A Literature Review on the Nurses' Planning Problems

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Abstract

In the need for improvement in productivity, hospital systems are facing human resources planning where they must guarantee the quality of patient care. In this paper, we propose a literature review on the nurses' planning problems within health organizations. The aim is to classify the different works that have addressed these problems in relation to objectives, constraints to respect and solving methods proposed in order to generate the new contributions and the suggestions for improvement.

1. Introduction

The human factor is the most important factor in hospital; he stands out as one of the key elements of flexibility, responsiveness and processes performance. The human resources management of any hospital is one of its strong points for development. Therefore, planning must be a central concern of those responsible. The human resources allocation to the different activities must meet a number of constraints (work regulations, workload, individual preferences and skills) while optimizing one or more goals (equity in the work, costs, service quality, etc.). It allows the human resources distribution quickly and efficiently on posts and teams. To cover the needs, planning and creating personal schedules must be flexible for any effective in one or several days or weeks. The health personals in the public sector in the most are polyvalent and auxiliary nurses with a share of 68% (Health Ministry, 2005). That's why we were interested in this job to the nurse's assignment problems and their schedules that have been addressed in the hospital for many years. According to official sources, Morocco has been experiencing a nursing shortage. There are 30 000 nurses, 15% perform administrative work, about 1 nurse in the public sector for 1134 inhabitants (WHO, 2013).

In this paper, we propose a non-exhaustive literature review on the nurse's planning problems within health organizations. The aim is to classify the different works that have addressed these problems in relation to objectives, constraints to respect and solving methods proposed in order to generate the new contributions and the suggestions for improvement. Paragraph 2 describes the planning problem in a care facility with the objectives and the constraints to meet. Section 3 classifies the works to the objectives, constraints and methods.

2. Planning Problems in a Nursing Care Facility

Several literature reviews have been published on the modelling and resolution techniques of the personal schedule problems and particularly nurses ([1-3]). They present syntheses allowing a characterization of the problems

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associated with the obtained results and a classification of the used tools. In this present paper, we are interested in the nurse's assignment problems by specifying the constraints to be respected and the objectives to be achieved.

In [4], different problems related to this assignment are explained, and the importance of this strategy within a healthcare service is shown. This planning must take into consideration several criteria: cost, workloads, personal satisfaction and service quality and must meet a set of constraints.

2.1. Objectives to Achieve

The nurses' planning is to organize in time a succession of tasks to achieve a particular goal. The objectives of this planning are several: the workloads optimization, the nurses' number, their productivities and performances and the financial costs associated.

Table 1. Assignment problem goals.

O1:	Cost	O1.1.	Minimize the overtime cost.
		O1.2.	Minimize the external nurses coverage cost.
		O1.3.	Minimize the nurse's preferences cost.
		O1.4.	Minimize the workload sum related to regular, extra and temporary hours.
O2:	Workload	O2.1.	Minimize the difference between the nurse with the more and the least load.
		O2.2.	Minimize the load increase in the quotas.
		O2.3.	Minimize the work overload.
		O2.4.	Minimize the difference between the maximum and minimum load.
O3:	Nurse Number	O3.1.	Minimize the nurses outsourcing number.
		O3.2.	Minimize the case number where the service is facing a staff shortage.
		O3.3.	Minimize the case number where too many nurses are assigned.
		O3.4.	Minimize the nurses' number.
O4:	Nurse Performances	O4.1.	Maximize the nurse utilization rate taking into account their competency profiles.
		O4.2.	Minimize the path length travelled by the nurses.
		O4.3.	Maximize the performance by increasing the points of each nurse.
O5 :	Service Quality	O5.1	Minimize the waiting day number spent by patients at the hospital for a surgical intervention.
		O5.2	Minimize the nurses' preferences.
		O5.3	Maximize the nurses' preferences.

Table 2. Assignment problem constraints.

