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RESEARCH PAPER

Multi-Objective Optimization of Nurse Scheduling Problem by Modeling Teamwork and Decision-Making Style

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Abstract

This study presents a multi-objective nurse scheduling model by considering and integrating teamwork and decision making styles in order to maximize job satisfaction. To achieve high job satisfaction, teamwork that minimizes incompatibility among team members is considered. Teamwork has a sustainable impact on job satisfaction in healthcare. In this study, a new mathematical model is proposed for scheduling nurses based on teamwork. First, nursing teams are generated by considering decision making styles. Then, each team is assigned to work shifts in the planning horizon. The unique multi-objective mathematical model considers the inconsistency of nurses' decision making styles, reliability of teams, allocation costs and penalty of violating soft constraints as the objective functions. A real case study is considered to show the applicability of the proposed model. Finally, the proposed multi-objective model is solved using the goal programming method. Sensitivity analysis shows the robustness of the proposed mathematical programming model and solution methodology.

Keywords:
Nurse Scheduling;
Team Working;
Decision-Making Style;
Reliability

Motivation and Significance

Nurses frequently need to work long hours under stressful conditions which can result in their exhaustion and job dissatisfaction. Job dissatisfaction is one of the major keys of nurses' turnover and absenteeism. In contrast, team working can be an important factor for job satisfaction and the nurses. Previous studies on nurse scheduling optimization problem have not considered teamwork and decision styles. This study is a new multi-objective optimization for nurse scheduling by considering both factors. This is the first study that takes teamwork and decision making style into account for establishing teams; with the aim of minimizing inconsistency in teams in a nurse scheduling problem.

Introduction

Team working is defined as an activity or a set of inter-related activities undertaken by a number of people in order to achieve a common objective. Team working can be an important factor for job satisfaction and professional fulfillment for employees; because working in a team improves employees' performance and makes the work enjoyable for them. It is also favorable

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for employees' motivation and the working place enthusiasm. Several factors have led to a greater need for team working in nursing. When nurses work as a part of a group, the job itself becomes simpler and more productive. The point that lack of team working may lead to medical errors was initially emphasized by the Institute of Medicine's (IOM's) report [1]. No one has the capacity to meet all the complex needs of patients [2]. Team working consists of team structures and team processes. The structure is related to size, roles, and type of hierarchy as well as accepted ways of behaving. Any of these factors can promote or destroy team cohesion.

Attributes of decision-making styles provide the necessary foundation for the application of improving communication, planning, leadership styles, and organizing teams. The purpose of organizing teams is to establish a united, supportive, and trustful team with high expectations in terms of doing tasks and at the same time respect personal differences and skills. A successful team organizing leads to improving unique personal abilities [3]. It seems that two aspects of decision-making have the highest portion in providing the description of key differences of decision making styles: 1) concentration (number of specified choices), and 2) use of information [3]. There is no relationship between the amount of information and the number of choices each person may make in a decision making process [3]. Driver combined these two aspects and produced a frame to categorize decision-making styles into 5 categories. Then, they investigated the interaction of persons with different decision-making styles and determined compatible decision-making styles. The description of this categorization is provided below [4]:

Table 1. Description of decision making style

		Use of information		
		Satisfying	**Maximizing**	
Number of specified choices	Uni-focus	Decisive	Hierarchic	Systemic
	Multi-focus	Flexible	Integrative	

Table 2. Interaction between decision making styles

Decision making styles	Decisive	Flexible	Hierarchic	Integrative	Systemic
Decisive	S	S	N	T	T
Flexible	S	I	T	N	T
Hierarchical	N	T	S	N	N
Integrative	T	N	N	I	N
Systemic	T	T	N	N	S

S; Suitable, N; Normal, T; Terrible, I; Ideal

One factor that affects team behavior is to know each other work styles and skills in nurse teams [5]. As mentioned before in this study, in addition of minimizing inconsistency in teams, it considers legal regulation and hospital policies. The rest of the paper is organized as follows:

Section 2 reviews the related literature; in Section 3, a description of the studied problem and its mathematical model is proposed. The solution methodology used is explained in Section 4. Then, a numerical example is solved to test the utilized approach, and sensitivity analysis is carried out to verify the effectiveness of our approach in Sections 4.1 and 4.2, respectively. Conclusions are given in the last section.

