HR MARS
Exploring Intellectual Capital

Priorities of the Nurse Schedule by using MODM Approach: A case Study

Fariborz Jolai

Professor, Department of Industrial Engineering, Tehran University, Tehran, Iran

Mohammad Ali Abbaszadeh

Ph.D. Student, Department of Management, Tehran University, Tehran, Iran

Seyed Mehdi Abtahi

Ph.D. Student, Department of Management, Zand Institute of Higher Education, Shiraz, Iran

Abstract

Scheduling and planning for allocating resources to the activities so that the activities can be done in the best manner and resources allocated appropriately is one of the most important problems of management and operation research. The hospitals are one of the organizations that face with this problem in allocating nurses to the shifts in the most appropriate time period so precisely that the defections could not be eliminated and the goals are achieved. Therefore, the present study was aimed to develop a model for nurse scheduling through goal programing technique. The proposed model includes different purposes as its goals and strives to achieve them. This model can be used for solving similar problems in the urgency units in hospitals. This problem has been solved by Lingo 8 and finally its results have been compared with the results of manual methods.

Keywords: Nurse Schedule, Goal Programming, Hard constraint, Soft constraint

1- Introduction

Some organizations such as hospitals and hotels allocate their manpower to several shifts. Therefore, the scheduling personals and allocating them to different shifts is an important problem for these organizations. This is why that the present study was aimed to solve the nurses scheduling problem. Scheduling nurses is considered as the process of creating a plan for scheduling shifts for every nurse in a hospital. The main purpose of this plan is scheduling so that can achieve hard constraints and consider the several purposes simultaneously [13]. There are several effective factors on the complexity of nurses scheduling plan that some of them include change in the patient demand, nurse's expertise, organizational policies, unpredictable absence, and the employees' wants about holydays, work time, and job models. Additionally, some of these may be in conflict with other ones [6]. The nurses scheduling is a difficult and

time-consuming function. This must determine shifts for every nurse so precisely in a long-term period that achieve the predetermined necessities. On the other hand, scheduling must be equal for employees and should not disorder their health, family plans, and social life.

Therefore, the purpose of this study is to develop a plan for nurses scheduling so that the nurses can be employed in their units effectively. This system also pays attention to the hospital necessities, equal conditions, and equal plans in scheduling and also considers their priorities for maximizing nurses' satisfaction. This can be helpful in offering qualified services. The problem and purpose of this study has been indicated in the second section. The necessity and importance of this study has been indicated in the part 3. Part 4 expresses the goals of this study. Literature review has been done in the fifth section. The mathematical model, variables, parameters, and formulation of constraints and goals and goal function have been indicated in the sixth section. Finally, solving method and conclusion of the study have been indicated in the last two sections.

2- Statement of problem

During the recent years, the pressure of costs on hospitals has been increased considerably. The concentration on the cost decreasing forces the hospital managers to administrate their organization in a better method. It is necessary to recognize inefficient use of resources and necessary activities done for eliminating such wastes in order to achieve this goal. Since nurses' salary is one of the large parts of the hospital costs, it is necessary to develop a plan for coordinating a better form of demand and supply. This can be helpful in decreasing operational costs. On the other hand, many organizations strive to use their employees in the best time and also increase their satisfaction from job conditions. This is an important factor in meeting customers' needs [7,19]. Therefore, it is necessary to use scheduling plans for this purpose. The scheduling plan achieves the predetermined organizational and individual necessities. This also not only strives to maintain nurses' family health and social life and be impartial with them [6].

3- Necessity and importance of the study

The nurse scheduling is a challenging function, because hospitals offer their services 24 hours a day. Unfortunately, nurses scheduling is done manually in most of the hospitals in Iran. The nurses usually spend more than 10 hours for scheduling their functions for a month. When they do this manually, it is impossible to consider all of the constraints and especially satisfying nurses' preferences fairly. This leads to nurses' dissatisfaction and finally doing job under stress conditions. Additionally, it is not expected from manual scheduling to minimize overtimes and use the manpower efficiently. This necessitates development of comprehensive decision support systems to consider these conditions. This system concentrates on the employees' affairs management and hereby improves productivity considerably. Also it is should be remembered that this system not only decreases hospitals' costs, but also increases employees' satisfaction. Since employees' satisfaction leads to improve services quality, it is expected that this system can deliver better services to the customers and also improve quality of health cares.

