 https://doi.org/10.1051/e3sconf/202341201074

Planning and scheduling of operating theater under resources constraints: State of the art and future trends and impact on energy consumption

Oumaima Hajji Soualfi[1], Abdellah El barkan[1], Bilal Harras[1]

[1]Faculty of Sciences and Techniques, Mechanical Engineering Laboratory, Sidi Mohamed Ben Abdellah University, Fez, Morocco.

Abstract. The management of operating theaters is currently the subject of considerable discussion, particularly with regard to the use of human and material resources, which are available in limited quantities. The first part of this paper deals with the management of hospital systems and operating theaters. In the second part, we review the main studies on planning surgical procedures under resources constraints, as well as the different methods for solving planning and scheduling problems in operating theaters. A comparative analysis is carried out in order to identify the fundamental ideas leading to the adoption of a new model capable of meeting the needs and satisfying the different constraints of this management. This article shows that planning and scheduling play a major role in the management of an operating theater, which remains difficult given the multiplicity of determinants involved. In this work, we describe the problem of planning and scheduling operating theaters according to several authors, aiming to evaluate and improve existing operating programs to make them feasible and of good quality. The depletion of the world's available energy resources requires the construction of hospital buildings that respect the environment and take into account energy efficiency while meeting different needs.

1 INTRODUCTION

The quality of life of citizens depends mainly on their well-being, therefore, health is one of the main concerns of society. Health systems, and in particular hospitals, are confronted not only with legislative and budgetary constraints but also with a strong competitiveness based on the quality of the care offered in hospital departments, emergency rooms and operating theaters. According to several studies [1], the operating theater constitutes nearly 10% of a hospital's operating budget because it involves various costly and scarce human and material resources such as surgeons, anesthetists, nurses. The operating theater is the area of the hospital where surgical care is provided to patients. The nature of this care requires a multitude of medical equipment and a high level of human skill. Therefore, the operating room is the resource-dense core of a hospital. It constantly interacts with different sectors, departments and medical activities. For example: "The operating room is at the interface of many activities: surgery, obstetrics, anesthesia, functional explorations, radiology and

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

biology [2]". Several researchers are interested in the management of operating theaters, trying to improve the functioning of this sector to maximize its efficiency and patient satisfaction. The operating theater is not only the most important and costly sector, but it is also the most complex service to manage and plan, given the many variables, the high number of actors, the difficulty of standardization and coordination of surgical interventions. The optimization of its functioning is therefore one of the first concerns of the managers and actors who operate there [3]. The objective of this article is to present a review of the literature that has approached, analyzed and developed the problems of planning and scheduling of surgical activities under resource constraints by proposing a homogeneous notation that clearly identifies the problem in the first part. The second part will focus on the positioning of the problem in terms of complexity, the different approaches of resolution, the adopted research methodology and on synthesis tables regrouping all the works already treated in the literature leading to a comparative analysis and to determine future researchs.

2 APPROACH AND RESEARCH METHODOLOGY

Conducting relevant research is based on different interrelated pillars, ranging from developing the main topic to synthesizing the information and evaluating it through a literature review. In order to establish as general and complete a bibliography as possible concerning the resolution of planning and scheduling problems in resource-constrained operating theaters. Several databases were primarily examined: PubMed/MEDLINE, Web of Science, Scopus, Embase, and the Cochrane Library. Moreover, the choice of these keywords or descriptors corresponding to the problems considered constitutes one of the essential steps of the research. Indeed, the keywords that were used are: planning; scheduling; operating theater; resource constraints; modeling; optimization. In addition, several combinations of the above-mentioned descriptors were also developed in order to refine the results. The search terms in each database included all MeSH terms and/or keywords associated with our research question. Search terms were combined using the Boolean operators "OR" and "AND" as appropriate. Search dates were limited to articles published after 1999 for relevance to current operating theater management practices. The selected literature includes about 600 documents, divided in a good proportion between scientific articles and some doctoral theses. A careful review allowed us to find 72 documents of interest for recent studies conducted between 1999 and 2023. In order to ensure the inclusion and review of the most relevant articles, the literature search protocol (Figure 1) was based on selecting journal articles and theses published in English and French.

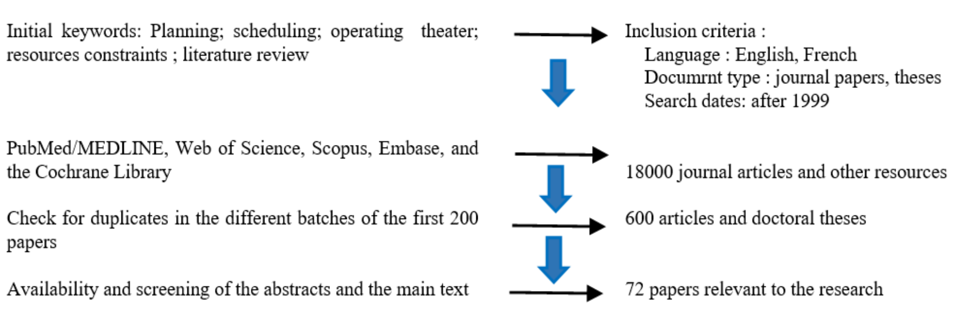

Fig.1. Procedure and research methodology.

Figure 2 describes the evolution of the number of articles selected for our literature review. By analyzing the figure, we can see that the number of publications concerning the problems of planning and scheduling operating theaters has been variable. The top of the peak is observed in 2008 and 2010.