Theoretical Literature review

In this section, teamwork in healthcare is investigated by focusing on goal programming and multi-objective models in nurse scheduling or healthcare problems. The importance of team working in health care has been examined by many researchers. Apker et al. [6] examined professionalism communication among team members in health care teams. Their research showed that collaboration, credibility, compassion, and coordination are four communicative skills for nurses. Utriainen and Kyngas [7] have studied nurse job satisfaction. They have shown that in addition to varying the job satisfaction of nurses according to their expertise, the interpersonal relation of nurses is an important factor in job satisfaction. Kalisch et al. [8] examined the influence of unit characteristics, staff characteristics and teamwork on job satisfaction with current position and occupation. Mahon and Nicotera [9] explored strategies that nurses choose to deal with conflict in the workplace. 57 nurses were chosen and the results showed that nurses have a strong preference to avoid direct conflict while nurse managers were less likely to avoid direct communication. The research by Brunetto et al. [10] examined supervisor—subordinates relationship upon nurse satisfaction, teamwork, role ambiguity, and well-being among 1138 nurses in both public and private sectors. Their finding showed nurses in private sectors had more satisfaction of supervisor—nurse. Burtscher and Manser [11] investigated team mental models with the aim of determining methods that could be applied in healthcare. They explained the capacity of research in this field and the potential benefits of team mental models in healthcare. To measure the nurse-nurse collaboration level, Kalisch and Lee [1] proposed multiple linear regression analysis to study the relationship among hospital, patient units, staff characteristics, and nursing teamwork. A higher level of teamwork and perceptions of adequate staffing leads to greater job satisfaction with current position and occupation. Poghosyan et al. [12] conducted a survey of nurse practitioners to better understand NPs' role, independent practice, and teamwork in primary care organizations. Dietz et al. [13] studied teamwork, team tasks, and team improvement strategies in the ICU to identify the strengths and constraints of the existing knowledge base, to guide future research.

Ferland et al. [14] showed multi-objective approach is a very flexible method for nurse scheduling problems with considering both hard and soft constraints. Azaiez and Sharif [15] proposed a binary goal programming for nurse scheduling with considering nurses' preferences. They understood nurse preferences from surveys. Topaloglu [16] proposed a goal programming model with both hard and soft constraints for scheduling emergency medicine residents in the monthly planning horizon. AHP is applied for computing the importance value of soft constraints used as coefficients in calculating violation of the soft constraints in the objective function. Maenhout and Vanhoucke [17] with aim of optimizing cost and job satisfaction utilized a branch and price procedure in nurse scheduling problems. Topaloglu and Selim [18] applied fuzzy set theory in NSP for managing uncertainties in nurse preferences and hospital management; they proposed a new multi-objective integer programming model, in which it minimizes nurses' total idle waiting time during the planning horizon. Yilmaz [19] developed mathematical programming model. Yilmaz [19] and Nelsey and Brownie [20] examined the leadership, teamwork, and mentoring in nursing. M'Hallah and Alkhabbaz [21] proposed a mixed-integer linear programming model to a nurse scheduling problem in Kuwaiti health care units. Wright and Mahar [22] analyzed effects of centralized scheduling decisions over departments in a hospital. They show by using a centralized model quality can enhance nurse schedules by almost 34%, reduce over time by approximately 80%, and reduce costs by approximately 11 %. Güler et al. [23] proposed goal programming model considering both hard and soft constraints for scheduling shifts of residents. Their aim was to satisfy all soft constraints by minimizing the violation of the soft constraints. Güler [24] has presented a hierarchical goal programming for the assignment of residents to outpatient clinics. Their model was able to satisfy the preferences of the residents and conforms with the departments requirements. Meskens et al. [25] proposed a multi-objective scheduling for scheduling operating rooms. They considered availability, staff preferences, and affinities among staff members in their study to optimize usage of operating room by minimizing over time and makespan and also maximizing affinities among team members of a surgical team. Wong et al. [26] presented a spreadsheet-based two-stage heuristic approach for the nurse scheduling problem (NSP) in an emergency department. In stage one, they generated nurse scheduling by satisfying all hard constraints. In stage two, they applied the sequential local search algorithm to improve the initial schedule by considering soft constraints (nurse preferences). Legrain et al. [27] developed a multi-objective mathematical model for nurse schedule problem for regular nurse and float nurse to cover a shortage in hospital. Jafari and Salmasi [28] proposed mathematical model of NSP in hospital in Iran considering available nurse shortage, hospital's policies, labor laws, governmental regulations to maximizing the nurses' preferences for working shifts and weekends. Hamid et al. [29] mathematical model to address the scheduling problem of inpatient surgeries by considering the decision-making styles of the surgical team members. The results showed that the proposed approach was able to present a significantly better schedule in comparison with the schedule proposed by the OR director.