4- Research purposes

Nowadays, lack of professional manpower and inefficient resources distribution (especially nurses) leads that the policy makers are determined to develop the decision support systems for allocating qualified manpower in the best manner. Therefore, the present study was aimed to develop a systematic method for allocating nurses to shifts with considering soft and hard constraints so precisely that achieve organizational scheduling policies, satisfying hospitals' demand for nurses, and satisfying nurses' wants and preferences.

5- Literature review

Modeling the scheduling problems is not a new idea. Many articles have been written about this problem and several approaches have been used for solving nurses' scheduling problem from the 1960s to now. In the primary studies, the problem of nurses scheduling was considered as an optimization problem and then it was solved through mathematical programing with a minimization or maximization goal function. The rotational scheduling was applied for the first time in 1970. Its advantages were less calculations and manual computations [24]. Also researches and studies about using artificial intelligence for nurses scheduling was started from the 1980s [8]. In the 1990s, more developments were achieved in applying network optimization techniques, linear programing, and integer programing for developing nurses scheduling. Also some authors used heuristic methods and simulation techniques for scheduling nurses [16]. The comprehensive review of the nurses scheduling systems and its different methods has been done by Salimifard et al. [1], [10], [20], [21].

Harvey and Mona [14] used network planning for rotational and non-rotational examination of scheduling problem. Meyer [17] used constraint planning for solving nurses scheduling. Recently, goal programming attracts attention to itself among optimization techniques, because it seeks to optimize several goals simultaneously. Musa and Saxena [18] indicated that zero-one goal programming and heuristic search is the most appropriate methods for solving nurses scheduling problems. Berrada et al [9] formulated nurses scheduling problem in the frame of a multi-purpose planning model. In order to solve the model, three techniques have been used including sequential, equivalent weights, and banned search techniques. Azaiez and Sharif [6] used zero-one goal programing for solving nurses scheduling problem. Topaloglu and Selim [22] discussed about the application of fuzzy goal programming in solving nurses scheduling problem. Aickelin and Li [3] used optimization algorithm for solving nurses scheduling problems. Additionally, optimization, heuristic, and meta-heuristic approaches can be used for solving nurses scheduling problems efficiently. Dowsland et al [11] applied Tabu search algorithm with strategic fluctuation for solving nurses scheduling problems. Aickelin and Dowsland [2] used genetic algorithm for solving nurses scheduling problems that considers the conflict between goals and constraints. Tsai and Li [23] present a two-stage mathematical model for solving nurses scheduling problem that considers the necessities of hospital, management and government rules, and shift preferences. Also genetic algorithm was used for achieving the best solution. Table 1 summarizes some of these studies.

Table 1: summary of the studies on nurses scheduling

Authors	Year	Research methodology	References
Duenas et al.	2009	Genetic algorithm with fuzzy priorities	[13]
Aickelin et al.	2007	Mimetic algorithm	[5]
Aickelinet al.	2004	Combination of the programming approaches and evolutionary algorithms	[4]
Jan et al.	2000	Genetic algorithm	[15]
Dowsland et al.	2000	Combination of Tabu search and network planning	[12]

6- Modeling nurses scheduling problem

6-1 The characteristics of problem

The scheduling policies are mainly based on the: 1- trends of hospital: that the supervisors consider them as priorities, 2- nurses wants, and 3- published policies. The importance of considering published policies depends on the ergonomic considerations. Indeed, individuals have several physical constraints and also lack of ergonomic considerations leads to their dissatisfaction and decrease productivity. Scheduling problem of this study is focused on the nine nurses in a one week period in the urgency unit of Iranian hospitals. In this study every shift includes two shifts with seven hours and one shift with 13 hours. This is indicated in table 2.

