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A Nurse Scheduling Model under Real Life Constraints

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Abstract

Background and Objectives: In this paper, a real life nurse scheduling model is developed based on the conditions in Iranian hospitals such as monthly shift rotation, consecutive morning and evening shifts, and consecutive evening and night shift.

Methods: The developed model considers both hospital constraints and nurses' preferences. Hospital constraints include assigning adequate qualified number of nurses to all working shifts and avoiding inappropriate sequence of nursing shifts. Nurses' preferences include the nurses' monthly requests and observing the fairness in ratio of work hours, off weekends, night shifts and undesirable shifts. A hybrid of lexicograph and weighted sum method was used to solve the multi objective problem. The objectives were normalized and the importance of the objectives was determined by the Analytical Hierarchy Process method. In this work, new conditions are considered based on customized considerations. The model was evaluated by comparing the computationally determined schedules with manually determined schedules.

Findings: Comparison of the manually and computationally determined schedules shows the superiority of computer-based method over the manual method based on the scales of the hospital.

Conclusions: The study provides further support for the utility of sophisticated computational method in improving hospital processes, which can ultimately translate into enhanced patient care and hospital performance.

Keywords: Nurse scheduling; Nurse preference; Shift rotation; Hospital Management

Background and Objectives

Hospitals and healthcare services work around the clock without any holidays. These conditions have impacts on nurses' satisfaction and efficiency. Good scheduling increases nurses' satisfaction, and consequently, improves the quality of health care. The situation is even more complicated in Iranian hospitals where there is a shortage of qualified nurses, calling for an effective allocation of human resources within each hospital. The nurse scheduling process as one stage in the process of human resource allocation consists of assigning working and free shifts to each nurse in a specified period of time. The scheduling must consider many constraints such as nurse demands, hospital policies, work regulations, and nurses' preferences. Although Nurse Scheduling Problem (NSP) has been under investigation for more than 40 years [1], it is still performed manually in many hospitals. Nurse scheduling is a difficult and time-consuming task. The time saved in scheduling can be used for more important duties to enhance the quality of the health care system.

The present work is concerned with solving NSP based on the conditions in Iranian hospital such as monthly shift rotation, consecutive morning and evening shifts, and consecutive evening and night shifts. The problem is formulated as a quadratic multi-objective programming model. The weights of the objectives are determined by the Analytical Hierarchy Process (AHP) method and a hybrid of lexicograph and weighted sum method is applied to solve the problem.

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Because of the differences in the magnitude of the objectives, they are normalized before applying the weighted sum method. To make a fair schedule, the requests of nurses are formulated in a different manner. To evaluate the model, it has been run at two wards of Hasheminejad Kidney Center (HKC).

Literature review

The nurse scheduling problem (NSP) has been researched for over 40 years [1]. Working shifts have been considered in different ways in these researches. There are few researchers who assigned nurses to fix shifts in which there is no rotation. Warner [2] classified nurses as a) 'permanent shift' who have no rotation and are assigned to only one type of shift and b) 'rotating shift' who rotate from one shift to another. [3] assumed that each nurse always works during the same shift and there is no rotation. [4] considered day and night shifts where the nurses are assigned to work the night shift for 3 months; then the assignments are changed to the day shift. Assigning nurses to fix shifts helps them to accommodate their sleeping and working time. Furthermore, the next scheduling gets more predictable for them; however, this type of scheduling is not useful enough where there is shortage of nurses. Some papers assigned nurses to rotational shifts, which are more usual in hospitals [5-11]. Other researchers assigned nurses to rotational shifts; however, they considered some constraints which controlled this rotation. [12] used lower and upper limits to bind the number of consecutive assignments that nurses require to work before rotation. Also Maenhout and Vanhoucke [13] controlled the number of consecutive assignments per shift type by minimal and maximal constraints. Such constraints minimize the undesirable effect of 'jet fatigue' arising from continual adjusting to new time period [14]. But the next scheduling is not predictable for nurses in this kind of scheduling.

In the majority of hospitals in Iran, nurses are divided into morning, evening and night groups. The nurses of each shift group are mainly assigned to that shift. But when one or more nurse of a group requests to be free, the nurses of other groups can be assigned to this shift to cover that. This kind of rotation helps nurses to accommodate their working and sleeping time, and makes the next scheduling predictable for them; this is while a fix shift model or a rotating shift model is not applicable for Iranian hospitals. There are about 800 hospitals in Iran, which need to develop an applicable nurse scheduling model. In this work, a new nurse scheduling model is described under the conditions in Iranian hospitals.