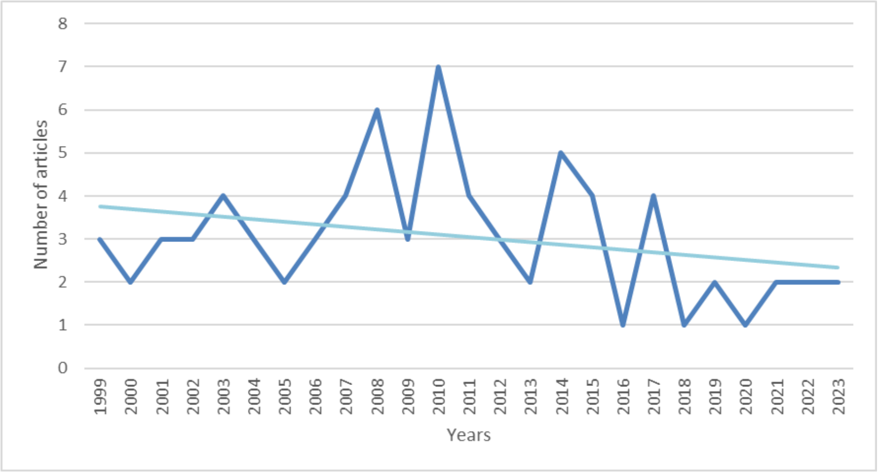

Fig.2. Evolution of publications of the problems of planning and scheduling of operating theater.

3 ABBREVIATIONS

In order to facilitate our work, we propose table 1 which contains all the abbreviations of the exact and approximate methods which will be used subsequently.

Table1. Abbreviation of exact and approximate methods.

Methods	Abreviation
Heuristics	H
Meta-heuristics	MH
Branch and Bound	BB
Branch and Price	BP
Integer programming	IP
Mixed integer program	MIP
Simulated annealing	SA

column generation	CG
Genetic algorithm	GA

4 OPERATING ROOM SCHEDULING RESOURCE BASED

a. Predictive programming focused only on operating rooms

Optimal use of the available operating room capacity is a goal of a very popular performance [4, 5, 6, 7, 8]. In some works of scheduling, overtaking normal hours is not allowed [9, 10, 11]. In others, although overtime is allowed, it is better to minimize it [12, 13,14, 15, 16]. The authors of [16] seek to maximize the room occupancy rate and minimize cancellations due to exceeding the time limits regular opening hours. The authors' objective was to maximize the occupancy rate operating rooms [6]. The authors proposed an exact method to construct the operating program. Due to the complexity of the method, they added a heuristic to their proposal. Later, the same authors took into account the availability of surgeons and have proposed as [17] a resolution approach based on a genetic algorithm [18]. The authors aimed to maximize the room occupancy rate while respecting regular opening hours. They proposed a two-step approach [19, 20]: Static planning phase in which the planning tool smooth's the interventions during operating room opening hours in order to minimize time overruns and therefore the risk of non-achievement. Dynamic step, the tool estimates by stochastic calculation the risk of non-implementation of interventions, then helps the negotiation between the different actors to make the necessary changes. The authors' objective was to maximize the rate of operating rooms use and to minimize over time, and therefore to minimize cancellations of scheduled operations [14]. They propose to deal with the problem of planning (called robust) using several construction heuristics and two neighbourhood searches (simulated annealing algorithm and greedy algorithm). An estimated safety margin is assigned at each of the rooms to absorb the variability of the durations. The cost calculation includes a fixed cost of opening rooms of operation and a variable cost of overtime on a daily basis determined [15]. The objective is to minimize the cost ceiling resulting from the cumulative drift of uncertain duration of interventions. The authors describe two types of models. The prime is a two-step stochastic linear program with binary decisions in the first step and a simple remedy in the second step (exact robust solution). The second is a mathematical model with a heuristic to find the solution.

b. Predictive programming including operating rooms and recovery room

Much work has been done on the problem of operating theater planning, with the constraint of the availability of recovery beds [4, 21, 22, 23]. The scheduling problem is likened to a two-story hybrid flow shop. The methods of resolutions adopted are: hybrid genetic algorithm, Taboo search algorithm and particle swarm optimization algorithm. [24] determine the start times for surgeries in the operating room by depending on the availability of beds in the post-anaesthesia care unit (PACU) and uncertainty about the duration of tasks. The problem is approached as a workshop flexible with fuzzy times. To solve this problem, they developed an algorithm genetics that determine the order of surgical interventions and heuristics for start times determination. The operative programming problem was solved in two stages. First, the authors proposed a linear integer program for planning. The complexity of the proposed model does not allow its resolution by a commercial solver, the authors had recourse to a heuristic inspired by the Hungarian method [25]. Secondly, in addition to operating rooms, the authors took into account the recovery beds. This problem was modeled as a two-story hybrid flow shop with a no-wait constraint, since the authors assume that operated patients should be directly transferred to the recovery room. To develop the operating program, [26] adopted a two-step approach. First stage, planning, the surgical acts are assigned to day rooms. The authors proposed a MILP the objective function was expressed in terms of cost. Step two, scheduling, the authors took into consideration the availability of recovery beds. They treated this problem as a two-story hybrid flow shop with the objective of minimizing overtime. Two different strategies were tested. In the first, no questioning of the assignment of interventions to rooms, while with the second, some assignments can be modified. In [27], the authors equated the scheduling problem with that of a two-story hybrid flow shop. The goal considered was to minimize the makespan in the recovery room. The authors of [4] solved the two sub problems (Advanced scheduling and Allocation scheduling) sequentially. They proposed a mathematical model in whole numbers with multi-objectives (to minimize the cost of overtime and to minimize the hours of underutilization). This model is solved by heuristic procedures and by a "Branch-and-Price" type algorithm, based on the generation of columns. The Allocation scheduling sub problem was modelled as that of a two-story hybrid flow shop with the objective of minimizing the makespan of the operating rooms and the recovery room. A hybrid genetic-Taboo algorithm solves the proposed hybrid flow shop.

c. Predictive programming including patient transport resources (stretcher-bearers)