Table 2: The shifts

Shifts	Morning shift	Evening shift	Night shift
Hours	7 Morning to 2 Evening	1 Evening to 8 Night	7 Night to 8 Morning

Frequency of the least nurses for every shift has been indicated in table 3.

Table 3: Frequency of the nurses for different shifts

	Morning shift	Evening shift	Night shift
Saturday	4	3	2
Sunday	4	3	2
Monday	4	3	2
Tuesday	4	3	2
Wednesday	3	2	2
Thursday	2	2	2
Friday	1	2	2

It is should be remembered that every nurse is determined to have 44 hours activity in the week. If a nurse has more than 44 hours activity in a week, it will be considered as overtime.

6-2 Goal programming model

6-2-1 Soft and Hard constraints of the model

Because of the large number of constraints that the goal programming seeks to achieve them, it may that there is not any feasible solution for a nurses scheduling problem. This is why that the constraints were classified in two groups. The first group includes hard constraints that should be satisfied and the second includes soft ones. The model was determined to satisfy these constraints. If it cannot satisfy all of the constraints, the possible deviation and violation should be minimized with regard to their importance. The soft and hard constraints are indicated in the following section.

6-2-1-1 Hard constraints

1. The first set of the hard constraints ensure that the least number of manpower for every shift is predicted. Since the number of nurses number necessities is different for different days, the model helps the user to consider shifts in different days.
2. The second set of the hard constraints are obligatory hours that are allocated for every nurse. The hours more than 44 are considered as overtime.
3. The third set of the hard constraints ensure that there are not any two continuous shifts (Night until Morning shifts) for nurses. This constraint is performed by hospital and also is suggested that an ergonomic constraint in the literature.
4. The fourth set of the hard constraints is considered for allocating the minimum and maximum shifts to every nurse. This set of constraint is considered for considering justice among nurses so that there are Night shifts in the nurses' schedules continuously.
5. No nurse should work complete overs working day. This constraint is focused by hospital and ergonomics. The fifth set of the constraints undertakes these constraints.

6-2-1-2 Soft constraints

1- The first set of the soft constraints are considered for allocating maximum shift for every nurse in every day.
2- Two continuous holydays have priority for every nurse. The second set of the soft constraints is used for placing free shifts in two continuous days.
3- The third set of the soft constraints is used for minimizing overtime hours.

6-2-2 Assumptions and symbols

The main assumption of this study is that the nurses scheduling starts from Saturday in every week. The business day started from 7 AM until 7 AM of next day. The length of scheduling is 7 days (1 week). In order to this, the following symbols have been used in this study.

n: refer to the number of scheduling days (n=7)

s: refers to the shifts in a day

m: refers to the number of available nurses for the unit

i: is the index of nurses (i= 1,….., m)

j: is the index of days (j=1,….., n)

k: is the index of shifts (k=1,….., s)

N_{jk}: the necessary nurses for k Night shift in day j

There are other symbols that will be defined in the future. The decision variable will be introduced as following:

$$X_{ijk} = \begin{cases} 1 & \text{If the nurse ``i'' is allocated to the shift k in the day j} \\ 0 & \text{Otherwise} \end{cases}$$

6-2-3 Modeling the constraints

Hard Constraints:

- Meeting necessary nurses in every shift

$$\sum_i X_{ijk} \geq N_{jk}, \qquad \forall \; j,k$$

- Allocating obligatory hours to every nurse

As indicated in the section 6-1, every business day includes two shifts with 7 hours and one shift with 13 hours. Also if the nurse works two 7 hours in Morning and Evening shifts continuously, his/her hours will be 13 hours. On the other hand, if the nurse works in Evening and Night shifts continuously, his/her shift will be 19 hours. In order to formulize this hours and express any nurse's hours exactly, two new shifts have been introduced. The first starts from 7 AM to 8 PM (k=4) and the second starts from 1 PM until 8 AM next day (k=5). These shifts add some new constraints to the model that has been indicated in the following section.