To the best of our knowledge in this study for the first time teamwork and decision-making style have been taken into account for establishing teams in nurse scheduling problems with the aim of minimizing inconsistency among them while optimizing reliability and costs, simultaneously.

Problem description and formulation

The nursing team working studied here consisted of registered nurses (RNs), licensed practical nurses (LPNs), nursing assistants (NAs), and unit secretaries (USs) work together on a patient care unit to provide nursing care to a group of inpatients. In this case, first, we determine nurses' team working based on decision-making style.

To provide scheduling, we have two types of constraints: hard constraints must be met, while soft constraints may be violated in some schedules. The following notations will be used for describing the problem's characteristics:

Sets:

K set of RNs
G set of NAs
H set of USs
M set of LPNs
S set of all shifts in a day
D set of days in planning horizon
T set of teamwork in a ward

Indicate:

i Category of available nurse expertise (NA, RN, UA, LPN)
s shifts
d days
t teamwork

Parameters:

C_{tsd} Cost of assigning team t to shift s in day d
C_{kt} Cost of assigning team t to shift s in day d
E_{tsd} Probability of medical error if team t is assigned to shift s in day d
S_{ViVj} Decision-making style inconsistency of two team member v_i and v_j ($v_i \neq v_j$)
$hmin_z$ Minimum number of SHIFT that team j must work in a week
$hmax_z$ Maximum number of SHIFT that team j can work in a week
a_{it} Number of available nurses of kind i in each team

w_i	Maximum number of shifts (workload) team *t* can work in a day
$\bar{N}$	Maximum number of late night shifts each team might work in a week
$\bar{W}$	Maximum number of weekend shifts each team might work in a week

Decision Variables:

x_{it} = 1; if nurse *i* is assigned to team *t*
= 0; otherwise

Y_{tsd} = 1; if team *t* is assigned to shift *s* in day d
= 0; otherwise

f_t = 1; if team t established
= 0; otherwise

Objectives:

$$Min \sum_{j \in i} \sum_{r \in i} \sum_{t} s_{s_{ViVj}} x_{it} x_{jt} \qquad i \neq j \tag{1}$$