	C1:	The post demands must be met.
Service Constraints	C2:	The team demands must be met.
	C3:	The day demands must be met.
	C4:	Each nurse has maximum tour duration.
	C5:	Each patient is always treated by the same nurse during the care period.
	C6:	The nurse's arrival date to the patient is fixed.
	C7:	Each nurse mustn't exceed a maximum number of services.
	C8:	The minimum number of nights in the programming period must be respected
	C9:	A nurse can't work in several teams during the day
	C10:	A nurse worked a weekend's day or evening, he won't be in service the next weekend.
	C11:	A nurse mustn't be assigned to a night team immediately after a day work.
	C12:	The nurses' number affected mustn't exceed the preferred number specify for each team and day.
	C13:	Work on Saturday implies that the Sunday is a worked day.
	C14:	The appropriate number of posts at regular time per week must be given to the nurses.
	C15:	Respects the gap between the quotas requirement and the nurses' number.
	C16:	The average cost generated by the intervention's assignment must meet.
	C17:	The working days number for each nurse depends on whether the nurse is in the full-time or the part-time.
Legal Constraints	C18:	The nurses are provided with regular or extra wages for each team.
	C19:	Respects the assignments number for each nurse.
	C20:	A nurse may not exceed a maximum number of patients for the care.
	C21:	The worked hours number per day for each nurse mustn't be exceeded the max number.
	C22:	The worked nurses' number for each team must be controlled with the maximum and minimum limits specified for each team.
	C23:	The consecutive day's number worked for each nurse must be respected.
	C24:	A nurse mustn't exceed the day number worked.
	C25:	A nurse mustn't exceed the weekend number worked.
	C26:	The rest hour number for each nurse must respect.
	C27:	The nurse, who worked on a holiday, takes a rest in the two days that follow.
	C28:	The nurses must take advantage of a minimum number of days off in each horizon, depending on their weekly workload.
Collaborators Constraints	C29:	Each nurse has a workload according to the assigned post.
	C30:	Each nurse has a workload according to the assigned team.
	C31:	Each nurse has a workload according to the nurse number available by day.
	C32:	If a nurse is assigned to the night during the week, the next day is a day off.

2.2. Constraints to Respect

Numerous constraints must be respected in the nurse's schedules. The planning must respect the working time of each nurse, take into account the maximum duration of the working time, the minimum duration of the pause and the maximum number of the consecutive work days. The constraints can be defined for each nurse, for example the workload, the days off etc.; it must also deal with the nurses' preferences in choice of the teams and vacations (Table 2).

3. Literature Review

The papers interested by the nurses' planning problems differ either by the objectives, the constraints to meet or by the methods and tools used in the resolution. We aim to present the works published in the last decade according to a classification by objective. In the following, we will select the overall objectives specifying the constraints and the methods used in the works.

3.1. Financial Cost

In order to optimize the costs related to the assignment and the planning problem, several works and techniques are proposed. [5] and [6] made the schedules that meet the demand for a nurses number with different qualifications on each team. The aim is to minimize the nurses preferences cost

[7] and [8] present a mathematical model which helps the managers in the schedules achievement with the more desirable times for nurses. The objective is to minimize the preferences cost and to maximize the service quality and the nurses satisfaction. The authors describe their experimental results by using CPLEX and LINGO software. [9] has developed a linear programming model which was solved by Lingo solver. The model is based on the quality criteria and considers the nurses preferences. In [10] discuss an integrated methodology for the nurse's allocation based on the service size, the nurse characteristics and the specific profiles. The general objective is also to minimize the workloads costs related to regular, extra and temporary hours assigned to nurses. The second objective is to minimize the cases number where the service is facing a staff shortage and the cases number where too many nurses are assigned. The problem is modelled with linear programming.