The authors [28] considered in their work: the go stretcher, operating theaters, recovery stations and return stretcher bars. This set is assimilated to a hybrid flow shop with cycles, in the form of a job shop with duplicated machines. The goal is to minimize the makespan. The authors proposed a heuristic using a variation of the Palmer index applied with the NEH (Nawaz, nscore and Ham) and LBM rules. The authors [29] envisage four stages: the transfer of the patient from his room to the operating room, the surgical procedure, the transfer of the patient to the awakening and transferring the patient from his wake-up bed to his room. The authors hold also account for cleaning the operating room after the procedure. Awakening is scheduled in operating rooms if transfer to the recovery room is not possible. To perform the scheduling, the authors propose a mathematical model and use a relaxation Lagrangian to solve it. The envisaged objective is to minimize the time taken to complete the different stages of the patient's journey. Four years later, the same authors assimilate the 4-step hybrid flow shop problem and solve it using Lagrangian relaxation [30].

d. Predictive programming including the intensive care unit (ICU)

Certain resources outside the unit influence the operating programs, in particular the ICU. Indeed, a patient requiring intensive care after surgery cannot be scheduled only if there is a bed available in the intensive care room. In [31, 32, 33], authors focus their work on the management of intensive care units. In [31], the authors presented a study of the performance of an intensive care unit using a simulation tool. The intensive care unit is modelled as a queue multiserver. Performance indicators are the probability that a patient will be accepted without expectation or rejection rate. In [32, 33], the same authors assessed five ICU bed allocation strategies. The aim of their study is to minimize the number of elective operations cancelled due to lack of beds in the ICU. The authors propose in their model, concerning the random arrival variables of ICU patients, service times for non-elective patients and service times of elective patients, the probability distribution laws that these variables follow. The reserving beds in the intensive care unit for elective operations would reduce by one significantly the number of cancelled interventions. As a result, the author recommend reserving a number, estimated by calculation, of beds for the care of elective patients. The authors of [34] envisioned a three-storey flow shop for the development of the operating program. In addition to the operating rooms and the post-intervention (wake-up) service, the third floor is the intensive care unit. The aim was to reduce the gap, for all surgeons, between the weekly supply and demand for intensive care beds for operated patients.

e. Predictive programming including other resources

For the development of the operating program, other human and material resources have been taken into account. In [35,36], the authors attempts to determine the capacity of resources such as recovery beds and stretcher bearers, using a simulation of discrete events. In a context of outpatient surgery, the authors [37] modelled the problem of planning by that of a flow shop in two stages with a constraint without waiting between the two floors. Rooms operations are the first floor with surgeons as the main resource. The second floor represents all recovery beds, nurses being the main resource. Two objectives are envisaged: to minimize the makespan and the number of nurses in the recovery room. To solve this problem, a taboo search heuristic was used.[38] examine the resources of the problem and use a dual bin-packing model. Given the number of days and resources available for the schedule, they maximize the number of surgeries to be scheduled. They model the problem as a MILP and develop a heuristic to solve the problem without taking into account the second step (recovery). In [39], each surgical intervention is described as a predetermined sequence of activities with a maximum allowed waiting time between two consecutive activities, a set of resources being assigned to each activity. The authors took into account the intensive care unit in addition to the resources of the operating rooms. The problem is modelled as a (multi mode blocking job shop). The goal is to minimize the makespan, The authors develop a mixed linear number programming modelintegers (MILP). The authors [40] consider two categories of resources, renewable (surgeons, anaesthetists, nurses) and non-renewable (products, pharmaceuticals and sterilized equipment). The proposed mathematical model aims to minimize the costs of opening operating rooms and minimize the additional hours. Figure 3 presents a summary of works interested by programming of operating room focused on the various resources.

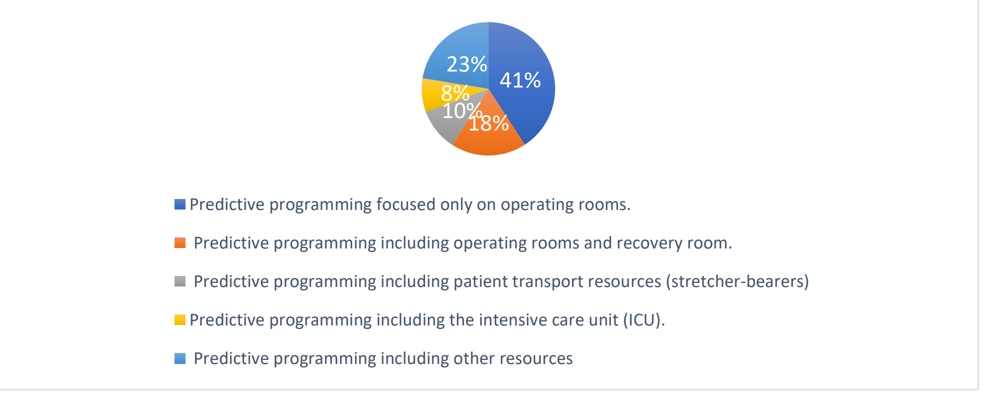

Fig.3. Percentage of jobs interested in resource-based operating room programming.

5 LITERATURE REVIEW OF THE PLANNING AND SCHEDULING OF SURGICAL INTERVENTIONS

a. Notations

The notation proposed for operative planning, based on three fields is similar to the work [41] for scheduling problems. The first field, denoted α, is the description of the considered structure, that is to say the characteristics of the operating rooms, surgeons and equipment. The second field, noted β, describes the management rules that govern the model, that is to say the rules that establish the interaction between surgical interventions (IC) and the different resources. The third field, noted γ, describes the objectives considered.

Fieldα: Structure

Rn : Number of rooms: n corresponds to the number of rooms in the operating room.
Sn: Number of surgeons: n corresponds to the number of surgeons intervening in the
the
operating room.
En: Number of equipment: n indicates the number of equipment in the operating room.
Ae: Availability of equipment is different from the planning of the rooms.
As: Availability of surgeons is different from the planning of the rooms.
ExperS: Duration of the operation depends on the experience of the surgeon.
PrefS: Preference of surgeons to work in the morning or in the afternoon is taken into account.

Fieldβ: Management rules

Programming model (OS, BS, MBS): three models of operative planning are identified.

