implement. This simplification of the construction of the schedule, however, brings disadvantages.

The major disadvantage is that this method favors surgical services that have a plannable activity in the medium and long term, for example ophthalmology, plastic surgery, and disadvantages other surgeons who can not predict their agenda in the medium term. Moreover, as pointed out (Kontak-Forsyth and Grant, 1995), this practice generates a high rate of programming, an under-utilization of resources, significant time overruns and generates strong tensions between the surgeons or the surgical services.

b) **Negotiation Between Actors :** Given the disadvantages of the FCFS strategy, the program can be developed normally under the direction of the head of the operating theatre following a process of negotiation between the different actors. (Kharraja, 2003), presents a model of process of construction of the operating program according to his study carried out at the CHU (University Hospital Centre) of Croix Rousse (Lyon).

1.5.2.3 Modified Block Scheduling

The allocation and range adjustment programming model" modified block scheduling" is a combination of block scheduling and open scheduling strategies. This strategy is based on block scheduling principles but offers more flexibility due to its consideration of several factors:

a) Free time slots to absorb any hourly overload or work overload. Generally, these ranges are assigned as for the "open scheduling" by the negotiation between the surgeons and the manager of the block.

b) The opportunity for a surgeon to give an unused time (or part) to other surgeons. So if the surgeons or the surgical units do not use enough their reserved time slots in an agreed period, for example 48 - 72 hours, they no longer have priority over these time slots and the block manager can then adjust them for to benefit other surgeons or surgical units (Chaabane et al., 2003).

1.6 Operating Block Scheduling

Given a set of planned appointment for a given day, scheduling consists of setting the order and time of passage of scheduled patients as well as the different resources mobilized. Planned interventions can be previously assigned to specific operating rooms; this assignment can be questioned or not, according to the scheduling approach used.

The resources considered are essentially the operating room and the beds in the recovery room. The goal of scheduling is usually to minimize the make-span (C_{max}, time of completion of the last operation) of the recovery room and / or operating rooms. This objective is equivalent to minimizing the time overruns in operating theaters and / or in the recovery room.

1.7 Problematics

In the health care system, especially the operating block, the aim is to provide care to all patients at the earliest possible time,most important is the patient must be satisfied. with the resources provided for this service works efficiently . All resources are exploited in working hours. There is no unexploited resource. We aim to build a system that runs all the human resources and equipment in perfect ideal and it can help with decision maker to give appointments to patients soon as possible and with great capacity to receive patients.

Unfortunately, There are many constraints limit us to reach our goal, including that the resources are limited and we has to improve it. Also, the problems that confront us are that there is no clear planning is the best or most effective for managing the critical resources, not to mention the ideal.

however,The operational programming consists in answering the requests for appointments to be programmed. It takes place over a period of on week and concerns the entire care unit (block and services) On the basis many problems accrue such as optimizing the human and material resources , planning of the appointments, the opening hours of the rooms, the schedule of occupation of the beds and the agenda of surgeons, one carries out the planning of the block,scheduling defines the last management step from planning of the block, it determines the order of passage the Appointments in each room of operations ,considered a NP-HARD problem,improving information systems is critical to do all the above.

In general, the structure of our problematics can be described as below: the problem of scheduling for one day where the constraints on the availability of beds in the recovery room will have to be taken into account. This is a two-stage problematics: operating rooms in the first floor and wake up beds in the second floor. The goal of this scheduling problematic is the minimization of the total cost of hours in the operating and recovery room.

1.8 Conclusion

We presented the context of the hospital establishments, especially that of the operating block. Since the operating theater is the most expensive sector of the hospital.

We note that operating programming is very complex task considering the planning of appointment and sizing the critical resources and scheduling in exceptional situation are major problematics in operating theater considering all the elements it implies and the constraints. Comprehensive and complementary approaches have been proposed to provide support for operating programming. In hospitals different strategies are used in operating blocks and it's really no approach is better than another.

Chapter 2

Related Work

2.1 Introduction

On our study we interested of investigation and find the best solutions for managing an operating block in exceptional situation, we have many problems to solve such as how to find the best time for opening the operating rooms?. How to manage the operating block under all constraints?. How to schedule the Appointments that we programmed?. In this chapter we present some works that touch a parts of our problematics and we tried to compare the solutions and follow the best approaches.

2.2 Sizing Critical Resources

Hospital systems are complex systems involving a large and varied number of human and material resources.
(**Hammami, 2006**) ,shows that the sizing of hospital systems is a rather difficult task for two reasons: the multiplicity of care flows, and the stochastic nature of the durations of activities composing these flows.

Sizing problems are often encountered in the literature in order to optimize critical resources. Most of this work is based on four resolution approaches: Markov chains, mathematical programming, queuing theory and simulation.

Markov chains are used by (**Kao and Tung, 1981**) to analyze the different flows of patients in care units and estimate their hospital stay time. Thus, it is possible to calculate the necessary resources in care staff and in hospital beds. (**Tancrez et al., 2011**) study the disturbance caused by the intercalation of emergencies in the operating program. This work makes it possible to size the number of rooms dedicated to urgent cases.

Several works use mathematical modeling to solve the problems dealt with (**VISSERS, 1995**). (**Vissers, 1998**) offers a three-step model. The first step is to look for the number of patients admitted to the hospital, the optimal number of hospital beds, nursing staff and operating rooms. The second step is to allocate these resources to the various specialties. Finally, the last step attributes the remainder of the means to specialties according to the critical resources already dimensioned.

To understand and analyze the functioning of hospital systems, simulation is widely used in literature (**Dumas, 1984**; **Harper and Shahani, 2002**; **Kim and Horowitz, 2002**). In this context, some work has been interested in sizing the number of operating rooms and wake-up beds (**Dussauchoy et al., 2003**), as well as beds in intensive care units .

(**Nouaouri, 2010**) The authors interested in operational programming in exceptional situations, resolution approach is based on two integer linear programs (P_1) and (P_2) . (P_1) The first model calculates the minimum number of operating rooms needed to treat all patients in time under constraints of the earliest arrival dates of surgeons. (P_2) The second model allows the best use of slices times of surgeons so that the proposed dimensioning is always optimal. Because of the size of the problem studied they could not consider a multi-objective approach that integrates both, the optimization of the number of operating theaters and the dates of arrival of surgeons at the latest.

A computational experiment has been preformed for the first and second model, in each case they show: the calculation time in seconds (CPU (s)), the number of constraints (N_{Cont}), The number of variables (N_{Var}), The number of repetitions (N_{Iter}) (Minimum number of rooms) and ST * (maximizing time margin for surgeons) for (P_2). $C_{max}(h)$ The total duration of the driver expressed in hours (h) and (TM) is the average occupancy rate of the operating rooms, and the results on Figure 2.1.

Instances	NO_c^*	$C_{max}(h)$	*TM(%)*	*CPU(s)*	*N.Cont.*	*N.Var.*
$P25.R_1$	5	10	67.00	0.1	63148	2104
$P25.R_2$	5	10	67.00	0.1	63148	2104
$P25.R_3$	5	10	67.00	3	63148	2104
$P25.R_4$	7	8.5	56.30	6.1	63148	2104
$P25.R_5$	7	8.5	56.30	2.5	63148	2104
$P50.R_1$	7	14.5	72.91	6	572845	7006
$P50.R_2$	7	14.5	72.91	9	572845	7006
$P50.R_3$	7	14.5	72.91	12	572845	7006
$P50.R_4$	9	12	68.52	16	572845	7006
$P50.R_5$	9	12	68.52	35	572845	7006
$P70.R_1$	10	17	59.41	73	1409158	13027
$P70.R_2$	10	17	59.41	112	1409158	13027
$P70.R_3$	10	17	59.41	140	1409158	13027
$P70.R_4$	11	15	61.21	148	1409158	13027
$P70.R_5$	11	15	61.21	176	1409158	13027

Figure 2.1: Results of model 1. (Nouaouri, 2010)

They also did an other experiment, calculation time in seconds (CPU (s)), the number of constraints (N_{Cont}), the number of variables (N_{Var}), the number of iterations (N_{Iter}), the value of the objective function (F.Obj.2), the percentage of patients treated (P (%)), the total duration of the operating program ($C_{max}(h)$) and the operating room occupation rate TON (%). In addition, they calculate for each instance the percentage of new patients treated in the case of pooling critical resources GN (%).

Problèmes tests	CPU (s)	N.Cont.	N.Var.	N.Iter.	F.Obj.2	P(%)	$C_{max}(h)$	TON(%)	GN(%)
$P25.4.R_1$	0.01	6841	5073	4289	25	100	12	69.79	4,2
$P25.4.R_4$	0.01	6841	5073	5427	25	100	12.5	67.00	8,3
$P50.4.R_1$	42	17519	12571	9255	41	82	13.75	90.16	12,5
$P50.4.R_4$	38	17519	12571	9422	41	82	15.25	89.52	16,7
$P50.6.R_1$	56	17519	12571	6875	50	100	14.5	85.05	12,5
$P50.6.R_3$	35	17519	12571	6145	50	100	15	82.22	12,5
$P50.6.R_4$	72	17519	12571	12577	50	100	14	88.09	16,7
$P50.6.R_5$	81	17519	12571	12577	50	100	14	88.09	16,7
$P70.4.R_1$	104	24484	20583	18962	46	66	15.5	96.12	12,5
$P70.4.R_4$	95	24484	20583	13369	46	66	16	96.87	16,7
$P70.6.R_1$	1378	24484	20583	153041	61	87	15.5	87.12	25
$P70.6.R_3$	586	24484	20583	27276	61	87	16	88.96	25
$P70.6.R_4$	847	24484	20583	50797	60	86	16	88.96	25
$P70.6.R_5$	620	24484	20583	43920	60	86	15.5	86.18	25
$P70.8.R_1$	25	24484	20583	5432	70	100	14,75	85.59	20,8
$P70.8.R_3$	18	24484	20583	89685	70	100	14,75	85.59	20,8
$P70.8.R_4$	172	24484	20583	13151	70	100	15	84.16	25
$P70.8.R_5$	181	24484	20583	14541	70	100	17.5	72.14	25

Figure 2.2: numeric results of simulation (Nouaouri, 2010)

They find that over all instances, the calculation time varies between 0.01 seconds (P25.4.R1) and 22.96 minutes (P70.6.R1). With a duration of less than or equal to 1 minute in 44% of cases and less than or equal to 5 minutes in 67% of cases.

(Ramis et al., 2001) studied the use of simulation for sizing the resources needed for an outpatient surgery center in Chile. The authors modeled the patient process throughout his stay in the outpatient surgery center. The patient arrives in the morning and leaves in the evening of the same day. His path has been identified by the different entities composing the system through which he passes. There are four main entities: the admission infirmary, the preparation and post-Appointment chambers where the nurses prepare the patient before his Appointment and monitor his post-Appointment state after the Appointment, the operating theaters and finally the beds in the recovery room. The authors, through this identification of the patient journey, want to model the use of future equipment to maximize the number of admitted patients and know the resources needed for Appointments.
They used the five-month data estimated by different distributions that will be used by the mathematical model. These data are completed and validated by the surgeons, anesthesiologists and nurses of the center. They selected 15 different pathologies to study them. They then defined the following durations: on the one hand the length of stay in the operating room and the duration of preparation of the patient who depend on the type of pathology, on the other hand the duration of admission, the duration of cleaning and the duration of patient awakening that are the same regardless of the pathology. For each of these durations distributions laws have been defined. Nurses and doctors are considered versatile resources. The center starts at 7:00 and must close at 14:00 and patients arrive every 30 minutes. The model is implemented under ARENA and the authors presented an animated screen illustrating the center with all its resources and the running of the simulation. Dynamic statistics are

presented: number of patients in the system, percentage of occupancy of the different entities of the center, The authors described the model but did not present it. Physicians and nurses validated the model results that were subsequently compared against current hospital data. Thanks to these simulations the authors have studied the current functioning of the system and the improvement alternatives of which they give an example. Currently the rooms for preparation and post-Appointment care are the same, so a patient is assigned to one room during his stay in the center. During the Appointment of a patient, his room of preparation remains unavailable until his return for the post-Appointment care and his final departure. The authors propose to dedicate the rooms, some for the preparation and the others for the post-Appointment care. They observe an increase in the number of admitted patients (at most 10) without exceeding the closing time.