Problem definition

This work is concerned with solving NSP based on the conditions which are unique in Iranian hospitals. Before selecting HKC, some other hospitals were studied to recognize nurse scheduling in Iran. Then HKC was selected to test the model because of its importance as a top-ranked tertiary hospital in Iran. To evaluate the model, it was run at two wards of HKC; Shafa and Omid. The problem is formulated for a planning period of one month. Each ward at HKC is run by a number of nurses and one head nurse.

Working shifts include the morning shift from 7 AM to 2 PM, the evening shift form 1 PM to 8 PM, and the night shift from 7:30 PM to 8 AM. Because of the nurse shortage in Iran, it is not uncommon for nurses in Iran to work for more than one shift a day. They might be assigned to consecutive morning and evening shifts, called the Long shift from 7 AM to 8 PM, or consecutive evening and night shift, called the EN shift from 1 PM to 8 AM. As Long and EN shifts are too long and exhausting, they are considered as undesirable shifts and are preferably avoided.

Nurses must be free the day after a night shift based on the regulation of Iranian hospitals.

In this research, the nurses were divided into four groups: Morning, Evening, Odd Night, and Even Night groups. It's preferred to assign nurses to shifts according to their shift group. For example, nurses in the Odd Night group are preferred to assign into odd nights of the month. Nurses are rotated among the groups on a monthly basis in order to make the scheduling fair. This kind of rotation that we called "monthly shift rotation" helps nurses to accommodate their working and sleeping time, and makes the next scheduling predictable for them. In the other hand, on holidays, there are a lot of requests from the nurses for free day, and because of nurse shortage, it is not possible to satisfy all these requests. Therefore, in this condition, nurses rotate from their shift to the other to cover all working shifts.

The nurses can specify days they prefer to be free in the following month. They can additionally specify the shifts they desire to be on duty or to be free. To make a fair schedule, it is important to maximize the number of each nurse's requests satisfied regardless of the number of requests made. Indeed, more requests do not necessarily win more favorable considerations. For example, when there is a certain nurse A who has made 10 requests and another nurse B

Table 1 Weights of the objectives obtained by the AHP method

Ward	**Objective**						
	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
Shafa	**0.1697**	**0.0961**	**0.1153**	**0.1153**	**0.1619**	**0.1435**	**0.1982**
Omid	**0.1896**	**0.0965**	**0.1202**	**0.1202**	**0.1383**	**0.1603**	**0.1749**

who has made 6 requests in a certain month, a preferable situation is to satisfy 7 requests of nurse A and 6 requests of nurse B instead of 8 requests of nurse A and 5 requests of nurse B.

There are some senior nurses at each ward who are more skillful and it is necessary to assign at least 1 senior nurse to each shift.

The initial model was run for four planning periods (months). The results were presented to the hospital and the feedbacks from the hospital were used to improve the solution and make the model closer to the real world conditions. Therefore, the formulation was changed, and some different approaches were used to solve the multi-objective problem. The presented solution approach was selected because the results were more satisfying for the hospital and the time of running this approach was lower than the other approaches. The model and the solution approach presented in this work are the improved ones.

Methods

Model development

The problem consists of scheduling some nurses for a planning period of one month in a non-cyclical way. The number of nurses and the planning period can be defined by the user. The objective of the nurse scheduling model is to satisfy nurses' requests, and to make a fair schedule considering nurse demands, work regulations and hospital policies. Constraints are divided into two groups: hard constraints, which must be satisfied to have a feasible solution; and soft constraints, which may be violated though satisfying them enhances the scheduling quality. Hard and soft constraints are determined based on the feedbacks from the hospital.