OS : Open Scheduling
BS : Block Scheduling
MBS : Modified Block Scheduling
NonProg: Non-programmed patients (Non Prog) do not belong to the list of programmed or to be programmed interventions
PriorP: Allocation of the patient to the room from the waiting list depends on the priority of his intervention
ChoiceP: Patient has the possibility to choose his surgeon

Fieldγ :goals

OT: Number of overtime to minimize.
OR: Room occupancy rate to be maximized.
N-OR: Number of operating rooms to be minimized.
NUS: Number of unaffected surgeries in the rooms to be minimized.
NAS: Number of affected surgeries to be maximized.
NS: Number of slots allocated to the different surgeons to be minimized.
Cw: Cost of waiting for patients to be minimized.
C_T: Total cost of intervention to be minimized.
CAU : Average costs of under-utilization of the rooms to be minimized.
CAO: Average costs of overuse of rooms to be minimized.
Cur: Cost of using the rooms.
Cuur: Cost of underutilization of rooms.
C_{NP}: Costs of non-planning of patients scheduled over the planning horizon to be minimized.
Tw: Waiting time between two surgeries to be minimized.

C_O: Cost of opening rooms during overtime to be minimized.
GWSD: Gap between weekly supply and demand of all surgeons to be minimized. That is to say the difference between the opening time of the operating room (which is available) and the number of hours of intervention required by all surgeons in the week.
D_{ADID}: Difference between the appointment date and the intervention date to be minimized.
NMR: Number of multipurpose rooms to be minimized.
NT: Number of teams needed to minimize.

b. Resolution methods

Solving optimization problems relies on technical operations research. Several problem solving approaches have been developed to deal with various planning problems in different types of environment. The methods of solving planning problems can be classified into two types of methods: exact methods and approximate methods. The exact methods aim to determine the optimal solution to the problem but can be very time consuming and memory intensive for large problem cases. They depend on the magnitude of the problems treated and jobs to be planned [42]. They often require a very great computational effort [43]. The approximate methods aim to obtain the best solution, but the optimality is not guaranteed. They are often applied to solve NP-hard problems. Their objective is to considerably reduce the computational effort by reducing the space of solutions to explore [44].

c. Synthesis for the fieldα

In the field α, the authors of all the articles studied gave the minus one characteristic of the considered structure. The authors of three articles considered the surgeon's experience in the construction of the operating schedule [36, 45]. Only one article considers preference of the surgeon in the choice of his assistant [46]. Several articles in the literature whose characteristics are summarized in table 2 were studied. The "X" sign is present in a box if the parameter at the header of the table column is considered in the article indicated on the row.

Table 2. field α – Structure.

Authors	Rn	Sn	En	Surgeon			Equipement
				As	ExperS	PrefS	Ae
Kharraja et al.,(2004) [47]	X	X		X			
Fei et al.,(2005b) [48]	X						
Kharraja et al.,(2006) [36]	X	X		X	X		
Jebali et al.,(2006) [28]	X	X	X	X			X
Hammami et al.,(2007) [49]	X	X		X			
Chaabane et al.,(2007) [50]	X	X	X	X			X
Hans et al.,(2008) [12]	X						
Fei et al.,(2008) [51]	X						
Chaabane et al.,(2008) [52]	X	X		X			
Iser et al.,(2008) [53]	X	X		X			
Fei et al.,(2010) [5]	X	X		X			
Rodier,(2010) [54]	X	X		X			
Roland et al.,(2010) [46]	X	X		X		X	
Aniba et Jebali.,(2011) [55]	X						
Agnetis et al.,(2012) [56]	X	X		X			

Bouguerra et al.,(2015) [57]	X	X		X			
Razmi et al.,(2015) [58]	X		X				X
Pariente et al.,(2015) [45]	X	X		X	X		
Chraibi, (2015) [59]		X	X	X			
Alejandra Duenas ,(2017) [60]	X	X	X				
Arnaud Augustin,(2017) [61]	X		X				
Janvier Pensi, ,(2017) [42]			X				
Linda Wahyuni ,(2018) [62]	X		X				
Seyda Gür, (2019) [63]	X	X	X				
Bilal Bou Saleh, (2020) [64]	X	X	X				
Valérie Dorval, (2020) [65]	X	X	X				
Arezki et al,(2020) [66]	X	X					

d. Synthesis for the field β

As shown in table 3, we see that the majority of articles used the open programming model Only [5, 12, 28, 45, 46, 48, 51, 54, 55, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66]. Few articles that have used open scheduling and scheduling by pre-allocation of time slots. The different management rules for models in the literature that we have studied are summarized in table 3. The most frequent scheduling model is the open scheduling model or Open Scheduling. A single article gives priority to the affection of patients in the construction of the operating schedule. Three articles give patients the option of choosing their surgeon.

Table3. field β–management rules.

Authors	Programming model			Patient		
	OS	BS	MBS	NonPro	PriorP	ChoiceP
Kharraja et al.,(2004) [47]		X	X			
Fei et al.,(2005b) [48]	X					
Kharraja et al.,(2006) [36]	X	X				
Jebali et al.,(2006) [28]	X					
Hammami et al.,(2007) [49]			X			
Chaabane et al.,(2007) [50]	X		X			
Hans et al.,(2008) [12]	X					
Fei et al.,(2008) [51]	X					
Chaabane et al.,(2008) [52]	X	X				
Iser et al.,(2008) [53]		X				
Fei et al.,(2010) [5]	X					X
Rodier,(2010) [54]	X					
Roland et al.,(2010) [46]	X					
Aniba et Jebali.,(2011) [55]	X			X		
Agnetis et al.,(2012) [56]	X	X			X	
Bouguerra et al.,(2015) [57]	X					X
Razmi et al.,(2015) [58]	X			X		
Pariente et al.,(2015) [45]	X					
Chraibi, (2015) [59]	X					
Alejandra Duenas ,(2017) [60]	X					
Arnaud Augustin,(2017) [61]	X					
Janvier Pensi, ,(2017) [42]	X	X				
Linda Wahyuni ,(2018) [62]	X					
Seyda Gür, (2019) [63]	X					
Bilal Bou Saleh, (2020) [64]	X					