2.3 Appointments programming

The planning problem involves assigning surgical Appointments to operating rooms over a planning horizon (usually one week). The objective is generally to minimize a set of costs (under or over the use of operating rooms, hospitalization or waiting, under resource constraints such as any Appointment must be assigned to one and only one time slot of a day and each time slot of each day can be assigned to one and only one Appointment and the sum of the durations Appointments must not exceed the hourly availability of the operating room for a given day and the Appointment time per day of each surgeon must not exceed the duration of the surgeon's availability for the day in question and the number of Appointments requiring a bed must be less than the number of beds available at the reception service during the period of hospitalization.

The works dealing with this problems, most often involve mathematical programming tools (integer or mixed linear programming, multi-objective programming, heuristics). However, we find also some works using tools such as simulation.

(Chaabane, 2004), On this study identify the management problem in case an operative block was solved domain manufacturing, they use linear model like tool for programming was proposed by (Guinet and Chaabane, 2003), the constraints taken into account is the hours of opening the operative block with supplementary hours and hospitalization date for the patient and Appointment date, operative period, horizon time.

The objective is to minimize the exploitation of operative block, this tool based on heuristic issues of Hungarian method.

A computational experiment has been preformed, The number of Appointments is N: [10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90], the number of rooms operations is: [1, 2, 3] and the number of available beds is: [15, 30, 60]. A two-week horizon was considered with Appointments of an average duration of 3 hours and a standard deviation of 2 hours. The start date at the earliest and the end date at the latest are 4 days and 7 days average and 3 days standard deviation, respectively. The duration of stay is equal to 2 days if the duration of Appointment is less than or equal to 3 hours, otherwise to 3 days, the results on Figure.2.3

Nombre d'interventions	Capacité en nombre de salles	Nombre de lits	Pourcentage de problèmes résolus	Ecart maximum	Ecart moyen
10	1	15	97%	35,71	6,14
15	1	15	84%	26,09	8,46
20	1	15	50%	18,75	10,46
25	1	15	6%	24,24	18,00
30	1	15	3%	14,29	14,29
25	2	15	97%	50,00	8,79
30	2	15	75%	26,47	11,42
35	2	15	41%	**50,00**	20,85
40	2	15	6%	21,05	17,19
30	2	30	88%	28,57	7,96
35	2	30	69%	32,43	12,53
40	2	30	56%	45,45	17,37
45	2	30	22%	18,60	12,37
50	2	30	6%	25,42	22,71
55	2	30	9%	18,18	14,15
60	2	30	13%	17,65	15,62
45	3	30	84%	25,00	10,80
50	3	30	91%	36,00	14,23
55	3	30	88%	30,77	14,25
60	3	30	66%	30,00	17,22
60	3	60	81%	26,47	14,74
65	3	60	75%	28,57	17,73
70	3	60	72%	30,38	17,49
75	3	60	78%	23,33	14,49
80	3	60	72%	22,12	18,57
85	3	60	66%	24,53	17,78
90	3	60	72%	21,62	14,67
Moyennes				**27,84**	**14,45**

Figure 2.3: Programming Appointments by (Chaabane, 2004).

The quality of the tool was judged on two criteria: the number of fully resolved problems (Percentage of fully resolved problems) and the difference in the cost of the proposed solution with respect to a lower limit of the optimum, it is based on a break-up of Appointments into unitary sub-Appointments that makes it possible to no longer take into account capacity constraints.

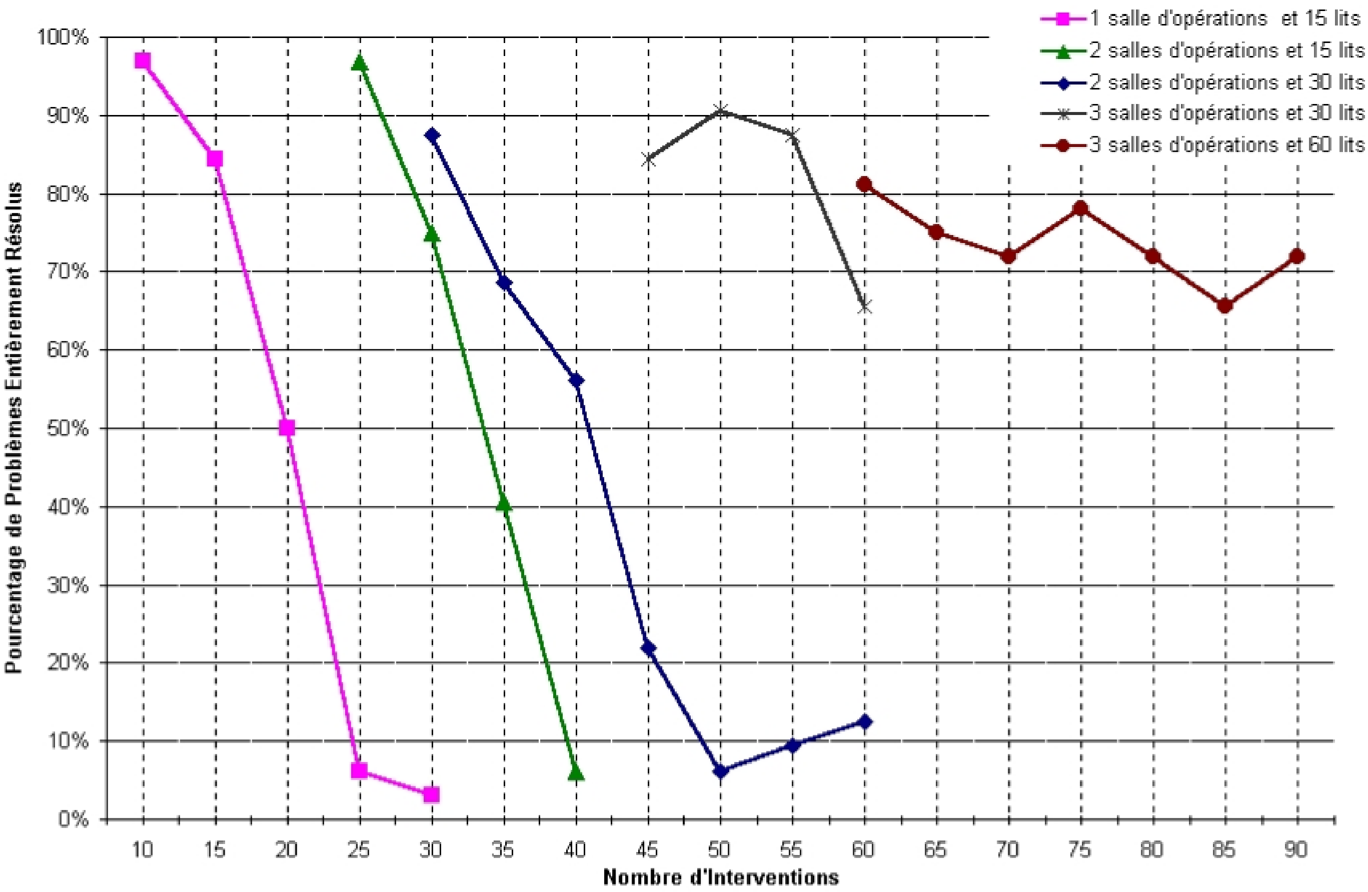

Figure 2.4: Programming Appointments-percentage of problems fully resolved by (Chaabane, 2004).

(**Dexter et al., 1999**), propose to use "off-line" bin packing heuristics for Appointment planning and the addition of additional Appointments in an already established schedule. The technique is to assign Appointments to operating rooms (or time range) by maximizing the filling of each room and minimizing the number of rooms used. The constraints taken into account relate to the capacity of the operating rooms. However, these constraints may be slightly violated (allow hourly exceedances of the order of 15 minutes). The authors compare different classical heuristics of bin-packing and conclude that the heuristic "best-fit Decreasing" is the best, It ensures the best occupancy rate of the rooms.

(**Fei, 2006**), address the problem of planning a set of Appointments scheduled for one week in an operating theater, on a set of identical operating theaters, with the objective of minimizing the costs of overtime and underutilization of the operating theaters. The constraints considered are the deadlines for Appointments and the maximum capacity of operating theaters. The authors use a column generation approach to solve the problem; they propose an exact method (branch-and-price) as well as a heuristic.

(**Hans et al., 2008**), process planning with the objective of maximizing the use of operating theaters and minimizing the risk of overtime due to uncertainties in response times. The authors propose to assign a safety time to each operating room to absorb the variability of operating times. The "security time" in a given room is a function of the variability of the hours of Appointments assigned to the room. The constraints taken into account when assigning patients concern the adequacy of operating rooms and the availability of medical teams. The authors propose several heuristics for solving the problem. However, the authors assume that the duration of Appointments assigned to a given room have the same variance and that the sum of these durations follows a normal distribution, regarding emergency surgery it is not considered.

2.4 Operating Room Schedule

The scheduling defines last step of the operating room management process. From the planning of block, it determines the order of passage the Appointments in each room of operations, the problem is proven to be NP-hard. Scheduling consists of giving a pass order planned appointments on the different resources of the operating theater. There is two categories of work according to the resources considered:

- **Ordering centered on the operating rooms :** the resources are essentially is the operating theater.
- **Operating Room scheduling :** the resources considered are operating rooms, recovery room beds, and possibly other resources such as stretcher bearers, cleaning crews, surgeons, nurses, and intensive care room. Given patients planned for each operating room, the problem scheduling consists in determining the sequence and hours of passage (starting time) of the patients. We're interested in scheduling several operating rooms.

(**Chaabane, 2004**), the scheduling problem has been identified as a two-stage hybrid flow-shop problem without waiting time if they do not take into account the bearers.when they consider the bearers, the problem of scheduling Appointments is identified with a three-stage hybrid flow-shop with precedence constraints. They experimented the following heuristics: **CDS:** Campell, Dudek and Smith, **SZW:** Szwarc, **NEH:** Nawas, Enscore and Ham, **NEHP:** Nawas, Enscore and Ham with simplified Palmer index . Other weights of the NEH heuristic were tested (Dannenbring weight: (j) and $(M-j+1)$) and gave less improvements.

According to three plans of comparison: first plan , To compare for each heuristic the results obtained for each of the rules of assignment FAM and LBM the results on Figure.2.6

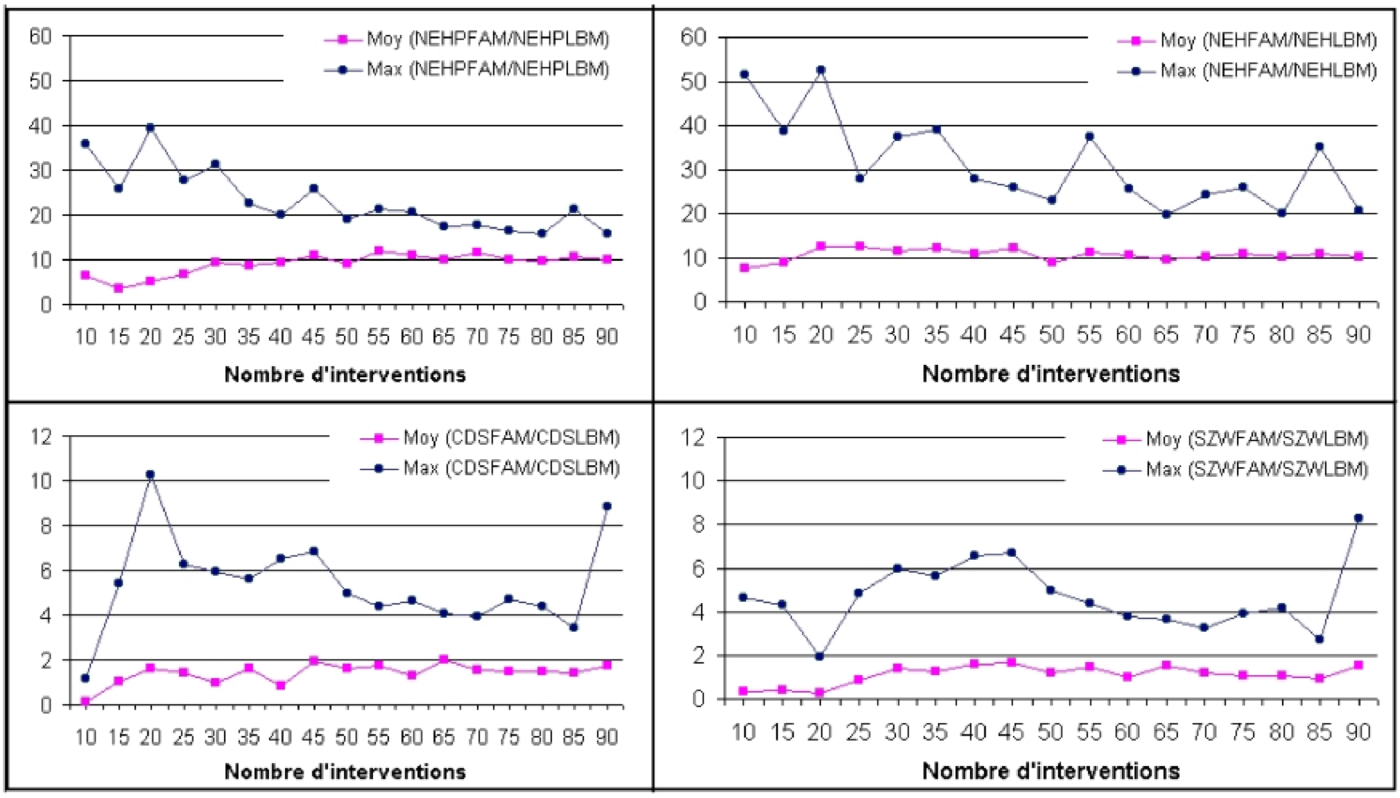

Figure 2.5: Comparison of FAM and LBM assignment rules by (Chaabane, 2004).