$$Min \sum_{t} \sum_{s} \sum_{d} E_{tsd} y_{tsd} \tag{2}$$

$$Min \sum_{k} \sum_{t} c_{kt} x_{it} \tag{3}$$

$$Min \sum_{s} \sum_{d} c_{tsd} y_{tsd} \tag{4}$$

$$Min \sum violating\ soft\ constraint \tag{5}$$

Teamwork Constraint

$$\sum_{i \in K} x_{it} \geq a_K \tag{6}$$

$$\sum_{i \in G} x_{it} \geq a_G \tag{7}$$

$$\sum_{i \in H} x_{it} \geq a_H \tag{8}$$

$$\sum_{i \in M} x_{it} \geq a_M \tag{9}$$

$$x_{it} \leq f_t \qquad \forall t, i \tag{10}$$

$$y_{tsd} \leq f_t \qquad \forall t, s, d \tag{11}$$

Hard Constraint

$$\sum_{s} y_{tsd} \leq wi \tag{12}$$

$$\sum_{t} y_{tsd} = 1 \qquad \forall s, d \tag{13}$$

$$\sum_{s} \sum_{d} y_{tsd} \geq hmin_z \tag{14}$$

$$\sum_{s} \sum_{d} y_{tsd} \leq hmax_z \tag{15}$$

$$y_{t(\max\{s\}d)} + y_{t(\min\{s\})(d+1)} \leq 1 \tag{16}$$

$$\sum_{t} x_{it} \leq 1 \tag{17}$$

Soft Constraint

$$\sum_{d} y_{t(\max\{s\}d)} \leq \bar{N} \tag{18}$$

$$\sum_{s} y_{t,s,max\{d\}} \leq \bar{W} \tag{19}$$

Eq. 1 minimizes the summation of inconsistency in decision-making style in the nurse teams. Eq. 2 minimizes the expected number of medical accidents considering their probabilities for different teams. Eq. 3 aims to minimize the cost of allocating nurses to teams. Eq. 4 minimizes the cost of allocating nurse teams to shifts considering hard constraints. Eq. 5 minimizes the violation of soft constraints using the goal programming approach. In soft constraints, a positive deviation is penalized. Eqs. 6, 7, 8, and 9 necessitate that the minimum number of each category of nurses must be assigned to each team. Eqs. 10 and 11 show that X and Y are able to take values when team t is formed. Eq. 12 limits the maximum number of shifts each nurse team may be assigned per day. Eq. 13 implies that only one nurse team must be assigned to each shift. Eqs. 14 and 15 set the minimum and maximum working hours in the planning horizon for each nurse team. Eq. 16 implies that a team that has a night shift must not be assigned to the morning shift of the next day. Eq. 17 necessitates that each person is assigned to only one team. Eqs. 18 and 19 confine the number of late-night and weekend shifts to which each nurse can be allocated in the planning horizon.

Solution methodology

Goal programming is one of the methods that has been widely used in nurse scheduling problems[30]. In this section, we present a goal programming method that is applied for solving the multi-objective nurse scheduling model proposed in Section 3.

Goal programming

Goal programming is a variation of linear programming considering more than one objective function. Goal programming allows a decision-maker to incorporate environmental, organizational, and managerial aspects into the model through goal levels and priorities. Goal programming can be employed in decision-making problems with a single goal (objective) and multiple sub-goals, as well as in cases with multiple goals and sub-goals. Goal programming necessitates the establishment of a weighting system for the goals. These weights can be ordinal or cardinal. Below, the model of the goal programming method is briefly presented:

$$\begin{aligned}
&Min \ \left\{P_1\left(d_1^+\right), P_2\left(d_2^+\right), P_3\left(d_3^+\right), P_4\left(\sum_t\left(d_{4,t}^+ + d_{5,t}^+\right)\right)\right\} \\
&s.t. \\
&Z_1 + d_1^- - d_1^+ = 0 \\
&Z_2 + d_2^- - d_2^+ = 0 \\
&Z_3 + d_3^- - d_3^+ = 0 \\
&\textstyle\sum_d y_{t,\max\{s\},d} + d_{4,t}^- - d_{4,t}^+ = \bar{N} \\
&\textstyle\sum_s y_{t,s,\max\{d\}} + d_{5,t}^- - d_{5,t}^+ = \bar{W} \\
&\ldots \\
&\text{Other Constraints}
\end{aligned} \tag{20}$$

In the abovementioned model, the third part of the objective function is the summation of objectives 3 and 4 of the basic model. The fourth objective is formed by summing the positive deviational variable of soft constraint. P1 to p4 show priority in goal programming. In our case study, the priority of objectives has been determined by nursing managers at the hospital.