Valérie Dorval, (2020) [65]	X					
Arezki et al,(2020) [66]	X					

e. Synthesis for the field γ

We identified several criteria in the different models of the studied literature. Among the most widely used criteria, we note the intervention cost to be minimized, present in the articles of [28, 47, 50, 51, 58, 59]. We also have the waiting time between two interventions to minimize, present in nine articles. Then the cost of opening rooms during overtime to be minimized appears in five papers. The room occupancy rate to be minimized is considered in four papers. The criteria taken into account in the different models proposed in the literature are summarized in table 4. The minimization of costs, overtime, room occupancy rate and waiting time between two surgical operations are most common.

Table 4. Field γ– Goals.

Authors	OT	DADID	OR	N-OR	NT	NMR	Cur	NUS	NS	CAO	CT	Cuur	Tw	CNP	NAS	GWSD	CO	CAU
Kharraja et al.,(2004) [47]															X	X		
Fei et al.,(2005b) [48]											X							
Kharraja et al.,(2006) [36]																X		
Jebali et al.,(2006) [28]											X	X						X
Hammami et al.,(2007) [49]								X	X									
Chaabane et al.,(2007) [50]											X						X	
Hans et al.,(2008) [12]	X		X															
Fei et al.,(2008) [51]											X							
Chaabane et al.,(2008) [52]													X			X	X	
Iser et al.,(2008) [53]	X																	
Fei et al.,(2010) [5]	X		X										X					
Rodier,(2010) [54]				X	X	X												
Roland et al.,(2010) [46]							X										X	
Aniba et Jebali.,(2011) [55]										X				X			X	X
Agnetis et al.,(2012) [56]			X															
Bouguerra et al.,(2015) [57]			X										X					
Razmi et al.,(2015) [58]											X						X	
Pariente et al.,(2015) [45]		X											X		X			
Chraibi, (2015) [59]				X							X							
Alejandra Duenas ,(2017) [60]				X		X	X											
Arnaud Augustin,(2017) [61]													X					
Janvier Pensi, ,(2017) [42]													X					
Linda Wahyuni ,(2018) [62]				X									X					
Seyda Gür, (2019) [63]				X	X	X												
Bilal Bou Saleh, (2020) [64]				X														
Valérie Dorval, (2020) [65]			X	X														
Arezki et al,(2020) [66]				X	X													

f. Synthesis of resolution methods

In Table 5, we summarize the methods encountered in the treated literature We can see that these methods are varied. First of all, among the methods exact, Linear Programming has been used in sixteen papers. Other approaches are proposed to find solutions and limit computation times. Many authors used a branch algorithm and price. [51] used a branch and bound algorithm. Different heuristics were used, heuristics dedicated to problems of operative planning such as heuristics of [36, 46, 47, 52, 53, 54, 55, 56, 57, 66]. Metaheuristics are also present with [12, 46, 58, 60]. We also find a hybridization of methods between heuristic, simulation method and metaheuristics [42, 54]. Other authors consider a two-stage stochastic scheduling problem for a weekly operating room with an exponential number of possible scenarios [67]. Computational results show that the proposed model is capable of finding optimal solutions [67]. [68] have proposed a simulation optimization approach to find heuristic solutions to a surgical programming problem, followed by a discrete-event simulation model to numerically evaluate the performance of surgical procedures. To solve the difficult integrated planning and scheduling problem, [69] devise a branch-and-price-and-cut algorithm based on the time-indexed formulation of the problem.

Table 5. Review of operating theater planning and scheduling modeling.

Authors	IP	MIP	BB	BP	H	S	H+S	CG	MH	H+S+MH	DAI
Kharraja et al.,(2004) [47]	X				X						
Fei et al.,(2005b) [48]	X			X							
Kharraja et al.,(2006) [36]	X				X						
Jebali et al.,(2006) [28]	X	X									
Hammami et al.,(2007) [49]	X										
Chaabane et al.,(2007) [50]	X										
Hans et al.,(2008) [12]							X		X		
Fei etal.,(2008) [51]	X		X					X			
Chaabane et al.,(2008) [52]					X						
Iser et al.,(2008) [53]					X						
Fei e tal.,(2010) [5]	X							X			
Rodier,(2010) [54]	X				X		X			X	
Roland et al.,(2010) [46]	X				X				X		
Aniba et Jebali.,(2011) [55]	X				X						
Agnetis et al.,(2012) [56]	X				X						
Bouguerra et al.,(2015) [57]	X				X						
Razmi et al.,(2015) [58]	X								X		
Pariente et al.,(2015) [45]	X										
Chraibi, (2015) [59]		X									
Alejandra Duenas ,(2017) [60]									X		
Arnaud Augustin,(2017) [61]	X										
Janvier Pensi, ,(2017)										X	

[42]											
Bilal Bou Saleh, (2020) [64]											X
Valérie Dorval, (2020) [65]	X					X					
Arezki et al,(2020) [66]					X						

S:simulation;**H+S:**heuristic+simulation ; **DAI** : Distributed Artificial Intelligence.

Figure 4 shows the percentage of resolution methods used to plan and schedule operating theaters.