Nombre d'interventions	Nombre de salles d'opérations	Moy (NEHPFAM/ NEHPLBM)	Moy (NEHFAM/ NEHLBM)	Moy (CDSFAM/ CDSLBM)	Moy (SZWFAM/S ZWLBM)	Max (NEHPFAM/N EHPLBM)	Max (NEHFAM/ NEHLBM)	Max (CDSFAM/ CDSLBM)	Max (SZWFAM/ SZWLBM)
10	3	6,44	7,39	0,13	0,35	35,76	51,40	1,17	4,67
15	3	3,42	8,8	1,06	0,43	25,91	38,76	5,45	4,31
20	3	5,2	12,49	1,63	0,24	39,34	52,52	10,25	1,92
25	3	6,72	12,38	1,39	0,89	27,66	27,97	6,25	4,83
30	3	9,36	11,62	0,94	1,38	31,25	37,53	5,94	5,94
35	3	8,72	12,19	1,59	1,28	22,43	38,90	5,62	5,62
40	3	9,28	10,95	0,87	1,56	19,99	27,83	6,51	6,57
45	3	10,85	12,14	1,94	1,67	25,94	25,84	6,81	6,72
50	3	8,98	8,94	1,6	1,21	19,19	22,99	4,99	4,99
55	3	11,83	11,01	1,75	1,47	21,25	37,36	4,36	4,39
60	3	10,89	10,46	1,29	0,98	20,71	25,56	4,66	3,79
65	3	10,02	9,49	2,02	1,5	17,5	19,79	4,04	3,65
70	3	11,6	10,02	1,53	1,19	17,85	24,40	3,91	3,23
75	3	9,99	10,93	1,49	1,06	16,57	25,75	4,71	3,88
80	3	9,52	10,03	1,49	1,03	15,79	19,95	4,37	4,19
85	3	10,6	10,78	1,39	0,94	21,38	35,05	3,43	2,69
90	3	9,98	10,16	1,77	1,5	15,78	20,75	8,86	8,28
Moyenne		**9,02**	**10,58**	**1,40**	**1,10**	**23,19**	**31,31**	**5,37**	**4,69**

Figure 2.6: Comparison of FAM and LBM assignment rules by (Chaabane, 2004).

second plan: Compare the heuristics with the rule of assignment FAM with respect to the NEHP heuristic with the LBM assignment rule.Fig.2.5

At last, Compare the heuristics with the LBM assignment rule against the NEHP heuristic with the LBM assignment rule. They consider 3 operating rooms, 3 recovery beds and 2 pairs of stretcher bearers.

The operating times for each floor were defined as follows: average 120 minutes and standard deviation 60 minutes for operating rooms and for wake up beds is 60 minutes average and standard deviation 30 minutes, for the stretcher average 30 minutes and of standard deviation 10 min. We compared the value of the C_{max} (Block Close Date) generated by each FAM and LBM assignment rule for each heuristic. they note that FAM rule gives more expensive solutions than those provided by LBM, this difference is on average from 1% to 10% and can reach up to 31% at maximum.

note that the **CDS** and **SZW** heuristics have similar behaviors and the two assignment rules provide very close C_{max}, FAM is more expensive than LBM of 1% on average and 10% at most. The NEHP and NEH heuristics generate high C_{max} with the FAM rule which can reach 40% in the case of NEHP and 52% in the case of NEH. The averages remain around 10%. This difference seems to be explained by the number of solutions calculated by **CDS** and **SZW** (M total solutions) and NEHP and NEH (of the order of N2 partial solutions), M being the number of stages (here 3) and N the number of Appointments.

(Saadani et al., 2006) , they find this problem like a scheduling of workshops (flow-shop hybride) and the approach proposed is a new heuristic in O(N^2) and The results obtained by experimentation they compared there heuristics with previous developments (Chaabane, 2004). The new heuristic seems to be more efficient especially in cases of large numbers of works (in more than 79.77% of cases).

there proposition a heuristic using a variation of the Palmer index applied with the NEH and LBM rules. This heuristic has been effective in comparison to a work already presented for the same problem. In fact, it gives an improvement of 79.77% . This improvement is more interesting when the number of jobs increases. This heuristic could be improved by acting on the LBM rule. However, this method has not yet been tested with a larger number of operating rooms.

(Vanberkel et al., 2009) , have considered the problem of sequencing deterministic duration Appointments in several rooms. Operating rooms are used to carry out planned Appointments as well as unplanned (urgent) Appointments. When an urgent patient arrives, he is operated in the first available room. Otherwise, as soon as an outstanding Appointment is completed, the urgent Appointment can begin and the Appointment that has been planned will be delayed. The authors propose to schedule planned Appointments in order to reduce the waiting time for urgent Appointments.

(Cardoen, 2006) The authors propose an exact method and a heuristic based on integer programming to solve the problem. **(Cardoen, 2007)**, the same authors develop a column generation approach to improve the performance of the resolution method.

(Chaari, 2010) the author identify two type of schedule robust and deterministic scheduling ,they proposed a genetic algorithm for a robust scheduling ,with organization flow shop hybrid constitute there study . A computational experiment has been performed to verify the efficiency of the genetic algorithm for deterministic scheduling on this case the objective is to minimize only the completion date jobs and experiment is carried out of way static without integrate disturbance and also to validate it for robust scheduling using simulation to evaluate the robustness quality ,a simulation model has been implemented on ARENA 12.0. The results show that the proposed method can produce better, so-called compromise solutions between efficiency and robustness for a very high degree of uncertainty.

(HOUARI, 2012) They have addressed the resolution of a scheduling problem in a flexible production system using evolutionary algorithms.they presented there adaptation of two population-based meta-heuristics solutions. These are evolutionary methods called Memetic Algorithm with Population Management (MA / PM) and scatter search. For the first, it is about a genetic algorithm hybridized with techniques of local search and measurement of distance making it possible to control the diversification of the solutions in the population, in second one extracts a set of reference R containing the best solutions of the initial population.
A computational simulation has been performed ,these approaches have been compared with other evolutionary methods, to get an idea of the effectiveness of each of the methods used, Then they gave the results and the interpretations obtained from the different simulations made by adding breakdowns to the machines in the system.
A simulation model was implemented on Core (TM) 2 Duo CPU with 2.1 GHz and 2 RAM Dildo, varying the rate of arrival of parts and keeping the capacity of the fixed queue. The performance criteria considered are: production rate (part output rate), cycle time, work-in-progress, AGV utilization rate, and machine production rate.
The results obtained all showed that the metaheuristics that they studied gave better performances for the rate of production, the rate of use of the machines and the transport system for a flexible system of saturated production especially for small queuing capacities. waiting even with the presence of breakdowns.
For the cycle time, it's not clear that one metaheuristic gives a better cycle time than the others for all the queuing capabilities, but it can be said that the scattered search gives a reasonable cycle time for a saturated system and small queues.

(Nouaouri, 2010) , the authors interested in operational programming in exceptional situations with the reactive taking into account of different types of disturbances . The criticality of the exceptional situation imposes the efficiency and joint control of the various human and material resources. In this context, the operating rooms can be shared between several surgeons. They move from one operating room to another to perform the Appointments assigned to them.

Indeed, in the case of over-equipment in operating theaters, the property of optimizes the occupation of surgeons, preparing the patient in masked time in another room. This allows to assimilate the problem addressed to a problem of scheduling on parallel identical machines, so they modeling this problem with two-stage flow shop hybrid based on linear model . they propose an scheduling algorithm :

The ASCI algorithm allows, from the results of the linear model, to provide the details of the proposed scheduling. Consider example the instance P25.4.R1. The the result of the ASCI algorithm

Algorithms 1 ASC1 Algorithm

1: **Initialize:** $F_s = 0 \; \forall s \in [1, \mathbf{S}]$;$\mathrm{G}_h = 0 \; \forall h \in [1, H]$
2: **Inputs:** Give the set φ
3: i=1,s=1,h=1
4: **if** $t_i \geq F_s$ **then** ▷ assign i to the operating room s
5: $\quad F_s = t_i + d_i$
6: $\quad$ **if** $t_i + u \geq max(\mathrm{G}_h, rc_h)$ **then** ▷ assign i to the surgeon h
7: $\quad\quad \mathrm{G}_h = t_i + d_i - \delta_{post}$
8: $\quad\quad \varphi = \varphi / \{i\}$
9: $\quad\quad$ **if** $\varphi = \phi$ **then**
10: $\quad\quad$ **else** $i = i + 1$, go to line **4**
11: $\quad\quad$ **end if**
12: $\quad$ **else** $h = h + 1$,go to line **6**
13: $\quad$ **end if**
14: **else** $s = s + 1$, go to line 4/

is detailed in 2.7 and 2.8

Victimes	t_i	s	h	Victimes	t_i	S	h
2	0	1	1	16	360	1	2
61	30	3	4	20	390	2	4
33	45	2	1	12	390	4	1
37	120	1	1	50	405	3	2
65	120	2	2	35	420	1	3
58	180	4	3	8	450	2	2
48	225	2	2	46	495	3	2
3	240	3	1	30	525	2	3
10	240	4	3	68	540	1	4
5	285	3	1	41	600	1	1
52	300	1	2	15	615	4	2
39	300	2	4	54	630	1	3
43	330	4	3				

Figure 2.7: Room Program and Surgeons by (Nouaouri, 2010).

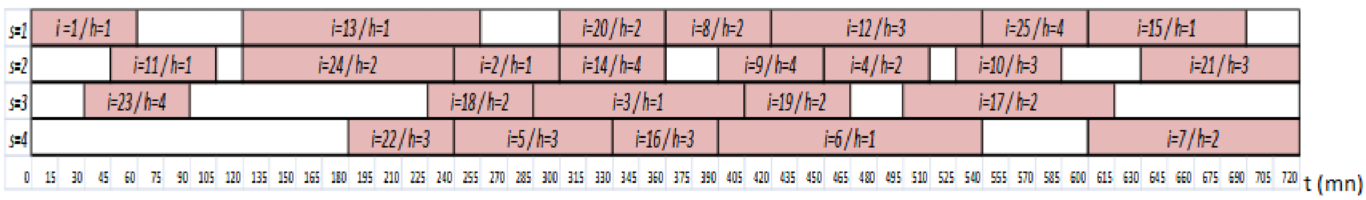

Figure 2.8: Result of planning and scheduling of Appointment (algorithm ASC1) by (Nouaouri, 2010)

Notes : as result of example of 25 patient 4 rooms and 4 surgeon makespan was equal to 720 mn with room occupancy TON(%)= 69,79%.

(Fei et al., 2010) share the problem in two parts: (1) planning Appointments, by assigning each patient the day it will be operated, and the necessary resources (operating room and surgeon) to the realization of his operation. (2) Daily scheduling of Appointments in the operating rooms under the constraints of availability of beds in the recovery room. However, (Roland et al., 2009 a) propose an approach that simultaneously integrates the planning and scheduling of Appointments in the operating rooms.

(Hammami, 2006) Develop 3 linear programs in whole number: (1) formation of groups of surgeons. (2) Construction of the Allocation Master Plan (PDA) to allocate individual beaches and common beaches to surgeons. (3) Assignment of Appointments to PDA. Indeed, the program begins by filling the individual ranges, then the common beaches, and if there are still unaffected Appointments then they are placed in the unmarked beaches. The latter represent the sum of untapped times per hour range for surgeons operating in the same room and on the same day (Kharraja and Mainit, 2003). This problem assumes that other services (recovery rooms, hospitalization services,...) are well sized.