In order to ensure obligatory hours allocation, the following constraints have been added to the model for every nurse.

$$\sum_j 7X_{ij1} + 7X_{ij2} + 13X_{ij3} + 13X_{ij4} + 19X_{ij5} \geq 44, \qquad \forall \; i$$

- Any nurse cannot be allocated to both PM and AM shifts.

$$\sum X_{ij3} + X_{ij5} + X_{ij+1,1} + X_{ij+1,4} \leq 1, \qquad \forall \;\; i, j = 1,...,n-1$$

- In order to behave nurses fairly, the ratio of their AM shifts should be equivalent. The following constraints will be added for every nurse. These also indicate the minimum and maximum of the AM shifts for every nurse. These constraints indicate implicitly that PM shifts are more than AP shifts for every nurse.

$\forall i,$

$$\sum_j X_{ij3} + X_{ij5} \geq 1,$$

$$\sum_j X_{ij3} + X_{ij5} \leq 2,$$

- The following constraint has been added for preventing from allocating a nurse to a perfect day.

$\forall i, j$

$$\sum X_{ij1} + X_{ij2} + X_{ij3} \leq 2,$$

$$\sum X_{ij1} + X_{ij5} \leq 1,$$
$$\sum X_{ij3} + X_{ij4} \leq 1,$$

The constraints of modeling

Since two new shifts are introduced for expressing exact hours, the following constraints should be added to the model.

$$\sum X_{ij1} + X_{ij2} + X_{ij4} \leq 1, \quad \forall i, j$$
$$\sum X_{ij2} + X_{ij3} + X_{ij5} \leq 1, \quad \forall i, j$$
$$\sum X_{ij4} + X_{ij5} \leq 1, \qquad \forall i, j$$

6-2-4 Formulating the goals

In order to add the soft constraint to the scheduling model, the following goals have been added to problem. Therefore, the problem has three goals that they have been indicated in the following section.

Goal 1: since allocating two shifts to a nurse is not favorable, this goal ensures that one shift is allocated for every nurse in one day.

$$\left\{ \sum (X_{ij1} + X_{ij2} + X_{ij3}) \right\} - d_{1ij}^+ + d_{1ij}^- = 1, \quad \forall i, j$$
$$\left\{ \sum (X_{ij4} + X_{ij5}) \right\} - d_{1ij}'^+ + d_{1ij}'^- = 0, \qquad \forall i, j$$

$d_{1ij}^{-}, d_{1ij}'^{-}$ and $d_{1ij}^{+}, d_{1ij}'^{+}$ are the deviation from first goal for nurse i that only positive deviations are fined.

Goal 2: this goal encourages two continuous holydays for every nurse.

$$\sum_{j}^{j+1}(X_{ij1} + X_{ij2} + X_{ij3} + X_{ij4} + X_{ij5}) - d_{2ij}^{+} + d_{2ij}^{-} = 0, \quad \forall i, j = 1,...,n-1$$

This goal seeks to allocate two continuous holydays for every nurse. Therefore, the positive deviations will be fined.

Goal 3: this goal seeks to minimizes unnecessary overtimes and costs.

$$\sum_{j}(7X_{ij1} + 7X_{ij2} + 13X_{ij3} + 13X_{ij4} + 19X_{ij5}) - d_{3i}^{+} + d_{3i}^{-} = 44, \quad \forall i$$

d_{2i}^{-} refers to the deviation from goal for nurse i. because of the second hard constraint, it is not necessary to add positive deviation and only the negative one is fined in the model.

6-2-5 Allocating importance weights

The importance weights that are allocated to the goals indicate relative importance of the goals in comparison to other goals. The fines for breaking these goals refer to their importance weights. The P_1, P_2, and P_3 refer to these levels. In order to utilize this model in scheduling, the goal of one shift for every nurse in the hospital is considered as the most important goal. Also P_2 and P_3 are considered as the second and third goals respectively. After evaluation and comparison, weights are allocated to the goals so precisely that the most importance (7) is allocated for P_1, 5 for P_2 and then 2 for P_3. It is should be remembered that these weights can be different from a hospital or section to another. However, the model can allocate weights for every nurse autonomously.