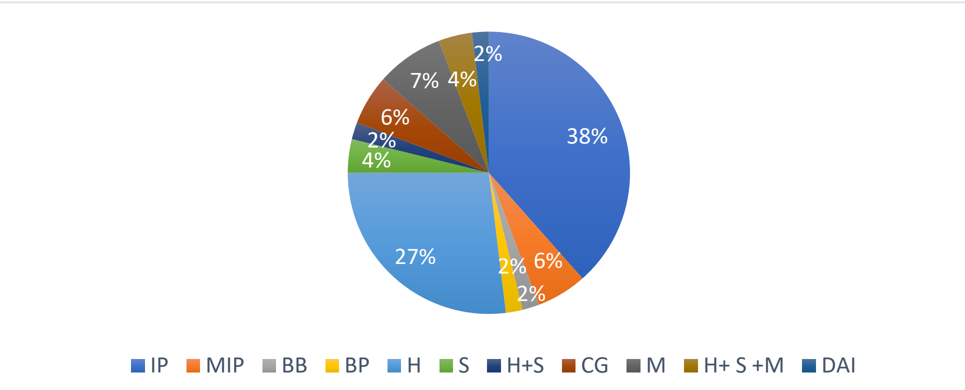

Fig.4. Percentage of Solving Methods Used.

6 OPERATING THEATER AND IMPACT ON ENERGY CONSUMPTION

The management of healthcare services provided to patients in hospitals is becoming increasingly valuable. Hospitals want to reduce costs on the one hand, and increase patient satisfaction on the other. The operating theatre is the largest cost and revenue center in a hospital [70]. However, its management is difficult because of conflicting priorities and different preferences of the parties involved [70], but also because of the scarcity of expensive resources. In addition, health care managers must meet the increasing demand for surgical services [70]. The increasing economic problems due to deteriorating environmental conditions and depleting energy sources in today's world challenge the efforts to design environmentally compatible hospital buildings, which consider energy efficiency also covering different functions and requirements [71]. However, in the operating theaters, where the comfort requirements of the hospital have been used to the fullest, efforts to provide green criteria and energy efficiency have remained limited [71]. Operating theatres have increased energy consumption requirements to keep them functioning properly [72]. Installed heating, ventilation and air conditioning (HVAC) systems represent the largest installed electrical capacity [72]. Energy-saving systems and techniques can reduce energy consumption without sacrificing comfort or service quality, while improving air sanitation [72]. Energy savings mean money savings that can be invested in other priorities to improve specific medical services [72]. Energy-efficient design and operation of mechanical systems can allow continuous operation of operating theatres support systems without the need for shutdowns that may compromise the integrity of the operating room in order to realize cost savings [72].

In general, energy efficiency must be strongly supported at the highest management level, as energy conservation is a never-ending battle [72]. Operating conditions and new technologies must be continually evaluated, new systems and techniques must be targeted for possible incorporation and reasonable goals and long-term energy targets must be set [72].

7 CONCLUSION AND PERSPECTIVES

The classification described and the notation proposed allowed us to structure the state of the art concerning the problem of operative planning. We made the summary of the three fields defined in the rating. The resolution methods proposed by the cited authors have been presented. The observation is that the assumptions and constraints taken in account are specific to each author. The "Open Scheduling" (OS) is the most widely used. Operative programming is mainly handled using the linear programming in integers. We have dedicated this work to a literature review sweeping different established approaches to solve the problem in question. Few authors have applied their solutions to real cases, hence the need to deepen our research to find better answers, in order to promote the optimization of the operating room.

References

1. A. Macario, F. Dexter, R. D. Traub. Hospital profitability per hour of operating room time can vary among surgeons. Anesthesia & Analgesia, 93(3), 669-675 (2001).
2. M. Revel, G. Nicolas, C. Bara, M. O. Moreau, D. Nicolle, M. Duret. Synthèse des travaux du groupe sur l'implantation et l'organisation des plateaux techniques. Ministère de la santé, de la famille, et des personnes handicapées, 35p. (2003).
3. M. Lamiri, J. Dreo, X. Xie. Operating room planning with random surgery times. *In 2007 IEEE International Conference on Automation Science and Engineering* (pp. 521-526). (2007, September).
4. A. Testi, E. Tanfani, G. Torre. A three-phase approach for operating theatre schedules. Health care management science, 10(2), 163-172. (2007).
5. H. Fei, N. Meskens, C. Chu. A planning and scheduling problem for an operating theatre using an open scheduling strategy. Computers & Industrial Engineering, 58(2), 221-230. (2010).
6. Y. Liu, C. Chu, K. Wang. A new heuristic algorithm for the operating room scheduling problem. Computers & Industrial Engineering, 61(3), 865-871. (2011).
7. F. Bonvoisin, *Evaluation de la performance des blocs opératoires: du modèle aux indicateurs* (*Doctoral dissertation, Université de Valenciennes et du Hainaut-Cambresis*). (2011).
8. S. P. Devi, K. S. Rao, S. S. Sangeetha. Prediction of surgery times and scheduling of operation theaters in ophtholmology department. Journal of medical systems, 36(2), 415-430. (2012).
9. B. Addis, G. Carello, A. Grosso, E. Tànfani. Operating room scheduling and rescheduling: a rolling horizon approach. Flexible Services and Manufacturing Journal, 28(1), 206-232. (2016).
10. M. E. Bruni, P. Beraldi, D. Conforti. A stochastic programming approach for operating theatre scheduling under uncertainty. IMA Journal of Management Mathematics, 26(1), 99-119. (2015).
11. P. Cappanera, F. Visintin, C. Banditori. Addressing conflicting stakeholders' priorities in surgical scheduling by goal programming. Flexible Services and Manufacturing Journal, 30(1), 252-271. (2018).
12. E. Hans, G. Wullink, M. Van Houdenhoven, G. Kazemier. Robust surgery loading. European Journal of Operational Research, 185(3), 1038-1050. (2008).
13. B. T. Denton, A. J. Miller, H. J.Balasubramanian, T. R. Huschka. Optimal allocation of surgery blocks to operating rooms under uncertainty. Operations research, 58(4-part-1), 802-816. (2010).