(Kharraja et al., 2002; Gun) model the problem of planning Appointments in the operating rooms and the recovery room as a two-stage hybrid flow shop. The operating rooms are "parallel machines" on the first floor and the recovery room beds are "identical parallel machines" on the second floor. (Kharraja et al., 2002) Consider this problem of hybrid flow shop with blockage. That is, the patient can only be assigned to a bed if a place is free in the recovery room. The objective function is the minimization of Makespan (C_max). Thus the problem considered estFH2/Block/C_max.

2.5 Conclusion

We presented the works and tools to deal with our problematics such as sizing the critical resources and Appointment programming and scheduling the Appointments, as we present sizing the critical resources with simulation is widely used and it is the most effective it used by (Nouaouri, 2010; Ramis et al., 2001) the modeling of (Nouaouri, 2010) based on linear program with a simulation was interesting but they didn't take into account RR and hospitalization room, (Ramis et al., 2001) they used five-month data estimated with use of simulation .
Second, on Appointment programing (Chaabane, 2004) has a good model based on domain manufacturing but they go far in management and (Dexter et al., 1999), use linear model same as (Nouaouri, 2010) and they propose off-line "bin-packing" heuristic, the issues in implementing the algorithm , they based on simulation to find which "bin-packing" is the best, with more issues "In contrast, off-line algorithm may not be practical at some surgical suites because surgeons or patients may not accept having to wait until the cutoff time to learn whether they will have surgical time for a case". At last, on scheduling most works use a manufacturing methods, flow shop hybrid, such as (Nouaouri, 2010; Chaabane, 2004; Fei, 2006; Saadani et al., 2006; Chaari, 2010). Form literature, we found that the simulation is the best tool to size the critical resources and the help with the decision it is a linear model with simulation and for planning and programing the Appointments it's linked to scheduling problem and the best tool available it is the flow shop hybrid, so we based on linear model proposed by (Nouaouri, 2010) and we modified his algorithm of scheduling to consider additional constraints,

we going to integrate the availability of beds in the RR and hospitalization beds in the algorithm.

Chapter 3

Resolution Methods and Experiments

3.1 Introduction

In the previous chapter, we presented the work of the planning of the operating theaters, taking into account the strategies of "block scheduling" We saw that the operational programming is not only constituted of the planning but also of the scheduling of the Appointments in an operating room. In this chapter, we integrate the constraint on the availability of beds in the RR and hospitalization beds, also we based on method on manufacturing domain on a tool called "flow-shop-hybrid" with linear model proposed by (Nouaouri, 2010) and we modified his algorithm of scheduling to consider the additional constraints. Our goal is to minimize the cost of operating hours of the block. To do this, it suffices to minimize the duration of completion of all the Appointments affected in a schedule for the operating rooms as well as for the RR and the hospitalization room, also give date of Appointment to each patient soon as possible. we present the problem solving of production workshops scheduling, the problems of the hybrid "flow shop" two-stage with additional constraints offer great similarities with our problems of scheduling of the operating theaters. As a consequence, we will compare the workshop scheduling with the operating block scheduling. Then, we present the main methods to solve them and more particularly the problems of the "flow shop" hybrid type and we are going to adopt of workshop scheduling on operative block, our approach to reach our goal is to divide the problem into two steps first sizing of critical resources, Second, scheduling and assignment predictive Appointments in the operating rooms.

3.2 Production Systems

A production system is generally seen as the association of a set of interacting resources to perform a production activity. Indeed, the production is carried out by a succession of so-called operations of transformation, transfer, assembly and disassembly by exploiting the available resources (machines, means of transfer, ...) to transform raw materials (components entering the system) into finished products coming out of this system (Letouzey, 2001). Before entering into the details, it is necessary to specify some definitions of the usual terms that we will use in this research work for the description of the scheduling problems of production workshops. We take the definitions given by (Duvivier, 2000).

3.2.1 Decomposition of the Production System

Production systems can be very complex systems and difficult to manage in view of all their functional components (manufacturing, purchasing, distribution, maintenance ...). They are therefore much studied, and have been for a long time. Several approaches have been envisaged in order to better understand how they work and better understand them, (Tamani, 2008).

The application of systems theory to production systems suggests a decomposition of these systems into three subsystems:

- **The physical system of production:** transform raw materials or components into finished products. It consists of human and physical resources (Letouzey, 2001).
- **the decision system:** Control The physical production system, organizes and coordinates tasks by making decisions based on data transmitted by the information system.
- **The information system:** intervenes between the production and decision systems and within the latter, for the management of information used in decision-making.

3.2.2 Definitions of Main Terms

Operation : An operation (or task) is a basic work to be located in the time by a start or end date and whose completion requires some time interval called duration.

Product : A product is the result of several elementary operations applied to a raw material or an intermediate product. In the general case, these operations are partially ordered in time according to a precedence graph called range of manufacturing.

Resource : A resource is a technical or human means intended to be used for the completion of an operation and available in limited quantity (capacity).

Machine : In the context of shop scheduling problems, the term machine refers to the resources used to carry out the overall project.

Make-span : Make-span is the time needed to manufacture all the products of the instance considered according to the order of manufacture imposed by a fixed schedule.

Stage (floor) : A stage represents a set of parallel machines, each of which can realize, possibly with different performances, a single operation on a product.

Additional resource : The term additional resource represents a technical or human means critical, with the exception of machinery, which is required by the operations of the different products on the same floor in a manufacturing system. In general, scheduling problems can be characterized by three sets of elements:

- **T** : a set of products that consist of one or more operations .
- **E** : a set of floors that consist of one or more parallel machines.
- **R** : a set of one or more kinds of additional resources.

Additional resources may be renewable or non-renewable. A resource is renewable if after being allocated to one or more tasks, it becomes available again in the same quantity after the completion of these tasks. In our hospital case, surgeons can be considered as resources additional renewable.

3.3 Workshop Scheduling Problem

In this section w'll Define some of the basics workshop schedule elements with principal idea of multi-machine workshop problem and the main idea of flow-shop problem and how we adopt it on operative block schedule

3.3.1 Definition of Workshop scheduling problem

Definition by (Hans et al., 2008), In a shop problem, a part must be machined or assembled on different machines. Each machine is a disjunctive resource, that is, it can only execute one task at a time, and the tasks are linked exclusively by web constraints. More precisely, the tasks are grouped into one entities called jobs or batches. Each batch consists of m tasks to be performed on n separate machines. There are three types of shop floor problems, depending on the nature of the constraints that bind tasks in the same batch. When the order of passage of each lot is fixed and common to all the batches, it is called a flow-shop. If this order is fixed but specific to each lot, it is a multi-path shop (job-shop). Finally, if the sequencing of the tasks of the works is not imposed, one speaks of workshop with free tracks (open-shop). An optimality criterion often studied is the minimization of the total delay of the scheduling (makespan). This criterion is particularly interesting since the early orders are dominant subsets 1 for many regular criteria. Moreover, the analysis of the schedules at the earliest possible makes it possible to determine critical paths, that is to say paths on which any delay has consequences on all the chain, or bottlenecks, that is to say that is, the steps that will limit the production of the whole shop.We assume that the execution times of the tasks are given by an integer matrix $P : mn$, where $p_i j0$ is the execution time of the task $T_{ij}T$of the batch J_j carried out on the machine Mi.A classic lower limit for the workshop problems, denoted C_{max}^{LB}, is equal to the maximum of the load of the machines and the durations of the batches.

3.3.2 The Elements of a Scheduling Problem

Tasks : A task is an elementary entity organized in time, with a start date t_i or end c_i, whose realization is characterized by a duration p_i (we have $c_i = t_i + p_i$). task i uses one (or more) resource k with an intensity a_{ik} often assumed to be constant during the execution of the task. according to, three parameters characterize a task:

- **The duration of operation or execution time pi (Processing time) of the task**
- **The availability date or date starts no later than r_i (release time).**
- **The due date or end date at the latest d_i (due date).**

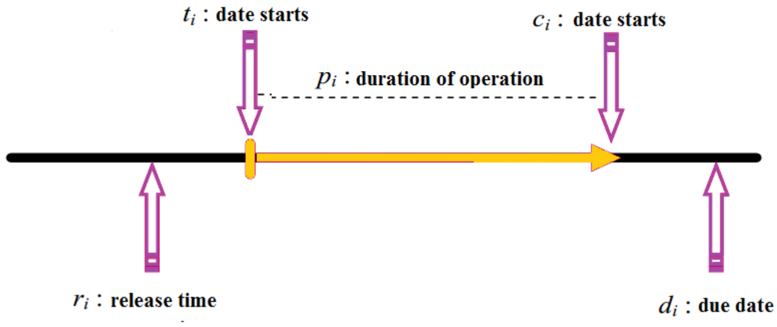

Figure 3.1: Characteristics of a task i by (T'Kindit & Billaut(2006)

Resources : A resource k is a technical or human means required for the realization of a task and available in limited quantity, its capacity A_k.
There are several types of resources. A resource is renewable if after being used by one or more tasks, it is available again in the same quantity (men, machines, space, etc.) the quantity of resources used at each moment is limited. Otherwise, it is consumable (raw material, budget, etc.) overall (or cumulative) consumption over time is limited.

Disjunctive (or non-shareable) resources can be distinguished that can only perform one task at a time (machine tool, manipulator robot) and cumulative (or shareable) resources that can be used by several tasks simultaneously. workers, workstation).

Constraints : A constraint expresses restrictions on the values that variables that represent relations between tasks and resources can simultaneously assume. There are two types of constraints, time constraints and resource constraints.

- **The temporal constraints :**
  The temporal constraints concern the imposed production times. These constraints can be:
  - Deadlines constraints, some tasks must be completed before a fixed date.
  - Precedence constraints, a task i must precede task j.
  - Early date constraints, due to the unavailability of certain factors necessary to start the execution of tasks.
- **Resource constraints :**
  These constraints concern the limitation of the quantity of resources of each type. In this context, two types of resource constraints are distinguished:
  - Disjunctive constraints: inducing a constraint to perform tasks over disjointed time intervals for the same resource.

– Cumulative constraints: involving the limitation of the number of tasks to be performed in parallel.

Objectives : Business objectives have diversified and the scheduling process has become increasingly multi-criteria. The criteria that a scheduling has to meet are varied. In general, there are several classes of objectives concerning scheduling (Esquirol et al., 1999).

- **The objectives related to time:** For example, there is the minimization of the total execution time, the average completion time, the total adjustment times or delays with respect to the delivery dates.
- **Resource Objectives:** maximizing the load of a resource or minimizing the number of resources needed to complete a set of tasks are objectives of this type.
- **Cost objectives:** these objectives are usually to minimize the costs of launch, production, storage, transportation, etc.

3.4 Multi-machine workshop problems

Scheduling problems can be classified according to the number of machines and their order of use to manufacture a product (manufacturing range) that depends on the nature of the workshop. A workshop is defined by the number of machines it contains and by its type. A classification can exist according to the number of machines and the order of use of the machines, to carry out a work (for example manufacture of a product which depends on the nature of the workshop). A system (example workshop) is defined by the number of machines it contains and by its type [(Tahar, 2006)].

The different types are:

- **A machine :** each task consists of a single operation.
- **Parallel machines:** they fulfill all the same functions. Depending on their speed of execution. one distinguishes: the identical machines where the speed of execution is the same for all the machines and all the tasks, and the uniform machines where each machine has a clean and constant execution speed and the speed of execution is the same for all the machines tasks of the same machine.
- **Dedicated machines:** they are specialized to perform certain operations. In this category, each task consists of several operations. Depending on the mode of passage of operations on different machines, three specialized workshops are differentiated.

3.5 The Hybrid Flow Shop Problem

3.5.1 Presentation

The scheduling problem of the hybrid flow shop is one of the most difficult and also the most common problems in the industrial field. Gupta, in 1988, opened the field of studies of hybrid flow shop scheduling problems and proved that the simplest case of this problem is NP-complete (the case where there is only one machine in the first stage). and two machines in the second floor). Since then, a lot of research has been carried out and the methods and techniques used range from heuristics to meta-heuristics (like simulated annealing, taboo research, genetic algorithms, etc.) and to hybrid methods, using exact methods, with the aim of minimizing the make-span or the total residence time (or average) of the works or the number of late works, etc.

A hybrid flow shop organization is our case study. It involves scheduling a set of n typical jobs that are representative of the production scenarios possible $J_1, J_2, ..., J_n$ in a multi-stage production facility.

Each job J_i consists of k type operations O_{jt}: O_{jt} is the operation of the job treated by the stage t.

The stage t contains a set of $M^t \geq 1$ identical parallel machines, which means that the jobs can be executed either on one or the other of the machines of the same floor. Each job must pass on one of the machines in each floor.