[11] treated the cyclic schedules problem for nurses, while minimizing the external nurses coverage cost. The problem is formulated as an integer linear programming and then decomposed by using the Lagrangian relaxation (LR). To ensure fairness, the nurses are successively assigned to the lists. When the demand changes significantly, the allocation is repeated. In the case where one or more nurses can't work, the schedule must be updated to replace the absent nurses.

[12] and [13] have developed several versions of the genetic algorithm, which the difference remains in the permutations coding and the genetic operators used for each encoding. The heuristic has been modified with a genetic algorithm to solve the nurses schedule problem. [14] Presents a mathematical programming model in two stages. The first step permits the optimization of the holiday periods in the nurse schedules. The model is resolved by LINGO. A model is created in the second step to cover the days off. This model is a mixed integer nonlinear programming problem (MINLP) solved by the genetic algorithm in MATLAB software.

3.2. Workloads Optimization

[15] And [16] have presented a decision support system for the optimization of the nurse's allocation to patients in order to minimize the work overload. The problem has been modelled using a linear program resolved on CPLEX. The other work solves this problem with a stochastic programming model and shows how it could save up to 273 hours of the nurse's overload during a year in each unit medical/surgical.

[17] and [18] offer a problem modelling in a mixed integer linear program (MILP), whose objective is to minimize the arduousness's gap between the nurses and to find the best compromise between: the cost, the service quality and the social satisfaction. They have also presented a comparison of the different techniques in terms of the objective function value obtained and the response time. The model has been validated on different commercial solvers LINGO, CPLEX and GLPK. [19] has treated the same problem but in allocation children to the nurses. They decompose the problem in two stages: the first stage assigns the nurses to posts. This step is obtained by solving a problem relaxation. The second step is resolved with a programming model by constraints.

In emergency home service, the nurses' assignment problem is always present. In [20] considers a set of constraints and rules in the nurse's assignment, in particular those related to the needs for daily jobs and holydays. They have proposed two variants of mathematical models having same objective function. The first variant presents a linear program while the second presents a nonlinear program. The nurses' allocation in this model is only on a six month horizon and for a fixed nurses numbers (N=7). In [21] develops a mathematical model using mixed integer linear programming (MILP). The model assigns the nurses to 7 posts and 4 teams according to their number available per day.

3.3. The Nurses Number Optimization

In the purpose of the nurses number optimization, [22] presented a study on the application of the fuzzy logic theory for the scheduling problem to deal the hospital management and the nurse preferences. To solve this problem, three different fuzzy programming models are developed. As well, [23] presents this problem using a mathematical programming model. The goal is to minimize the inactivity time of nurses and their number. Then, the Lingo is used to ensure the best solution for the model.

Also, [24] studied the schedules design problem for the nurses working in the healthcare units in Kuwait. The objective is to reduce the nurses subcontracted. The nurses can apply to work or rest on the specific week. The authors propose a mathematical model with the mixed integer programming resolved with the CPLEX solver. The model used to treat the nurses preferences by the permutations of the work teams.

3.4. The Nurses Performances

[25] Is interested in a dynamic assignment problem of the nurses on different posts in the day by taking into account their workload and their competence degree. She proposed a mathematical programming formulation by choosing to optimize the nurse utilization. To solve this problem, the CPLEX software is used.

Thus [26] presented a decision support system for performing the nurse tours in home care structure. The system also allows the patients' assignment to the nurses taking into account a set of constraints (the patient's availability, the visits, the nurse's pause ...). The objective is to minimize the distance duration travelled by the nurses. To achieve this objective, they have established a mixed integer linear program (MILP). The mathematical model presented is resolved by two incremental solvers LINGO and CPLEX. Then, to compare the performance of two solvers cited previously, they have achieved a set of tests by varying four parameters: the nurses' number, the patients' number, the planning horizon and the visits number.