14. D. Min, Y. Yih. Scheduling elective surgery under uncertainty and downstream capacity constraints. European Journal of Operational Research, 206(3), 642-652. (2010).
15. S. Rachuba, B. Werners. A robust approach for scheduling in hospitals using multiple objectives. Journal of the Operational Research Society, 65(4), 546-556. (2014).
16. Y. Wang, J. Tang, R. Y. Fung. A column-generation-based heuristic algorithm for solving operating theater planning problem under stochastic demand and surgery cancellation risk. International Journal of Production Economics, 158, 28-36. (2014).
17. P. Landa, R. Aringhieri, P. Soriano, E. Tànfani, A. Testi. A hybrid optimization algorithm for surgeries scheduling. *Operations Research for Health Care, 8*, 103-114. (2016).
18. I. Marques, M. E. Captivo, & M. Vaz Pato. An integer programming approach to elective surgery scheduling. OR spectrum, 34(2), 407-427. (2012).
19. D. Conforti, F. Guerriero, R. Guido. A multi-objective block scheduling model for the management of surgical operating rooms: New solution approaches via genetic algorithms. *In 2010 IEEE workshop on health care management (WHCM)* (pp. 1-5). IEEE. (2010, February).
20. I. Marques, M. E. Captivo, M. V. Pato. Scheduling elective surgeries in a Portuguese hospital using a genetic heuristic. Operations Research for Health Care, 3(2), 59-72. (2014).
21. E. Marcon, K. Said, & S. Gerard. Minimization of the risk of no realization for the planning of the surgical interventions into the operating theatre. In *ETFA 2001. 8th International Conference on Emerging Technologies and Factory Automation. Proceedings (Cat. No. 01TH8597)* (pp. 675-680). IEEE. (2001, October).
22. E. Marcon, , S. Kharraja G. Simonnet. The operating theatre planning by the follow-up of the risk of no realization. International Journal of Production Economics, 85(1), 83-90. (2003).
23. L. Dekhici, & B. Khaled. Operating theatre scheduling under constraints. Journal of Applied Sciences,, 14(10), 1380-1388. (2010).
24. G. X. Huang, W. Xiang, C. Li, Q. Zheng, S. Zhou, B. Q. Shen, & S. F. Chen. Surgical scheduling based on hybrid flow-shop scheduling. In Applied Mechanics and Materials (Vol. 201, pp. 1004-1007). Trans Tech Publications Ltd. (2012).
25. W. Yu, M. Yunhui, Z. Huabo, T. Jiafu. A particle swarm optimization algorithm on the surgery scheduling problem with downstream process. *In 2013 25th Chinese Control and Decision Conference (CCDC) (pp. 850-855). IEEE.* (2013, May).
26. S. Lee, Y. Yih . Reducing patient-flow delays in surgical suites through determining start-times of surgical cases. European Journal of Operational Research, 238(2), 620-629. (2014).
27. H. W. Kuhn. The hungarian method for the assignment problem. In 50 Years of Integer Programming 1958-2008. Springer, 6, 29-47. (2010).
28. A. Jebali, A. B. H. Alouane, P. Ladet. Operating rooms scheduling. International Journal of Production Economics, 99(1-2), 52-62. (2006).
29. S. Kharraja. Outils d'aide à la planification et l'ordonnancement des plateaux médico-techniques *(Doctoral dissertation, Saint-Etienne).* (2003).
30. S. Chaabane, A. Guinet, L. Trilling. Pilotage conjoint de ressources hospitalières humaines et matérielles: un problème d'ordonnancement avec cycles. In *Conférence GISEH* (pp. 9-11). (2004, September).
31. V. Perdomo, V. Augusto, X. Xie, Operating theatre scheduling using lagrangian relaxation. *In 2006 International Conference on Service Systems and Service Management (Vol. 2, pp. 1234-1239). IEEE.* (2006, October).
32. V. Augusto, X. Xie, V. Perdomo. Operating theatre scheduling with patient recovery in both operating rooms and recovery beds. Computers & Industrial Engineering, 58(2), 231-238. (2010).
33. S. C. Kim, I. Horowitz, K. K. Young, T. A. Buckley. Analysis of capacity management of the intensive care unit in a hospital. European Journal of Operational Research, 115(1), 36-46. (1999).
34. K. Seung-Chul, H. Ira. Flexible bed allocation and performance in the intensive care unit. Journal of Operations Management, 18(4), 427-443. (2000).
35. S. C. Kim, I. Horowitz. Scheduling hospital services: the efficacy of elective-surgery quotas. Omega, 30(5), 335-346. (2002).