Once the execution of a job has started on a machine, it can not be interrupted. This amounts to saying that scheduling is not preemptive. The job can not be run in different machines. No job can start on this machine before the end of the current job.

For each job, the order of the operations in the k stages is the same: $O_{j1}, O_{j2}, ..., O_{jt}$ The machine M_{it} with $i = 1, 2, ..., M^t$ and $t = 1, 2, 3, ..., k$ can only execute one job at a time.

The working time of the job j at the stage t is note p_{jt} (the time of assembly, transport, discharge ... are contained in the operational time of the job).

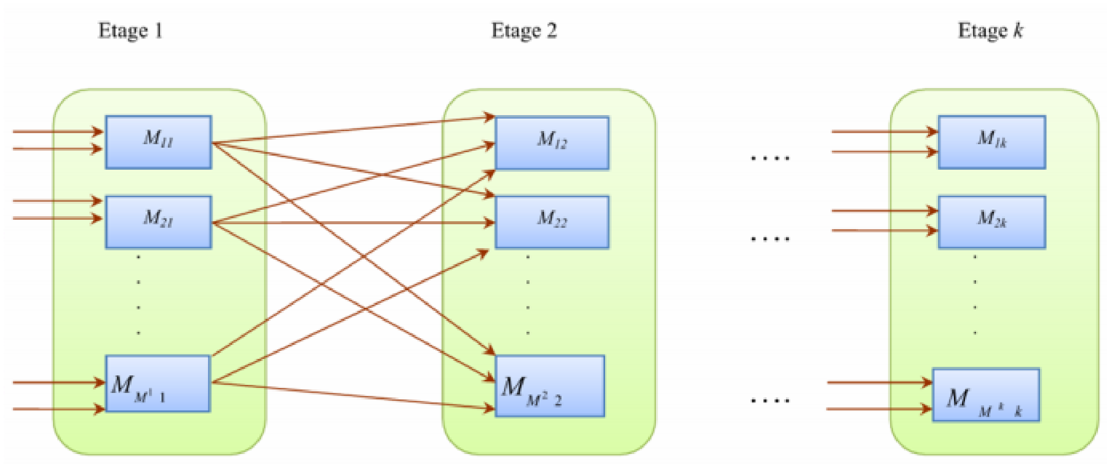

Figure 3.2: Hybrid flow shop with "k" floors by (Gupta, 1988)

3.5.2 Sizing Problem Based on Scheduling

We present a mathematical formalization of the sizing problem based on scheduling, with a view to its optimization (Chaari, 2010). We are interested in a multi-stage hybrid flow shop organization. A program linear Mixed Variables has been developed, allowing the joint of completion C_{max} and the number of machines in each floor for a set of typical tasks of the forecasting activity. Different sets of weights are awarded to each of these sub-objectives. The objective of this program is to determine a compromise between the number of machines to be allocated in each floor and the date of completion of the work (C_{max}).

3.5.3 Linear Model in the Production System

Parameters and variables : t Floor index t = 1, ..., k

M^t_{Max} Maximum number of machines in each floor t .

i Machine index , i = 1, ...,M^t_{Max}

j,l Job Index j, l = 1, ..., n ;

$Cout_{it}$ Cost of the machine i on the floor t ;

P_{jt} Execution time of job j in floor t ;

λ A relative weight to both objectives [0, 1] ;

B Great positive value ;

Variables :

C_{jt} Completion time of job j in floor t

C_{Max} makespan.

X_{ijlt}= 1 if the job j is executed immediately before the job l on the machine i on the floor t, 0 if not

X_{i0lt}=1 if the job j is executed first on the machine i on the floor t, 0 if not

$X_{ij(n+1)t}$=1 if the job j is executed last on the machine i on the floor t, 0 if not

Y_{it}=1 if the machine i is used in the floor t, 0 if not

2-Mathematical model with mixed variables

This problem is formulated as follows:

$$Minimiser[\lambda \times Ecart(C_{max}) + (1-\lambda) \times Ecart^{'}(\sum_{i=1}^{M_{Max}^t} \sum_{t=1}^{k} Cout_{it} * Y_{it})] \tag{3.1}$$

$$\sum_{i=1}^{M_{Max}^t} \sum_{j=0}^{n} X_{ijlt} = 1 \quad \forall t = 1,2,...,k \quad \forall j = 1,2,...,n \tag{3.2}$$

$$\sum_{i=1}^{M_{Max}^t} \sum_{l=1}^{n+1} X_{ijlt} = 1 \quad \forall t = 1,2,...,k \quad \forall j = 1,2,...,n \tag{3.3}$$

$$\sum_{l=1}^{n} X_{i0lt} = Y_{it} \quad \forall t = 1,2,...,k \quad \forall j = 1,2,...,M_{Max}^t \tag{3.4}$$

$$\sum_{j=1}^{n} X_{ij(n+1)t} = Y_{it} \quad \forall t = 1,2,...,k \quad \forall j = 1,2,...,M_{Max}^t \tag{3.5}$$

$$\sum_{j=0}^{n} X_{ijlt} = \sum_{j=1}^{(n+1)} X_{iljt} \quad \forall t = 1,2,...,k \quad \forall j = 1,2,...,M_{Max}^t \quad \forall l = 1,2,...,k \tag{3.6}$$

$$X_{ijlt} \leq Y_{it} \quad \forall t = 1,2,...,k \quad \forall j = 1,2,...,M_{Max}^t \forall l = 1,2,...,k \quad j = 1,2,...,n \tag{3.7}$$

$$X_{ijjt} = 0 \quad \forall t = 1,2,...,k \quad \forall j = 1,2,...,M_{Max}^t \quad j = 1,2,...,n \tag{3.8}$$

$$C_{lt} \geq C_j t + \sum_{i=1}^{M_{Max}^t} X_{ijlt} P_{lt} + B[\sum_{i=1}^{M_{Max}^t} X_{ijlt} - 1] = 1 \quad \forall t,l,j \quad j \neq l \tag{3.9}$$

$$C_{lt} \geq C_{l(t-1)} + P_{lt} \quad \forall t = 2,...,k \quad \forall l = 1,2,...,n \tag{3.10}$$

$$C_j^k \leq C_{Max} \quad \forall j = 1,2,...,n \tag{3.11}$$

$$X_{ijlt} \in \{0,1\} \quad \forall i = 1,2,...,M_{Max}^t \quad \forall j = 1,2,...,n \tag{3.12}$$

$$\forall t = 1,2,...,k \quad \forall l = 1,2,...,n$$

$$Y_{it} \in \{0,1\} \quad \forall i = 1,2,...,M_{Max}^t \quad \forall t = 1,2,...,k \tag{3.13}$$

$$C_{Jt} \geq 0 \quad \forall j = 1,2,...,n \quad \forall t = 1,2,...,k \tag{3.14}$$

Comments :

The objective function is to minimize a weighted sum of the difference between the make-span and the best job completion date and the difference between the cost of the dimensioning obtained defined by the sum of the costs of the parallel machines in each floor and the least expensive design. In order to have known scales for both criteria, we standardized the values corresponding to these units using the utility function. Two approaches may be possible. A first,which consists of allowing to linearly combine the two criteria and a second, which allows the user to limit one of the two criteria and to minimize the other. In this thesis, we have chosen the first approach and the implementation of the second is invisible in future work.

Constraints (3.2) and (3.3) ensure that each job is assigned to a single job machine in each floor. Constraints (3.4) ensure that only one job is executed in first position on each machine on each floor (you can not run two jobs at the same time on a single machine). The constraints (3.5) indicate that only one job is executed last on each machine on each floor. The constraints (3.6) im pose a sequence of jobs in each machine for each floor. The constraints (3.7) make it possible to maintain that the job j assigned to the machine i at a given floor is executed on the same machine at this floor. Constraints (3.8) indicate that the job that has finished running on one machine in the same floor can not be re-executed in another machine on that same floor.

The set of constraints (3.9)-(3.11) determine the completion time of each job. Constraints (3.9) indicate that if the job j is executed before the job l by the same machine in a particular floor, job j completes its execution before job l starts. The constraints (3.10) make it possible to ensure that each job can start its execution in the stage 1 + t only when it ends in the stage t. The constraints (3.11) ensure that the Cmax must be greater than the completion time of each job j in the last stage k. The constraints (3.12) and (3.13) are decision binary variables that can take the value 0 or 1. The constraints (3.14) require that the completion date of the jobs be positive.

3.6 Adopting Workshop Scheduling on Operating Blocks

The strategy of the operating programming adopted "block scheduling", the problem of scheduling Appointments within an operating theater is similar to problem of type hybrid two-stage "flow shop" with different operating times between floors with or without additional resource constraints. The first floor is composed of operating theaters, identical or specialized according to the operative programming strategies, and the second floor is recovery room containing one or more identical beds. It should be noted that our model differs from the classic "flow shop" hybrid problem in two stages:

- The operating rooms on the first floor are specialized in the case of block scheduling "and identical in the case of" open scheduling ". So in the first case, the Appointments assigned to a room operation can not be moved to other operating theaters.
- If there is no bed available in RR at the end of an appointment then the patient will have to stay in the operating room until a bed is releases in recovery room.

Tableau [3.1] below establishes the relationship between the terminology used in industrial management and that used for the management of an operating theater.

Management of a production workshop	operating room management
Operation	appointment in the operating room Alarm clock in the recovery room
Product	entire appointment (in the operating room and recovery room), patient
Resource	Material Resources: rooms, beds, ... Human Resources: nurses, surgeons, anesthetists, ...
Machine	Operating Rooms, Recovery beds
Makespan	The makespan of the operating room: the length of time between the start time of the first operation in the operating room and the end time of the last appointment in the recovery room; operation: the time between the start time of the first operation in the operating room and the end time of the last operation in the operating room.
Floor	Operating rooms on the first floor, Second floor recovery room
Additional resource	Surgeons in the strategy of the "Block scheduling ", Each operating room has a surgeon.

Table 3.1: Terminology used in industrial management and hospital management.

3.7 The Proposed Approach

To solve the problems (give each patient the time for the nearest surgery and better take into account the material and human resources) we proposed a plan or a method in two stages:

3.7.1 Sizing of Critical Resources

the hospital must have a decision support tool that will allow it to know the capacity it needs to mobilize. To calculate the number of minimum operating rooms, we need to know the numbers of patients who require surgical procedures, as well as the time use of the surgical teams at the receiving hospital (according to the guard table). Based on these data and prior to any simulation exercise, the hospital should plan several scenarios.

We deal with the problem of sizing critical resources in the framework of linear programming exercises with simulations. We seek, more precisely to propose a tool of decision support to size the number of operating rooms necessary, in general to minimize the make-span (C_{max}, time of completion of the last operation) of the recovery room and / or the operating rooms. This objective is equivalent to minimizing the time overruns in operating theaters and / or in the recovery room.

for sizing critical resources we detail the mathematical model it proposed by (Nouaouri, 2010) to address this issue. For a simplification issue (especially with regard to computing time), it only provides scheduling of patients over time. Indeed, the program checks at every moment the availability of resources.

Before describing the problem, here are the different notations used:

N Number of victims.
S Number of operating rooms.
H Total number of surgeons.
H_t Number of surgeons present at the hospital at time t.
t Horizon of the study.
d_i Operating time of the victim i.
dl_i Deadline for appointment of the victim i.
t_i Date of the beginning of the appointment of the victim i.

The decusion variables :

$n_{it} = 1$ if the appointment i occupies an operating room at time t, 0 otherwise.

$X_{it} = 1$ if the appointment i starts at time t, 0 otherwise

$q_{it} = 1$ if the appointment i is assigned to a surgeon at time t, 0 otherwise.