3.5. Service Quality

[27] and [28] propose an approach based on care processes. The objective is to minimize the patient residence period in the hospital, the costs supported and as well as respecting the care quality. The authors propose two interventions planning strategies in an operating block: (1) a planning fixes the rooms allocation to the surgery specialties; (2) a planning fixes the rooms allocation to the surgery specialties depending on the load. [29] Presents two planning problems to minimize the arduousness's increase in the quotas obligation and maximize the preferences. The demands for a regular unit is generally fixed in advance and considered as a quota. The preferences generally explain if a nurse wants to be in work or not on a particular date. The authors propose models resolved by CPLEX.

The following summary tables (3-5) present a classification of works cited previously. It helps to identify the different optimization criteria, constraints and tools. The abbreviations of the tools and the methods used in the table 5 are: *LP:* Linear Program; *NLP:* Nonlinear Program; *MILP:* Mixed Integer Linear Program; *GA:* Genetic Algorithm; *BOA:* Bayesian Optimization Algorithm; *LR:* Lagrangian Relaxation; *HEU:* Heuristics; *STOC:* Stochastic; *FL:* Fuzzy Logic.

So, we can see a very large variety of constraints, objectives and methods employed in the various works depending on the viewpoint specificity of each author. Most works adopts a linear program form and among the found allocation's criteria are cost, workload and the nurses' number.

Table 3. Summary table of the different constraints used.

Auteurs	The constraints																																	
	Operational constraints of service													Legal Constraints								Constraints collaborators												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
(Ademir et al., 2013)			*													*			*														
(Aicklin et al., 2004)		*	*					*					*									*.		*									
(Azaiez et al., 2005)			*					*																*									*
(Bard et al., 2007)		*	*																*		*			*		*	*						
(Bellabdaoui et al., 2013b)	*	*	*						*	*	*	*	*			*			*		*					*			*	*	*	*	
(Bellabdaoui et al., 2013a)	*	*	*																*								*		*		*		
(BEN BACHOUCH et al., 2009)			*	*		*													*		*												

Auteurs	The constraints																																
	Operational constraints of service													Legal Constraints							Constraints collaborators												
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
(Bouarab et al, 2010)	*		*											*												*		*					
(El Oualidi et al., 2012)	*	*	*																*				*	*			*		*		*		
(GLAA, 2008)	*		*	*																	*			*									
(JEBALI et al., 2003)	*		*	*		*													*														
(JEBALI et al., 2007)	*		*	*		*			*							*			*														
(Li et al., 2006)		*	*						*							*			*														
(M'Hallah et al., 2013)		*	*						*		*								*		*					*							
(Maenhout et al., 2013)	*	*	*																														*
(Moz et al., 2004)	*	*	*						*										*							*							
(Moz et al., 2007)	*	*	*						*										*		*					*							
(Punnakitikashem et al., 2005)		*							*										*														
(Punnakitikashem et al., 2006)		*							*										*														
(Purnomo et al., 2007)		*	*						*										*		*												
(Rönnberg et al., 2010)	*	*	*												*						*	*			*								
(Schaus et al., 2009)	*	*	*						*										*	*			*	*					*				
(Topaloglu et al., 2010)		*	*								*	*									*		*	*									
(Trilling et al., 2005)	*	*	*				*				*								*		*		*	*		*	*						
(Trilling et al., 2006)	*	*	*				*				*								*		*		*	*		*	*						
(Trilling et al., 2007)	*	*	*				*				*								*		*		*			*	*						
(Tsai et al., 2010)			*																		*					*							
(Wright et al., 2006)	*	*	*											*									*	*									*
(Wright et al., 2013)	*	*	*						*					*			*		*		*					*							*
(Yilmaz, 2012)			*						*										*		*	*											

Table 4. Summary table of the different objectives.