36. S. Kharraja, P. Albert, S. Chaabane. Block scheduling: Toward a master surgical schedule. *In 2006 International Conference on Service Systems and Service Management (Vol. 1, pp. 429-435). IEEE*. (2006, October).
37. N. Smolski, E. Marcon, S. Chaabane, B. Luquet, J. Viale. Impact des stratégies de brancardage sur l'occupation de la SSPI: étude par simulation. *44ème Congrès national d'Anesthésie et de Réanimation, 19-22*. (2002).
38. V. N. Hsu, R. De Matta, C. Y. Lee. Scheduling patients in an ambulatory surgical center. Naval Research Logistics (NRL), 50(3), 218-238. (2003).
39. B. Vijayakumar, P. J. Parikh, R. Scott, A. Barnes, J. Gallimore. A dual bin-packing approach to scheduling surgical cases at a publicly-funded hospital. European Journal of Operational Research, 224(3), 583-591. (2013).
40. D. N., Pham, A. Klinkert. Surgical case scheduling as a generalized job shop scheduling problem. European Journal of Operational Research, 185(3), 1011-1025. (2008).
41. B. Roland, C. Di Martinelly, F. Riane. Operating theatre optimization: A resource-constrained based solving approach. *In 2006 International conference on service systems and service management (Vol. 1, pp. 443-448). IEEE.* (2006, October).
42. J. Pensi. Résolution conjointe des problèmes de planification des opérations chirurgicales et des opérations de maintenance: application au cas des hôpitaux camerounais *.Doctoral dissertation, Université Clermont Auvergne.* (2017).
43. B. Fleischmann. The discrete lot-sizing and scheduling problem. European Journal of Operational Research, 44(3), 337-348. (1990).
44. C. Wolosewicz, S. Dauzère-Pérès, R. Aggoune. A new approach for solving integrated planning and scheduling problem. *IFAC Proceedings* Volumes, 39(3), 191-196. (2006).
45. J. M. Molina-Pariente, V. Fernandez-Viagas, J. M. Framinan. Integrated operating room planning and scheduling problem with assistant surgeon dependent surgery durations. Computers & Industrial Engineering, 82, 8-20. (2015).
46. B. Roland, C. Di Martinelly, F. Riane, Y. Pochet. Scheduling an operating theatre under human resource constraints. *Computers & Industrial Engineering, 58*(2), 212-220. (2010).
47. S. Kharraja, S. Hammami, R. Abbou. Plan Directeur d'Allocation des plages horaires: approche globale. *Gestion et Ingénierie des Systèmes Hospitaliers, GISEH'04*. (2004).
48. H. Fei, A. Artiba, N. Meskens, & C. Chu. Planification des interventions sur une semaine dans un bloc opératoire. (2005).
49. S. Hammami, P. Ladet, B. H. A. Atidel, A. Ruiz. Une programmation opératoire robuste. Logistique & Management, 15(1), 95-111. (2007).
50. S. Chaabane, N. Meskens, A. Guinet, M. Laurent. Comparaison des performances des politiques de programmation opératoire. Logistique Management, 15(1), 17-26. (2007).
51. H. Fei, C. Chu, N., Meskens, A. Artiba. Solving surgical cases assignment problem by a branch-and-price approach. International journal of production economics, 112(1), 96-108. (2008).
52. S. Chaabane, N. Meskens, A. Guinet, M. Laurent. Comparison of two methods of operating theatre planning: application in Belgian hospital. Journal of Systems Science and Systems Engineering, *17*, 171-186. (2008).
53. J. H. Iser, B. T. Denton, R. E. King. Heuristics for balancing operating room and post-anesthesia resources under uncertainty. *In 2008 Winter Simulation Conference (pp. 1601-1608). IEEE.* (2008, December).
54. S. Rodier. An attempt to unify and solve the questions of modeling and optimization within the hospital systems. Application to the New Estaing Hospital. Computer Science, Blaise Pascal University-Clermont-Ferrand II, France. (2010).
55. S. A. N. A. Aniba, A. I. D. A. Jebali. Approches stochastiques pour la planification des interventions au bloc opératoire. *9è Congrès International de Génie Industriel (CIGI'2011).* (2011).
56. A. Agnetis, A. Coppi, M. Corsini, G. Dellino, C. Meloni, M. Pranzo. Long term evaluation of operating theater planning policies. Operations Research for Health Care, 1(4), 95-104. (2012).
57. A. Bouguerra, C. Sauvey, N. Sauer. Mathematical model for maximizing operating rooms utilization. *IFAC-PapersOnLine*, 48(3), 118-123. (2015).

58. J. Razmi, M. S. Yousefi, M. Barati. A stochastic model for operating room unique equipment planning under uncertainty. *IFAC-PapersOnLine*, *48*(3), 1796-1801. (2015).
59. A. Chraibi. Outils d'aide à la décision pour la conception des blocs opératoires (*Doctoral dissertation, Université Jean Monnet-Saint-Etienne*). (2015).
60. A. Duenas, C. D. Martinelly, G. Yazgı Tütüncü, J. Aguado. A multi-objective hospital operating room planning and scheduling problem using compromise programming. *In Mexican International Conference on Artificial Intelligence* (pp. 379-390). Springer, Cham. (2016, October).
61. A. Augustin. Ordonnancement de bloc opératoire avec intégration des soins intensifs. Ecole Polytechnique, Montreal (Canada). (2017).
62. L. W. Santoso, A. Sudiarso, N. A. Masruroh, M. K. Herliansyah. Cluster analysis to determine the priority of operating room scheduling. *In AIP Conference Proceedings* (Vol. 1977, No. 1, p. 020058). AIP Publishing LLC. (2018, June).
63. Ş. Gür, T. Eren, H. M. Alakaş. Surgical operation scheduling with goal programming and constraint programming: A case study. Mathematics, 7(3), 251. (2019).
64. B. B. Saleh. Approche Intelligence Artificielle Distribuée pour une planification réactive et une aide à la conduite du processus de blocs opératoires hospitaliers (*Doctoral dissertation, Université Bourgogne Franche-Comté; Université Libanaise*). (2019).
65. V. Dorval. Planification des opérations chirurgicales sous contrainte de capacité. (2020).
66. C. Arezki, J. P. Boufflet, L. Mezouari, A. Moukrim. Planification d'interventions chirurgicales: heuristiques de construction et d'amélioration. In 21e congrès annuel de la Société Française de Recherche Opérationnelle et d'Aide à la Décision (ROADEF 2020). (2020, February).
67. Barakat, Y. et al (2021) . What contributions of Artificial Intelligence in Innovation? . E3S Web of Conferences, 2021, 234, 00105
68. Y. Xiao, R. Yoogalingam. A simulation optimization approach for planning and scheduling in operating rooms for elective and urgent surgeries. Operations Research for Health Care, 35, 100366. (2022).
69. R. Bargetto, T. Garaix, X. Xie. A branch-and-price-and-cut algorithm for operating room scheduling under human resource constraints. Computers & Operations Research, 106136. (2023).
70. B. Cardoen, E. Demeulemeester, J. Beliën. Operating room planning and scheduling: A literature review. European journal of operational research, 201(3), 921-932. (2010).
71. İ. Ayçam, & A. Yazici. Evaluation of operating room units within the context of green design criteria. Gazi University Journal of Science, 30(1), 1-15. (2017).
72. C. A. Balaras, E. Dascalaki, & A. Gaglia. HVAC and indoor thermal conditions in hospital operating rooms. Energy and Buildings, 39(4), 454-470. (2007).