6-2-6 Goal function

The goal function includes minimizing all of the weighted deviations from related goals. Goal function has been presented in the following section.

$$Z = p_1\left[\sum_{i}\sum_{j}d_{1ij}^{+} + \sum\sum d_{1ij}'^{+}\right] + p_2\left[\sum_{i}\sum_{j}d_{2ij}^{+}\right] + p_3\left[\sum_{i}d_{3i}^{-}\right]$$

7- Solving the model

The problem of nurse scheduling for urgency unit in a hospital with 9 nurses and three shifts for a week has been solved and its results have been presented in this section. This model has 567

variables, 419 constraints, and 188 goals. The problem has been solved by Lingo8 and its optimum solution has been indicated in table 4.

Table 4: The resulted scheduling for solving goal programming model

Nurses	Saturday			Sunday			Monday			Tuesday			Wednesday			Thursday			Friday		
	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N	M	E	N
A		*				*		*		*			*				*		*		
B			*		*		*			*				*			*			*	
C	*			*					*		*		*					*		*	
D			*		*			*		*											*
E		*			*				*		*			*		*					
F	*					*		*			*		*			*					
G	*			*			*			*								*			*
H		*		*			*					*			*						
I	*			*			*					*			*						

*In this table M denote Morning, E for Evening and N for Night.

The results of the goal programming scheduling are better than manual scheduling. One of the hard constraints is broken in the scheduling through goal programming. All of the nurses are provided with one shift in every day. Also two holydays are allocated to three nurses. It is observed in the manual method that 9 shifts are allocated in one day and only there is one holyday with two days.

8- Conclusion and empirical suggestions

Many organizations face with problem in employees scheduling area. Hospital is one these organizations. The hospitals must solve their nurse scheduling problem so precisely that the hard constraints of hospitals and nurses and also soft constraints of hospital, nurses, and agronomy be considered. This problem is attended by authors and different heuristic and meta-heuristic solutions have been offered for it. On the other hand, mathematical programming is considered as a powerful technique for solving this problem and achieving optimum solution. In the present study in Iranian hospitals, the nurses scheduling problem has been solved by goal programming. The soft constraints have been considered as goals in this model and the model seeks to minimize weighted deviations from goals. The results of the goal programming scheduling are better than scheduling that is resulted from manual method. The following empirical suggestions have been presented to the researchers and authors for developing this model:

1. Using the model in different units in every hospital with different constraints or several units that have common employees.

2. Considering nurses with different expertise that necessities some of the nurses for working in some shifts.
3. Considering nurses' preferences individually such as nurse's preference for working in an especial day and tendency to work in two continuous shifts.

Corresponding Author

Seyed Mehdi Abtahi, Ph.D. Student, Department of Management, Zand Institute of Higher Education, Shiraz, Iran. E-mail addresses: **abtahi.m@ut.ac.ir**