Auteurs	The objectives																					
	O1					O2									O3					O4		
	O1.1	O1.2	O1.3	O1.4	O1.5	O1.6	O2.1	O2.2	O2.3	O2.4	O2.5	O2.6	O2.7	O2.8	O3.1	O3.2	O3.3	O3.4	O3.5	O4.1	O4.2	O4.3
(Ademir et al., 2013)			*																			
(Aicklin et al., 2004)			*																			
(Azaiez et al., 2005)	*																					
(Bard et al., 2007)		*																				
(Bellabdaoui et al., 2013b)							*															
(Bellabdaoui et al., 2013a)									*													
(El Oualidi et al., 2012)									*													
(BEN BACHOUCH et al., 2009)																					*	
(GLAA, 2008)																			*			
(Bouarab et al, 2010)								*														
(JEBALI et al., 2003)																		*				
(JEBALI et al., 2007)					*																	
(Li et al., 2006)			*																			
(M' Hallah et al., 2013)															*							

| Auteurs | The objectives | | | | | | | | | | | | | | | | | | | | | |
| | O1 | | | | | | O2 | | | | | | | | O3 | | | | | O4 | | |
	O1.1	O1.2	O1.3	O1.4	O1.5	O1.6	O2.1	O2.2	O2.3	O2.4	O2.5	O2.6	O2.7	O2.8	O3.1	O3.2	O3.3	O3.4	O3.5	O4.1	O4.2	O4.3
(Maenhout et al., 2013)				*											*	*						
(Moz et al., 2004)	*																					
(Moz et al., 2007)	*																					
(Punnakitikashem et al., 2005)							*															
(Punnakitikashem et al., 2006)									*													
(Purnomo et al., 2007)		*																				
(Rönnberg et al., 2010)											*											
(Schaus et al., 2009)												*										
(Topaloglu et al., 2010)																		*				
(Trilling et al., 2005)													*									
(Trilling et al., 2006)													*									
(Trilling et al., 2007)														*								
(Tsai et al., 2010)						*																
(Wright et al., 2006)				*																		
(Wright et al., 2013)				*																		
(Yilmaz, 2012)																		*				

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Table 5. Summary table of the different methods and tools used.

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| Auteurs | Methods and tools | | | | | | | | | Auteurs | Methods and tools | | | | | | | | |
	LP	MILP	NLP	GA	BOA	LR	Heur	Stoc	FL		LP	MILP	NLP	GA	BOA	LR	Heur	Stoc	FL
(Ademir et al., 2013)							*			(Punnakitikashem et al., 2005)								*	
(Aicklin et al., 2004)				*			*			(Punnakitikashem et al., 2006)	*								
(Aicklin et al., 2009)										(Purnomo et al., 2007)		*					*		
(Azaiez et al., 2005)	*									(Rönnberg et al., 2010)	*								
(Bard et al., 2007)		*				*				(Schaus et al., 2009)	*								
(Bellabdaoui et al., 2013b)	*									(Topaloglu et al., 2010)	*								*
(Bellabdaoui et al., 2013a)	*									(Trilling et al., 2005)	*								
(BEN BACHOUCH et al., 2009)	*									(Trilling et al., 2006)	*								
(Bouarab et al, 2010)	*						*			Trilling et al., 2007)	*								
(El Oualidi et al., 2012)	*									(Tsai et al., 2010)	*								
(GLAA, 2008)	*									(Wright et al., 2006)	*		*						
(JEBALI et al., 2003)	*									(Wright et al., 2013)	*		*						
(JEBALI et al., 2007)	*									(Yilmaz, 2012)	*								
(Li et al., 2006)					*					(Moz et al., 2007)	*								
(M'Hallah et al., 2013)	*									(Moz et al., 2007)	*			*			*		
(Maenhout et al., 2013)		*																	

4. Conclusion

In this work, we have presented a literature review on the nurses' assignment problem not only for criticize and comment the research already done in this area but also for show the value of using aid methods decision in improving of the nurses satisfaction and the job's performance. We classified in tables the main objectives, constraints and methods of this problem in order to facilitate the literature tracing and identify trends for the future researches.

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