Table 2 The computerized schedule for a sample month[a,b]

Description	Month days																														
	Nurse Number	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
Morning Group	1	M	L	M	M	M	M	M	M	-	M	M	L	M	M	-	-	M	M	M	L	M	M	-	M	M	M	M	N	-	-
	2	-	-	M	M	M	M	M	E	L	M	M	-	M	M	N	-	M	M	M	M	M	M	L	M	M	M	M	M	N	-
	3	M	N	-	-	M	M	E	M	-	M	M	-	M	L	M	N	-	L	M	M	M	M	-	M	M	M	M	M	L	-
	4	M	-	M	M	N	-	M	M	L	M	M	-	N	-	M	N	-	M	L	M	M	M	-	M	M	M	M	M	M	-
Evening Group	5	E	-	E	E	E	E	E	L	-	E	E	L	E	E	N	-	E	E	E	E	E	E	L	E	E	N	-	-	-	-
	6	E	L	E	L	E	E	E	E	-	E	E	N	-	N	-	-	-	E	E	E	E	E	-	E	E	E	E	E	E	-
	7	E	-	E	E	E	N	-	-	-	E	E	-	E	E	E	L	N	-	N	-	E	E	-	E	E	E	E	E	E	L
Night 1 Group	8	N	-	N	-	N	-	N	-	N	-	N	-	N	-	L	-	-	-	-	-	N	-	N	-	N	-	N	-	N	-
	9	N	-	N	-	M	-	N	-	N	-	N	-	N	-	-	L	N	-	N	-	N	-	N	-	N	-	N	-	N	-
	10	N	-	N	-	N	-	N	-	N	-	N	-	-	-	N	-	N	-	N	-	N	-	N	-	N	-	N	-	M	L
Night 2 Group	11	-	N	-	N	-	L	M	N	-	N	-	N	-	N	-	-	L	N	-	N	-	N	-	N	-	E	E	N	-	N
	12	-	N	-	N	-	N	-	N	-	N	-	-	L	N	-	N	-	N	-	N	-	N	-	N	-	N	-	L	M	N
	13	M	-	M	N	-	N	-	N	-	N	-	N	-	M	L	-	L	N	-	N	-	N	-	N	-	N	-	N	-	N
Total number of morning nurses		4	2	4	4	4	4	4	4	2	4	4	2	4	4	4	2	4	4	4	4	4	4	2	4	4	4	4	4	4	2
Total number of evening nurses		3	2	3	3	3	3	3	3	2	3	3	2	3	3	3	2	3	3	3	3	3	3	2	3	3	3	3	3	3	2
Total number of night nurses		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Weekends[a] and holidays are shown in grey.
M[a]: Morning shift, E: Evening shift, N: Night shift, L: Long shift, EN: EN shift, -: free day