We present here the mathematical formulation of the problem as a linear integer program.

$$maximiser \sum_{i}^{N} \sum_{t}^{T} X_{it} \tag{3.15}$$

$$\sum_{t}^{T} X_{it} \leq 1 \qquad \forall i \in \{0..N\} \tag{3.16}$$

$$\sum_{i}^{N} n_{it} \leq S \qquad \forall t \in \{0..T\} \tag{3.17}$$

$$\sum_{i}^{N} q_{it} \leq H_t \qquad \forall t \in \{0..T\} \tag{3.18}$$

$$t_i = \sum_{t}^{T} t X_{it} + M(1 - \sum_{t}^{T} X_{it}) \qquad \forall i \in \{0..N\} \tag{3.19}$$

$$t_i - dl_i \sum_{t}^{T} X_{it} + M(1 - \sum_{t}^{T} X_{it}) \leq 0 \qquad \forall i \in \{0..N\} \tag{3.20}$$

$$t_i + M(1 - X_{it}) \geq rv_i \qquad \forall i \in \{0..N\} \tag{3.21}$$

$$\sum_{t'=t}^{t+d_i-1} n_{it'} \geq d_i X_{it} - M(1 - X_{it}) \qquad \forall i \in \{0..N\} \quad \forall t \in \{rv_i..dl_i\} \tag{3.22}$$

$$\sum_{t}^{T} n_{it} \leq d_i \sum_{t}^{T} X_{it} \qquad \forall i \in \{0..N\} \tag{3.23}$$

$$\sum_{t'=t+\delta_{pre}}^{=t+(\delta_{pre}+p_i)-1} q_{it'} \geq p_i X_{it} - M(1 - X_{it}) \qquad \forall i \in \{0..N\} \quad \forall t \in \{rv_i..dl_i\} \tag{3.24}$$

$$\sum_{t}^{T} q_{it} \leq p_i \sum_{t}^{T} X_{it} \qquad \forall i \in \{0..N\} \tag{3.25}$$

$$\sum_{t=0}^{rv_i-1} X_{it} + \sum_{t=dl_i+1}^{T} X_{it} = 0 \qquad \forall i \in \{1..N\} \tag{3.26}$$

$$\sum_{t=0}^{rv_i-1} n_{it} + \sum_{t=dl_i+p_i}^{T} n_{it} = 0 \qquad \forall i \in \{1..N\} \tag{3.27}$$

$$\sum_{t=0}^{rv_i-1} q_{it} + \sum_{t=dl_i+p_i}^{T} q_{it} = 0 \qquad \forall i \in \{1..N\} \tag{3.28}$$

$$n_{it} \in \{1..N\} \qquad \forall i \in \{1..N\} \qquad \forall t \in \{0..T\} \tag{3.29}$$

$$q_{it} \in \{1..N\} \qquad \forall i \in \{1..N\} \qquad \forall t \in \{0..T\} \tag{3.30}$$

$$X_{it} \in \{1..N\} \qquad \forall i \in \{1..N\} \qquad \forall t \in \{0..T\} \tag{3.31}$$

Comments :

The objective function (3.15) expresses the maximization of the number of Appointments performed. The constraints (3.16) ensure that a victim is affected, at most once, during the T horizon. The constraints (3.17) and (3.18) verify that at each moment, the number of rooms occupied (resp. busy surgeons) does not exceed the total number (resp., H_t). The constraints (3.19) retain the start date of appointment for each of the victims treated. We denote by M a very large positive number. If a victim can not be managed in time, the model sets the appointment date to the value M. The constraints (3.20) impose for each treated victim, that the date of care does not exceed the due date appointment. The constraints (3.21) make it possible to take into account the different arrival dates of the victims, at the hospital. The constraints (3.22) and (3.23) make it possible to set n_{it} to 1, so that at time t, an operating room is occupied by the victim i. Constraints (3.24) and (3.25), set q_{it} to 1, as long as a surgeon is, at the instant t, busy to prepare or to carry out the appointment of the patient i. These last four constraints (3.22) , (3.23) ,(3.24) , (3.25) allow us to obtain, at every moment, the number of occupied rooms and surgeons.
The constraints (3.26) ensure that $X_{it} = 0$ outside the interval $[rv_i, dl_i]$. (3.27) and (3.28) allow respectively $n_{it} = 0$ and $q_{it} = 0$, before the arrival of the victim at the hospital and for any end date of appointment not respecting the deadline imposed. The constraints (3.29), (3.30) and (3.31) are integrity constraints on the variables.

3.7.2 Scheduling and Assignment of Appointments in Operating Rooms

The scheduling it determines the order of passage of the Appointments in each room of operations in a operating room for a day. In this step, we develop a more detailed schedule taking into account the fact that a surgeon can not perform several operations at the same time and integrate less critical resources such as the number of beds in the recovery room. In general, the solution structure of our problem can be described as below: The scheduling of the operational programming is similar to a model of flow shop with two floors. As we have said, an operating theater is consists of two parts: the operating rooms and the recovery rooms where there are several recovery beds. Normally, patients will first be operated in operating theaters and then transferred to recovery room. This order is unique when the patient is operated under anesthesia. This precedence constraint is the same as the flow shop model.

In this context, we relied on ASC1 algorithm (Nouaouri, 2010) and modified and developed it to solve our problem. While the algorithm depends on the results of the linear program that we adopted in the first step (The sizing of critical resources).

The steps of the algorithm to get the best planning of surgical operations for patients:

- Making the best decision from the first program (Sizing Critical Resources) is a combination of linear programming and simulation. So this program also gives us the numbers of operating rooms needed to treat all or some patients each day.
- The algorithm generates a sequence of tasks, which are assigned to several of the operating rooms in the first floor following the FAM (First available machine) rule.

- the second floor is allocated to the wake-up rooms after the end of each operation.
- in the same floor (second floor) after waking up in each recovery room.

The last two steps were not used by (Nouaouri, 2010) in his own algorithm, We added these two steps to develop the algorithm.

The following **ASC1** algorithm can be used to derive from the results of the linear program the details of the allocation of Appointments to rooms and surgeons and to recovery rooms and hospital beds. It consists of assigning the appointment to the first operating room / recovery rooms and free beds with the time elapsing of each surgeon free. Let F_s and RR_n and N_l natural integers and φ the set of assigned and ordered Appointments.

Algorithms 2 Modified ASC1 Algorithm

1: **Initialize:** $F_s = 0 \forall s \in [1,\mathbf{S}]$; $\mathrm{RR}_n = 0 \forall v \in [1,\mathbf{n}], N_l \forall s \in [1,\mathbf{l}]$
2: **n**:total recovery room number
3: **period**: the duration of hospitalization
4: **Inputs:** Give the set φ
5: i=1,s=1,h=1,n=1
6: Min $(F_1,...,F_n)$
7: $t_i = F_s$ ▷ assign i to the operating room s
8: $F_s = t_i + d_i$
9: **if** $F_s \geq RR_n$ **then** ▷ assign i to the recovery room n
10: $RR_n = F_s + d_{iRR}$
11: **if** $RR_n \geq N_l$ **then** ▷ assign i to the hospital room l
12: $N_l = RR_n + period$
13: $\varphi = \varphi / \{i\}$
14: **if** $\varphi = \phi$ **then** **else** i=i+1, $gotoline$**6**
16: **if**
17: **else then** $l = l+1$,go to line **11**
18: **end if**
19: **else** $n = n+1$,go to line **9**

In the rest of this text, each time we discuss a "surgeon" resource, it will be equivalent to "the entire surgical team" made up of all the hospital practitioners, nurses, anesthesiologists, etc., who surround this surgeon.

3.8 Experiments and Analysis

3.8.1 Test Problems

The problem studied, we defined 50 patients with the duration of the appointment and 10 recovery rooms with 55 beds of hospitalization, based on random data. These instances, generated randomly according to the normal law, the number of operating rooms (S = 4, 6) and the time used by surgeons (R = $rc_1,...,rc_H where H = 4,6,$) reported in the table 3.2 , times and dates are given in minutes (mn).

R	$rc_1(mn)$	$rc_2(mn)$	$rc_3(mn)$	$rc_4(mn)$	$rc_5(mn)$	$rc_6(mn)$
R_1	0	0	0	30	30	30
R_2	0	0	0	30	30	30
R_3	0	0	0	30	30	60
R_4	0	0	30	30	30	60
R_1	0	0	30	30	60	60

Table 3.2: the time schedule of each surgeons by (Nouaouri, 2010)

A that test problem is written P.N.S.R; N is the number of patients, S is the number of operating rooms, and R is the agenda of surgeons (in this example consider the time from the moment surgeons enter the time frame to terminate operations), example P.50.6. R_1, or R_5 = (0,0,30,30,60,60), is a problem of 50 victims, 6 rooms operatives and 6 surgeons available.

i	$d_i(mn)$	duration RR(mn)	i	$d_i(mn)$	duration RR(mn)
1	120	150	26	90	120
2	60	90	27	90	90
3	60	60	28	90	60
4	60	90	29	120	90
5	120	150	30	60	60
6	60	60	31	150	240
7	60	90	32	90	120
8	60	30	33	60	60
9	90	150	34	120	150
10	90	120	35	150	90
11	90	90	36	60	60
12	150	150	37	120	150
13	60	60	38	90	60
14	60	30	39	60	30
15	120	150	40	90	150
16	60	30	41	90	30
17	60	60	42	60	30
18	60	30	43	60	60
19	90	120	44	90	150
20	60	60	45	60	30
21	60	60	46	120	180
22	150	300	47	90	60
23	60	30	48	60	60
24	120	180	49	120	240
25	150	150	50	60	180

Table 3.3: appointments durations and recovery rooms duration of 50 patients.

N°	beds	N°	beds
1	0	26	330
2	120	27	90
3	120	28	120
4	240	29	540
5	420	30	0
6	0	31	0
7	510	32	210
8	0	33	810
9	0	34	720
10	0	35	510
11	610	36	0
12	1000	37	90
13	120	38	420
14	0	39	1400
15	600	40	500
16	360	41	0
17	0	42	510
18	0	43	510
19	180	44	780
20	300	45	0
21	0	46	0
22	0	47	1400
23	0	48	90
24	0	49	990
25	900	50	990
		51	840
		52	780
		53	840
		54	480
		55	600

Table 3.4: Time remaining to empty hospitalization beds

3.8.2 The Results The Sizing of Critical Resources

In order to get optimization of the critical resources we based on linear program proposed by (Nouaouri, 2010), they build there model on a commercial software for solving linear Cplex 10.1 models on a cluster composed of 6 machines Bixeon® 3.00 GHz processor and 2 to 4 GB of RAM .. The results obtained are analyzed by studying the contribution of different options (Appointments) on the number of patients treated.

for each of the generated instances, he has resolved the linear program. We indicate: the calculation time in seconds (CPU (s)), the number of constraints (N_{Cont}), The number of variables (N_{Var}), The number of iterations (N_{Iter}), the value of the objective function (F.Obj.1), the percentage of victims treated (P (%)), the total duration of the operating program ($C_{max}(h)$) expressed in hours (h), and the occupancy rate of operating theaters TO (%).

$$TON(\%) =$$

$\sum_{i=1}^{N}\sum_{t=0}^{T}\sum_{h=1}^{H} d_i.X_{ith}\overline{C_{max}.S}$ (3.32)

We present in this table 3.5 the results of linear program with simulation What it did (Nouaouri, 2010) the instances for which it is obvious that all patient will be supported (capacity significantly greater or equal to the load).

Simulation	CPU (s)	N.count	N.var	N.iteration	Cmax(h)	F.Obj	TON(%)	P(%)
P.25.4.R1	0.01	6841	5073	4289	12	25	69.79	100
P.25.4.R4	0.01	6841	5073	5427	12.5	25	67.00	100
P.50.4.R1	42	17519	12571	9255	13.75	41	90.16	82
P.50.4.R4	38	17519	12571	9422	15.25	41	89.52	82
P.50.6.R1	56	17519	12571	6875	14.5	50	85.52	100
P.50.6.R3	35	17519	12571	6145	15	50	82.22	100
P.50.6.R4	72	17519	12571	12577	14	50	88.09	100
P.50.6.R5	81	17519	12571	12577	14	50	88.09	100

Table 3.5: Numerical results of the linear program with simulation by (Nouaouri, 2010)

they note that up to 50 patients the optimal solution is obtained in less than 30 seconds. These computation times are very acceptable and have a certain advantage for efficient operation of the linear program with simulation.

On the other hand, we find that the operating rooms are better occupied if all the patients are not treated at 100%, because the more we treat the patient (or the more the capacity increases), the higher the occupancy rate. TON (%) decreases. In the case where the capacity is lower than the demand, and because of the nature of the problem dealt with (maximization of the number of survivors), the program seeks to optimize the occupation of the rooms and the surgeons to be able to affect the maximum of patient. The following figure 3.3 affirms our point of view.