References

1. Salimifard, K., Mohamadi.Z.D. and Shahabi, K.Z."Review of Operation Research Techniques in Nurses Scheduling Problem", Second International Conference of Operation Research, 2009, Iran
2. Aickelin, U. and Dowsland, K. "An Indirect Genetic Algorithm for Nurse Scheduling Problem", *Computers & Operations Research*, Vol. 31, 2004, pp. 761-778.
3. Aickelin, U. and Li, J. "Bayesian Optimization Algorithm for Nurse Scheduling", In M. Pelican, K. Sastry, & E. Cantú-Paz (Eds.), Scalable Optimization via Probabilistic Modeling: From Algorithms to Applications, 2006, pp. 315–332, Springer.
4. Aickelin, U. and White, P. "Building Better Nurse Scheduling Algorithms", *Ann. Oper. Res.*, Vol. 128, 2004, pp.159–177.
5. Aickelin, U., Burke, E.K. and Li, J. " An Estimation of Distribution Algorithm with Intelligent Local Search for Rule-based Nurse Rostering, *Journal of Operation Research Society*, Vol. 58, 2007, pp. 1574-1585.
6. Azaiez, M.N. and Al Sharif, S.S. "A 0-1 Goal Programming Model for Nurse Scheduling", *Computers & Operations Research*, Vol. 32, 2005, pp. 491–507.
7. Bard, J.F. and Purnomo, H.W. "Cyclic preference scheduling of nurses using a Lagrangian-based heuristic", *Journal of Scheduling*, Vol. 10, Issue 1, 2007, pp. 5 – 23.
8. Bell, P., Hay, G. and Liang, Y. "A Visual Interactive Decision Support System for Workforce (Nurse)Scheduling", *INFOR*, Vol. 24, No.2, 1986, pp. 134-145.
9. Berrada, I., Ferland, J.A. and Michelon, P. "A Multi-objective Approach to Nurse Scheduling with both Hard and Soft constraints", Socio-Economic Planning Sciences, Vol. 30, 1996, pp. 183-193.
10. Burke, E.K., De Causmaecker, P., Berghe, V.G. and Van Landeghem. "The State of The Art of Nurse Rostering", *Journal of Scheduling*, Vol. 7, 2004, pp. 441-499.
11. Dowsland, K.A. "Nurse Scheduling with Tabu Search and Strategic Oscillation", European Journal of Operational Research, Vol. 3, 1998, pp.393-407.
12. Dowsland, K.A. and Thompson, J.M. "Solving a Nurse Scheduling Problem with Knapsacks, Networks and Tabu Search", *Journal of the Operational Research Society*, Vol. 51, 2000, pp. 825–833.

13. Duenas, A., Tütüncü, G.Y. and Chilcott, J.B. "A Genetic Algorithm for the Nurse Scheduling Problem with Fuzzy Preferences", *IMA Journalof Management Mathematics*, Vol. 20, 2009, pp. 369-383.

14. Harvey, H.M. and Mona, K. "Cyclic and Non-cyclic Scheduling of 12H Shift Nurses by Network Programming", European Journal of Operation Research, Vol. 104, 1998, pp. 582-592.

15. Jan, A. Yamamoto, M. Ohuchi, A. "Evolutionary Algorithms for Nurse Scheduling Problem", *Proceedings of the 2000 Congress on Evolutionary Computation, San Diego, USA, IEEE Press*, 2000, pp. 196–203.

16. Jaszkiewicz, A. "A Meta-heuristic Approach to Multiple Objective Nurse Scheduling", *Foundations of Computing and Decision Sciences*, Vol. 22, No. 3, 1997, pp. 169-184.

17. Meyer Auf'mHofe, H. "Solving Rostering Tasks as Constraint Optimization", In Burke, E.K and Erben, W, Practice and Theory of Automated Timetabling, 3rd International Conference, Vol. 2079, 2001, Springer Lecture Notes in Computer Science.

18. Musa, A.A. and Saxena, U. "Scheduling Nurses using Goal Programming Techniques", IIE Transactions, Vol. 16, 1984, pp. 216-221.

19. Pierskalla, W.P. and Brailer, D.J. "Application of Operation Research in Healthcare Delivery", Hand Books in Operation Research and Management, Edited by Pollock, S.M., Rothkopf, M.H.and Barnett, A.

20. Siferd, S. and Benton, W. "Workforce Staffing and Scheduling: Hospital Nursing Specific Models", *European Journal of Operational Research*, Vol. 60, No. 3, 1992, pp. 233-246.

21. Sitompul, D. and Radhawa, S. "Nurse Scheduling: A state of-the-art Review", *Journal of the Society for Health Systems*, Vol. 2, 1990, pp. 62-72.

22. Topaloglu, S. and Selim, H. "Nurse Scheduling using Fuzzy Modeling Approach", *Fuzzy Sets and Systems*, 2009.

23. Tsai, C.C. and Li, S.H.A. "A Two-stage Modeling with Genetic Algorithms for the Nurse Scheduling Problem", Expert Systems with Applications, Vol. 36, 2009, pp. 9506–9512.

24. Warner, M. "Scheduling Nursing Personnel According to Nursing Preference: A Mathematical Programming Approach", *OperationsResearch*, Vol. 24, 1976, pp. 842-856.