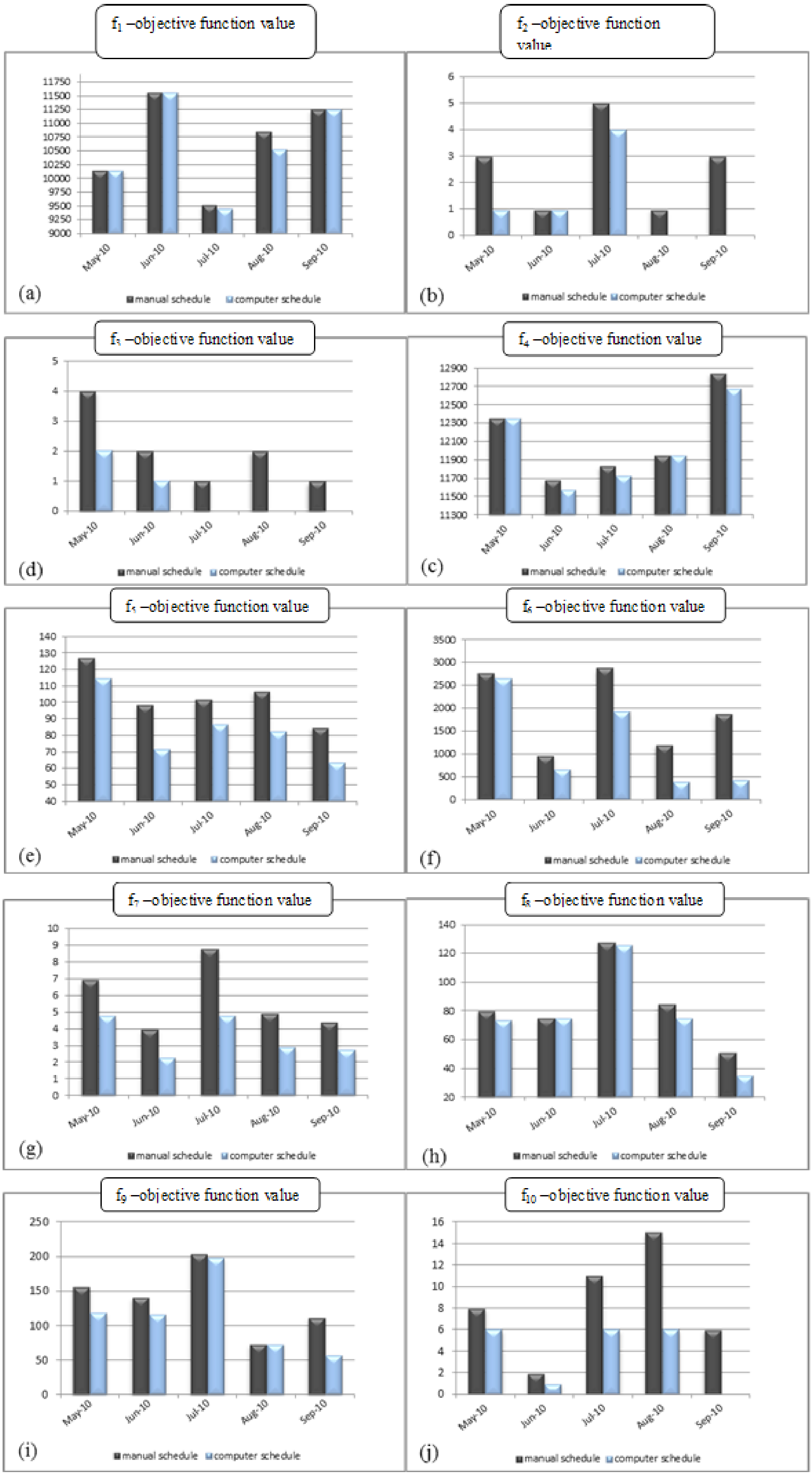

Figure 1 Comparison of the manual and computational schedules in Shafa ward

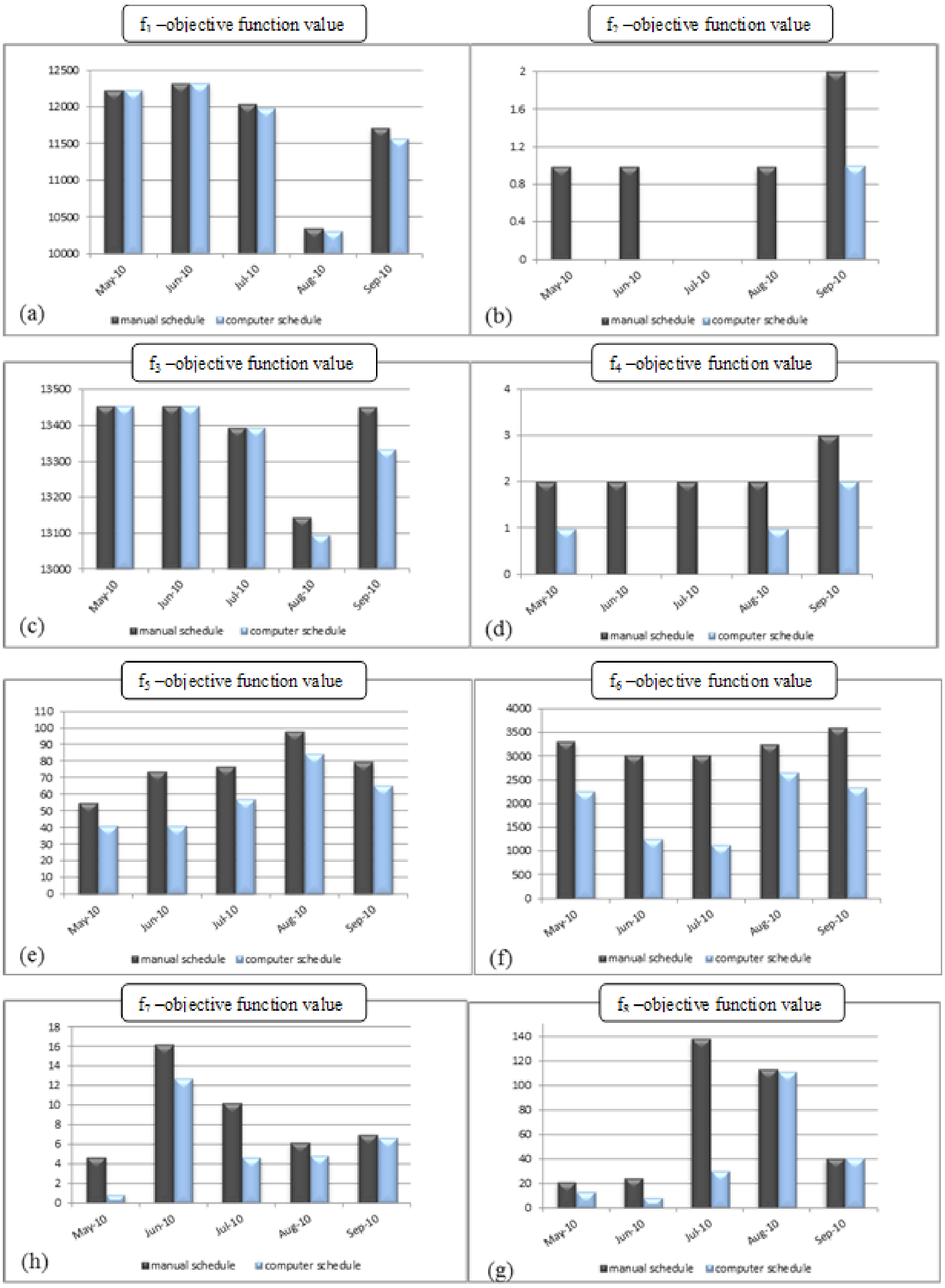

Figure 2 Comparison of the manual and computational schedules in Omid ward

Hard constraints

The hard constraints of the model are as follows:

1, 2) To allocate nurses to working shifts excluding night shifts on weekends and holidays;

On weekends (which contain Fridays in Iran) and holidays, the number of patients is less than in common days and it is possible to assign less nurses to these shifts when there are a lot of requests for free day from the nurses. Therefore, allocating nurses to working shifts on weekends and holidays is not considered a hard constraint.

3) To assign at least one senior nurse to each shift;

4) To avoid assigning nurses to working shifts after their night shift; it means that nurses must be free

after night shift.

5) To avoid assigning nurses to both morning and night shifts on a single day;

6) To avoid assigning a nurse to working days between his/her free days of request; when one nurse requests consecutive free days, it is not satisfying to assign him/her to working day between the free days. This constraint allows the nurses to enjoy consecutive free days.

7) To avoid assigning night shifts on even days to nurses in the Odd Night group; this constraint and the latter one are hospital policies.

8) To avoid assigning night shifts on odd days to nurses in the Even Night group;

Soft constraints

The soft constraints of the model are as follows:

9) To satisfy nurse demands for night shifts on weekends and holidays;

In certain months, there may be too many requests for free days and clearly it is not possible to satisfy all. In this condition, night shifts weekends and holidays can be assigned one nurse less than the desired number of nurses.

10) To avoid assigning nurses in the Morning and Evening groups to working shifts on two consecutive weekends or holidays;

11,12,13,14) To assign nurses to working shifts according to their shift groups; considering these conditions, as soft constraints, makes the model more flexible and permits each nurse to cover other shift groups when there are requests for free days from the nurses of those groups.

Objectives

The objectives of the problem are as follows:

15) To satisfy nurses' requests for free days; the first objective attempts to decrease the number of days that nurses' requests are not satisfied. In some months, there are many requests from nurses and it is not possible to satisfy all of them. In this condition, it is important to consider their requests fairly. If the first objective is formulated as linear, it decreases the sum of days that the nurses' requests are not considered. It means that it is possible to satisfy all requests of nurse 1 and none of the requests of nurse 2. Therefore, the first objective is formulated quadratic to increase the importance of each nurse's requests.

16) To minimize deviation between the desired and scheduled nurses on night shifts on weekends and holidays; this objective minimizes deviation in the first soft constraint.

17) To satisfy the nurses' requests for working free shifts; this objective is formulated quadratic to increase the importance of each nurse's requests.