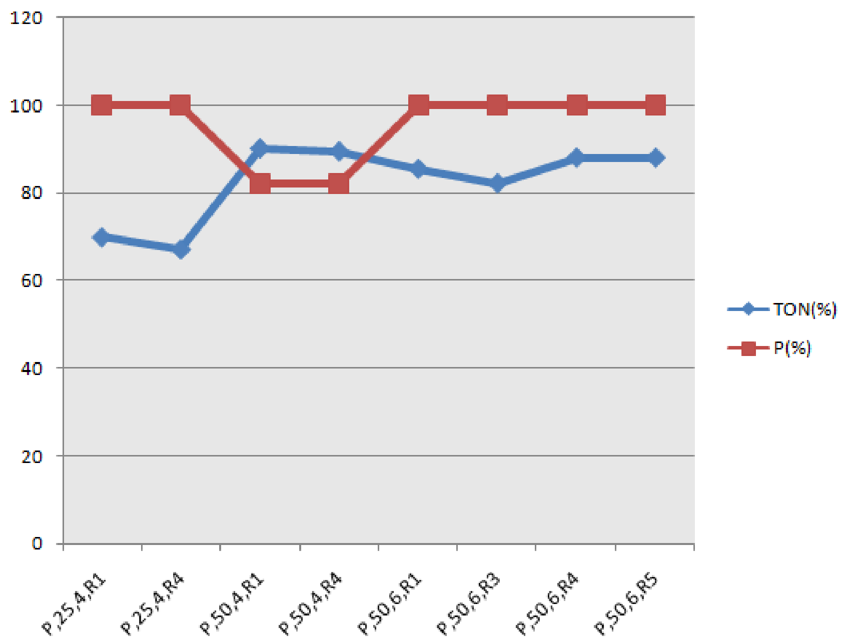

Figure 3.3: Evolution Operating Room Occupancy Rate / Percentage of Patient Treatment by (Nouaouri, 2010)

Moreover, the total duration of the planning (C_{max}) informs about the necessary time of mobilization of the operating block to absorb the maximum of patient. the occupancy rate never reaches 100%. This observation helps decision-makers to anticipate, and consequently to organize better, in order to save the maximum of human lives.

3.8.3 Results of Scheduling and Assignment of Operating Room Appointments

The modified ASC1 algorithm allows, from the results of the linear program, to provide the details of the proposed scheduling. Consider, by way of example, the instance P25.4.R1 The proposed program is detailed in Figure 3.4 and table 3.6

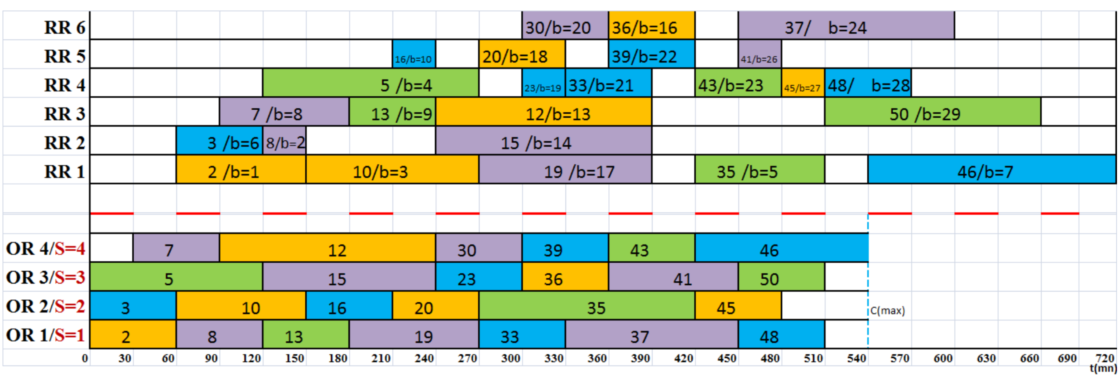

Figure 3.4: Result of planning and scheduling of appointments

i	t_i	OR	Surgeons	RR	Bed
2	0	1	1	1	1
3	0	2	2	2	6
5	0	3	3	4	4
7	30	4	4	3	8
8	60	1	1	2	2
10	60	2	2	1	3
12	90	4	4	3	13
13	120	1	1	3	9
15	120	3	3	2	14
16	150	2	2	5	10
19	180	1	1	1	17
20	210	2	2	5	18
23	240	3	3	4	19
30	240	4	4	6	20
33	270	1	1	4	21
35	270	2	2	1	5
36	300	3	3	6	16
39	300	4	4	5	22
37	330	1	1	6	24
41	360	3	3	5	26
43	360	4	4	4	23
45	420	2	2	4	27
46	420	4	4	0	0
48	450	1	1	4	7
50	450	3	3	3	28

Table 3.6: Program of rooms and surgeons. Results of Modified ASC1 Algorithm for 25 patients.

Also we did an other experiment for the instance P.50.6.R_1 The proposed program is detailed in Figure 3.5 and table 3.7.

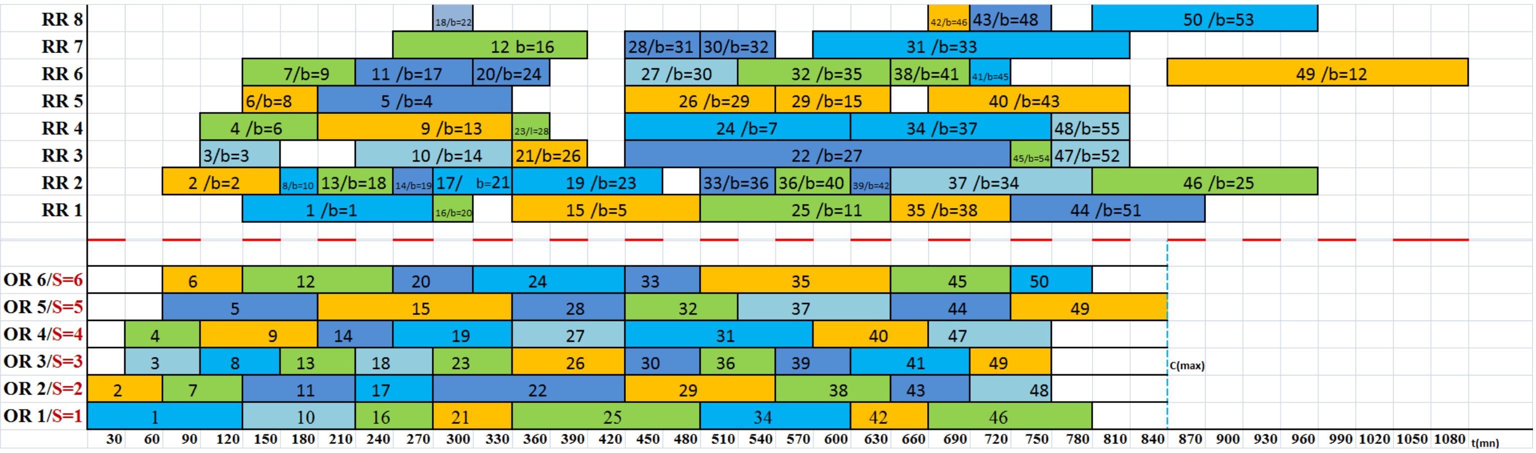

Figure 3.5: Program of rooms and surgeons. Results of Modified ASC1 Algorithm for 50 patients

i	t_i	OR	RR	Beds	i	t_i	OR	RR	Beds
1	0	1	1	1	26	330	3	5	29
2	0	2	2	2	27	330	4	6	30
3	30	3	3	3	28	330	5	7	31
4	30	4	4	6	29	420	2	5	15
5	60	5	5	4	30	420	3	7	32
6	60	6	5	8	31	420	4	7	33
7	60	2	6	9	32	420	5	6	35
8	90	3	2	10	33	420	6	2	36
9	90	4	4	13	34	480	1	4	37
10	120	1	3	14	35	480	6	1	38
11	120	2	6	17	36	480	3	2	40
12	120	6	7	16	37	510	5	2	34
13	150	3	2	18	38	540	2	6	41
14	180	4	2	19	39	540	3	2	42
15	180	5	1	5	40	570	5	5	43
16	210	1	1	20	41	600	3	5	45
17	210	1	2	21	42	600	1	8	46
18	210	3	8	22	43	630	2	8	48
19	240	4	2	23	44	630	5	1	51
20	240	6	6	24	45	630	6	3	54
21	270	1	3	26	46	660	1	2	25
22	270	2	3	27	47	660	7	3	52
23	270	3	4	28	48	690	2	4	55
24	300	6	4	7	49	720	3	5	12
25	330	1	1	11	50	720	6	8	53

Table 3.7: Program of rooms and surgeons. Results of Modified ASC1 Algorithm for 50 patients.

Notes : Examining On this example of 25 patient 4 rooms and 4 surgeon and we have enough RR and 55 beds, as result of scheduling by the modified ASC1 gives $C_{max} = 540mn$ with room occupancy $TON(\%) = 93,05\%$ it's very promising with average room occupancy 93,05% with great make-span 540 mn .

For example of 50 patient 6 rooms and 6 surgeon and we have enough RR and 55 beds, as result of scheduling by the modified ASC1 gives $C_{max} = 540mn$ with room occupancy $TON(\%) = 72,02\%$ and make-span 840 mn .

3.8.4 Comparison Scheduling of ASC1 and Modified ASC1

To evaluate the performance of scheduling algorithm there is two most important properties most consider the make-span and the occupancy of the critical resources .

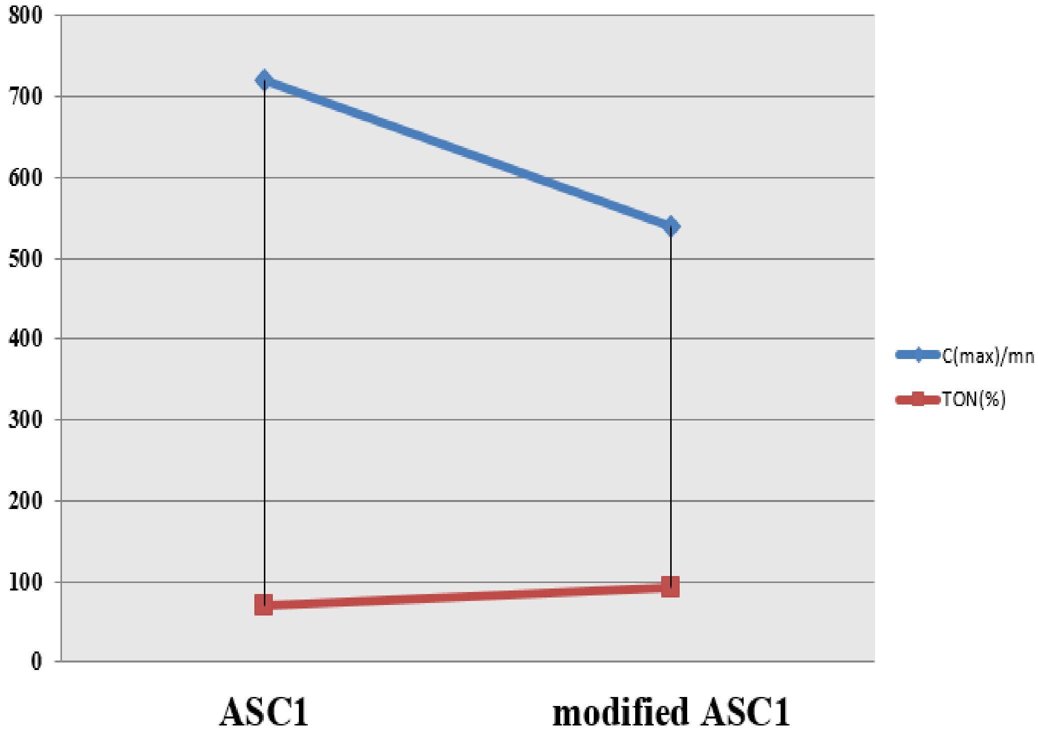

Figure 3.6: Comparison the make-span and the number of patients treated between ASC1 and modified ASC1

As we saw the results of ASC1 scheduling algorithm proposed by (Nouaouri, 2010) on the instance P.25.4.R_1 result of the model linear, we applied our Modified ASC1 on the same instance and we get interesting results such as the make-span of the original ASC1 was 720 mn but the modified ASC1 gives 540 mn and that is great advantage also for the second property the occupancy of the critical resources was $TON(\%) = 69,79\%$ by original ASC1 but the modified gives $TON(\%) = 93,05\%$ and there are more we have important note , that the modified ASC1 consider additional constraints such as RR and hospitalization beds .

Through these observations we conclude that the modified ASC1 is butter than original ASC1 on this case .

However, from the general perspective we can't confirm that the modified ASC1 is better than original ASC1 for a lot of reasons:

- because our limitation to implement our linear model with the additional constraints.
- consequence of the first reason we couldn't use the simulation to validate the optimization of the additional critical resources tha we consider

3.9 Conclusion

We have proposed in this chapter a methodological approach integrating optimization and simulation techniques for the decision-making for the operating block ,we adopted production systems scheduling based on flow shop scheduling on operating block . The goal is to minimize the cost of exploiting the operating rooms and minimize the closing date of the operating room after that we give agenda of Appointments. This methodological approach will help the decision-maker to validate the performance of operating block and also restructuring or designing a new operating theater. We developed and modified the scheduling ASC1 algorithm to do a planning and scheduling Appointments two-stage flow shop hybrid.This algorithm provides an accurate planning of operating rooms and surgeons with additional consideration of Post-appointment Monitoring Rooms and distribution of patients on hospitalization beds. The algorithm gives a high performance makespan equal to $540mn$ with occupancy rate equal to $93,05\%$ on instance $P.25.4.R_1$,however even when the results of the modified ASC1 was better than original ASC1 we can not prove that the modified ASC1 is better in every way because we couldn't implement our linear model to validate the optimization of the additional resources that we consider.

Conclusion and Prospects

An operating block, including operating rooms and recovery room (RR) is a sector whose management is particularly risky. To improve its efficiency in terms of operating costs, we organize appointments according to an operative planning meeting the constraints of availability of rooms and surgeons and recovery room (RR) with hospital beds. This problematic is as complex as it is important. Therefore focus on determining a feasible and effective operational program in exception situation. This program consists of daily scheduling of the operating room.

In this work, we dealt with a problematic scheduling of the start date of each patient's surgery with taking into account the limited human and material resources and schedule of each surgeon.

In the first step, we focus on the operational programming that presents the effective way we analyze the activities, resources and existing flows of the operating process. we have considered three general models, one concerning the strategy of block scheduling and open scheduling and modified block scheduling.

As part of second and third step, We have studied previous work and solutions to this problematics, we proposed a two-step solution, in the first step we did optimization (Make-span) block scheduling planning in exception situation. This scheduling models are treated as variants of the model "flow shop" hybrid two-stage, and are committed to using a linear programing with simulation is represented in sizing the critical resources. Secondly, we have solved a scheduling problematics such as flow shop hybrid. The propose algorithm is modified ASC1 which allows us to search for the best execution order of operations. The numerical experiments conducted have shown that the methods used allow the resolution of such problems and also offer quality solutions and start dates for each patient and the number of the operating room where the patient is treated with the number of the patient. recovery room (RR) used after the surgical operation and the number of hospital beds in disaster situation.

This work opens on issues that are intended to treat a larger number of patients, and to integrate other constraints related to various components of the hospital chain in exceptional situation (hospital services, availability of wake up beds and care staff, etc.).In this case, new approaches to resolutions, for the scheduling of appointments in the operating rooms, are necessary to remedy the problematic of calculation time which is sometimes prohibitive. However, in the case of a disaster with a limited effect, we plan to use our approach by reserving a capacity during the predictive scheduling of appointments in operating theaters, in order to be able to absorb any disturbances that will occur.

Here some future prospects: Take into account the time of change between two appointments, namely the time required to replace the equipment and prepare the instruments. We assume here that all necessary human and material resources, except surgeons, operating rooms and recovery beds, are always available. This is not always the case in the daily life of a hospital. To ensure consistency between planning (tactical level) and scheduling (operational level) decisions, it is necessary to find a mechanism that modifies the planning model according to the results of the scheduling. This work could serve as a basis for developing models closer to reality in order to better assist the hospital manager.

Bibliography

John T Blake and Michael W Carter. Surgical process scheduling: a structured review. *Journal of the society for health systems*, 5(3):17–30, 1997.

Brecht Cardoen. Optimizing a multiple objective surgical case scheduling problem, 2006. URL https://lirias.kuleuven.be/bitstream/123456789/120976/1/KBI_0625.pdf.

Brecht Cardoen. Determining surgery schedules on the operational level through column generation. 2007.

S. Chaabane. *Gestion prédictive des Blocs Opératoires: perating theatre predictive managemen*. 2004. URL https://books.google.dz/books?id=ROBKXwAACAAJ.

S Chaabane, A Guinet, N Smolski, M Guiraud, B Luquet, Eric Marcon, and J-P Viale. La gestion industrielle et la gestion des blocs opératoires. In *Annales francaises d'anesthesie et de reanimation*, volume 22, pages 904–908. Elsevier, 2003.

Tarek Chaari. *Un algorithme génétique pour l'ordonnancement robuste: application au problème du flow shop hybride*. PhD thesis, Université de Valenciennes et du Hainaut-Cambresis, 2010.

P Cuvillier. Bases d'organisation fonctionnelle d'un bloc opératoire: la charte opératoire. *Objectifs Soins octobre*, 57, 1997.

P Cuvillier and P Breack. Bloc opératoire: procédures, formation et démarche qualité. *Objectifs Soins novembre*, 57, 1997.

Ph.D. Franklin Dexter, M.D., M.B.A. Alex Macario, M.D., and Rodney D. Traub, Ph.D. Which algorithm for scheduling add-on elective cases maximizes operating room utilization? use of bin packing algorithms and fuzzy constraints in operating room management. *Anesthesiology*, 91(5): 1491, 1999. URL +http://dx.doi.org/.

M Barry Dumas. Simulation modeling for hospital bed planning. *Simulation*, 43(2):69–78, 1984.

A Dussauchoy, C Combes, F Gouin, and G Botti. Simulation de l'activité d'un bloc opératoire en utilisant des données recueillies au niveau d'un département d'anesthésie. In *Actes de la conférence GISEH*, 2003.

David Duvivier. Étude de l'hybridation des méta-heuristiques, application à un problème d'ordonnancement de type jobshop. Université du Littoral Côte d'Opale, 2000.

Patrick Esquirol, Pierre Lopez, and Pierre (19..-.... professeur de robotique) Lopez. *L'ordonnancement*. 1999.

Hongying Fei. *Vers un outil d'aide à la planification et à l'ordonnancement des blocs opératoires*. PhD thesis, 2006. URL http://www.theses.fr/2006TROY0004. Thèse de doctorat dirigée par Chu, Chengbin et Meskens, Nadine Optimisation et sûreté des systèmes Troyes 2006.

Hongying Fei, Nadine Meskens, and Chengbin Chu. A planning and scheduling problem for an operating theatre using an open scheduling strategy. *Computers & Industrial Engineering*, 58(2): 221–230, 2010.

Vincent Giard. Gestion de le production et des flux; production et techniques quantitatives appliquées à la gestion; ed. *Economica*, 2003.

Alain Guinet and Sondes Chaabane. Operating theatre planning. *International Journal of Production Economics*, 85(1):69–81, 2003. URL https://EconPapers.repec.org/RePEc:eee:proeco:v:85:y:2003:i:1:p:69-81.

S Hammami. Comment gérer l'urgence dans les services de soins. *DEA de Génie Industriel, Institut polytechnique de Grenoble*, 2002.

Sondes Hammami. *Aide à la décision dans le pilotage des flux matériels et patients d'un plateau médico-technique*. PhD thesis, Institut National Polytechnique de Grenoble-INPG, 2006.

Erwin Hans, Gerhard Wullink, Mark van Houdenhoven, and Geert Kazemier. Robust surgery loading. *European Journal of Operational Research*, 185(3):1038 – 1050, 2008. ISSN 0377-2217. doi: https://doi.org/10.1016/j.ejor.2006.08.022. URL http://www.sciencedirect.com/science/article/pii/S0377221706005844.

Paul Robert Harper and AK Shahani. Modelling for the planning and management of bed capacities in hospitals. *Journal of the Operational Research Society*, 53(1):11–18, 2002.

Habiba HOUARI. *Planification et Ordonnancement en temps réel d'un Job shop en utilisant l'Intelligence Artificielle*. PhD thesis, 2012.

Aïda Jebali. *Vers un outil d'aide à la planification et à l'ordonnacement des ressources dans les services de soins*. PhD thesis, Institut National Polytechnique de Grenoble-INPG, 2004.

Edward PC Kao and Grace G Tung. Bed allocation in a public health care delivery system. *Management Science*, 27(5):507–520, 1981.

Michael H Kennedy. *Bin-packing, Knapsack and Change-constrained Approaches to Operating Room Scheduling*. PhD thesis, Rensselaer Polytechnic Institute, 1992.

S Kharraja, S Chaabane, and E Marcon. Evaluation de performances pour deux stratégies de programmation opératoire de bloc. In *Conférence Internationale Francophone d'Automatique CIFA*, 2002.

Said Kharraja. *Outils d'aide à la planification et l'ordonnancement des plateaux médico-techniques*. PhD thesis, Saint-Etienne, 2003.

S Kim. C., horowitz, i., young, kk and buckley, ta (2000),". *Flexible bed allocation and performance in the intensive care unit", Journal of Operations Management*, 18(4):427–43.

Seung-Chul Kim and Ira Horowitz. Scheduling hospital services: the efficacy of elective-surgery quotas. *Omega*, 30(5):335–346, 2002.

M Kontak-Forsyth and AE Grant. Or booking policy: development and implementation. *Canadian Nursing Journal*, 13(1), 1995.

Agnès Letouzey. *Ordonnancement interactif basé sur des indicateurs: Applications à la gestion de commandes incertaines et à l'affectation des opérateurs*. PhD thesis, Institut National Polytechnique de Toulouse, 2001.

James M Magerlein and James B Martin. Surgical demand scheduling: a review. *Health services research*, 13(4):418, 1978.

E Marcon. Influence de l'ordonnancement des interventions dans les salles opératoires sur le fonctionnement de la salle de soins post-interventionnels (sspi). In *2ème Conférence Internationale Francophone en Gestion et Ingénierie des Systèmes hospitaliers*, 2004.

Issam Nouaouri. *Gestion hospitalière en situation d'exception: optimisation des ressources critiques*. PhD thesis, Artois, 2010.

P Patterson. What makes a well-oiled scheduling system? *OR manager*, 12(9):19–23, 1996.

Zbigniew H Przasnyski. Operating room scheduling. *AORN journal*, 44(1):67–68, 1986.

Francisco J Ramis, Jorge L Palma, and Felipe F Baesler. The use of simulation for process improvement at an ambulatory surgery center. In *Proceedings of the 33nd conference on Winter simulation*, pages 1401–1404. IEEE Computer Society, 2001.

JC Ridge, SK Jones, MS Nielsen, and AK Shahani. Capacity planning for intensive care units. *European journal of operational research*, 105(2):346–355, 1998.

Benoît Roland, Chr Di Martinelly, Fouad Riane, and Yves Pochet. Scheduling an operating theatre under human resource constraints. *Computers & Industrial Engineering*, 58(2):212–220, 2010.

Nour El Houda Saadani and Alain Guinet. Heuristics for operating theatre scheduling: Following the patient. In *Supply Chain Forum: an International Journal*, volume 13, pages 38–49. Taylor & Francis, 2012.

Nour-El-Houda Saadani, Alain Guinet, and Sondes CHAABANE. ORDONNANCEMENT DES BLOCS OPERATOIRES. In *6e Conférence Francophone de MOdélisation et SIMulation " Modélisation, Optimisation et Simulation des Systèmes : Défis et Opportunités "*., pages 1–7, Rabat, Morocco, April 2006. URL https://hal.archives-ouvertes.fr/hal-00379642.

MEHENNI Tahar. *UTILISATION DES METAHEURISTIQUES POUR RESOUDRE UN PROBLEME D'ORDONNANCEMENT SUR MACHINE A CONTRAINTE DE RESSOURCE NON RENOUVELABLE*. PhD thesis, Université Mohamed Boudiaf de M'sila, 2006.

Karim Tamani. *Développement d'une méthodologie de pilotage intelligent par régulation de flux adaptée aux systèmes de production*. PhD thesis, Université Savoie Mont Blanc, 2008.

Jean-Sébastien Tancrez, Benoît Roland, Jean-Philippe Cordier, and Fouad Riane. Étude de la perturbation par les urgences du planning opératoire. *Logistique & Management*, 19(2):43–52, 2011.

P.T. Vanberkel, Richardus J. Boucherie, Elias W. Hans, Johann L. Hurink, Wineke A.M. van Lent, W.A.M. van Lent, Wim H. van Harten, and Willem H. van Harten. *An exact approach for relating recovering surgical patient workload to the master surgical schedule*. Number 1908 in Internal Report (Memorandum). Stochastic Operations Research (SOR), 11 2009. ISBN ISSN 1874-4850.

JAN MH VISSERS. Patient flow based allocation of hospital resources. *Mathematical Medicine and Biology: A Journal of the IMA*, 12(3-4):259–274, 1995.

Jan MH Vissers. Patient flow-based allocation of inpatient resources: a case study. *European journal of operational research*, 105(2):356–370, 1998.