18) To avoid assigning the nurses in the Morning and Evening groups, to working shifts on two consecutive weekends and holidays; this objective minimizes deviation in the second soft constraint.

19) To assign nurses to working shifts according to their shift group; this objective minimizes deviation in the third group of soft constraints.

20) To divide work hours among the nurses on a fair basis;

21) To fairly divide weekends and holidays offs among the nurses; this condition is commonly considered as a constraint that limits the number of weekends and holidays offs for a nurse. In this work, however, this condition has been considered as an objective to increase the flexibility of the model. The 7th objective attempts to minimize the square of mean deviation of the number of nurses' weekends and holidays off.

22) To minimize the number of night shifts for each nurse in the Morning or Evening groups; as mentioned in the problem definition, nurses are categorized into shift groups, and they prefer to be assigned to working shifts according to their shift groups. However, when the nurses of night groups request to be free, the nurses of Morning or Evening group must be assigned to the night shift. Therefore, some night shifts might be assigned to each nurse in the Morning and Evening groups. The 8th objective attempts to decline the number of night shifts for each nurse in the Morning or Evening groups and to treat these nurses fairly, this objective has been formulated quadratic to increase the importance of each nurse. Similarly, the two later objectives have been formulated quadratic too.

23) To minimize the number of Long shifts assigned to each nurse;

24) To minimize the number of EN shifts assigned to each nurse.

The details of mathematical model developed and the solution approach are provided in Additional File 1. [16].

Results and Discussion

The mathematical model was fed into the GAMS software, and CPLEX solver was used to solve it. The number of constraints was more than 6,000, and there were more than 5,000 variables in the model. The results of the final model were then presented to the hospital in a time shift. Table 2 is an example schedule that has been created under real requirements for September 2010.

Before developing a user friendly software package based on the current model, the hospital opted for a trial period of the model in two wards of the hospital, Shafa and Omid wards. To evaluate the model, the final model was solved for 5 periods (from May to September 2010) in these two wards and the results were compared to the manual schedules. The maximum run time was found to be less than 5 minutes, and the relative gap for stages 1, 2 and 3 of the solution process was 0 but less than 0.0050 for the last stage. In this period, 97.16% of the nurses' requests were accepted in Shafa ward; this was 100% for Omid ward. Evaluation was performed based on the hospital scales, which are the objectives of the model. Figures 1-a to 1-j present the results of comparisons of the computerized and manual schedules in Shafa ward. The computerized schedule has been shown in light-colored columns. The objectives of the problem are defined as minimization; therefore, the solution with lower values of the objectives is the best. To compare the computerized and manual schedules, it is necessary to define the dominated solution. A feasible solution A dominates a feasible solution B to a multi-objective problem if solution A is at least as good as solution B on every objective and is strictly better than solution B on at least one objective [16]. As can be seen in Figure 1, the computerized schedule in May is the same as the manual schedule on objective 1, and it is better with respect to other objectives. Therefore, the computerized schedule dominates the manual one for May. In other months, the computerized schedule dominates the manual one in a similar way.

The results of comparing the computerized and manual schedules in Omid ward are presented in Figures 2-a to 2-j. As shown, the computerized schedule dominates the manual schedule in all months.

Conclusions

In this work, a real nurse scheduling problem was formulated as a quadratic multi-objective programming model. The objective functions for the optimization models focused on satisfying the nurses' requests, minimizing the deviation between the desired and scheduled shifts for the nurses, minimizing undesirable shifts for each nurse and developing fair schedules. A hybrid of the lexicograph and weighted sum methods was employed to solve the problem. Before applying the weighted sum method, the objectives were normalized because of their different magnitudes, and the AHP method was used to determine the weights of the objectives. The mathematical model was fed into the GAMS software, and the CPLEX solver was applied to solve the model. Comparison of the manual and computer schedules showed that the computerized schedule outperformed the manual one based on the scales of the hospital. At present, nurse scheduling at Shafa and Omid wards is accomplished by the model described in this work, and a user friendly software package is supposed to be developed based on the current model for all wards in the hospital.

As mentioned in Section 3, nurses are assigned to shift groups for each month by the head nurse based on their requests and scheduling in the previous months. Future works may focus on assigning nurses to each shift group in the model considering their requests and history of scheduling. Making an interactive scheduling may also be considered in future work.

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