The first objective function is nonlinear; since the proposed model is non-linear, it takes a long time to solve large-size problems. Thus, the model is linearized by rewriting Eq. 1. For this purpose, we define a new positive auxiliary variable *tt* to convert linear equation as shown below:

$$tt_{ijt} \leq x_{it} \tag{21}$$

$$tt_{ijt} \leq x_{jt} \tag{22}$$

$$tt_{ijt} \geq x_{it} + x_{jt} \tag{23}$$

$$tt_{ijt} \geq 0 \tag{24}$$

And

$$tt_{ijt} = x_{it} \ . x_{jt} \tag{25}$$

So, the first objective function is rewritten as:

$$Min \sum_{r \in i} \sum_{t} s_{ViVj} tt_{ijt} \quad i \neq j \tag{26}$$

Numerical example

In this section, a real case study of a public general hospital in Iran is considered and nursing teams are analyzed. The nursing teams consisted of registered nurses (RNs), licensed practical nurses (LPNs), nursing assistants (NAs), and unit secretaries (USs). The hospital has 3 units and in one of them in each shift of at least 2 NAs, 1 RN, 1 UA, and 1 LPN should be present. We focused on this unit because the required information is available and the managers accepted to provide the requested data. We asked four managers to assign a decision making style to the team members based on definitions of each style and consensus based decision-making is applied to finalize the style. Decision-making style of each person is shown in the following table:

Table 3. Decision making style of RNs 1 to 10

1	2	3	4	5	6	7	8	9	10
Flexible	**Hierarchic**	**Hierarchic**	**Hierarchic**	**Decisive**	**Flexible**	**Integrative**	**Flexible**	**Flexible**	**Decisive**

Table 4. Decision making style of NAs 11 to 15

11	12	13	14	15
Decisive	**Flexible**	**Integrative**	**Decisive**	**Decisive**

Table 5. Decision making style of LNAs 15 to 20

16	17	18	19	20
Integrative	**Flexible**	**Flexible**	**Integrative**	**Decisive**

Table 6. Decision making style of USs 20 to 25

21	22	23	24	25
Flexible	**Flexible**	**Hierarchic**	**Hierarchic**	**Hierarchic**

The value of inconsistency between different decision-making styles is defined as follows:

Table 7. Value of inconsistency between decision making style

Decision making styles	**Decisive**	**Flexible**	**Hierarchic**	**Integrative**	**Systemic**
Decisive	S=3	S=3	N=5	**T=7**	**T=7**
Flexible	S=3	I=1	T=7	**N=5**	**T=7**
Hierarchical	N=5	T=7	S=3	**N=5**	**N=5**
Integrative	T=7	N=5	N=5	**I=1**	**N=5**
Systemic	T=7	T=7	N=5	**N=5**	**S=3**

S; Suitable, N; Normal, T; Terrible, I; Ideal

In order to evaluate the accuracy of managers' evaluation on decision-making styles, ANOVA test is performed and the results are presented in the following table.

Table 8. ANOVA test on the results of managers' evaluation

Group	**F**	**Sig.**
RNs	3.07	0.12
NAs	3.74	0.09
LNAs	2.16	0.21
USs	2.51	0.17

According to the results, all the evaluations are acceptable at alpha=0.05. The cost of assigning each team to morning and evening shifts is equal to 1 unit. The cost of assigning teams to night and weekend shifts is 1.4. The cost of assigning NAs, RNs, UAs, and LPNs respectively is 1, 1.4, 0.8, and 1.7 units. Each team has a percent of error depending on the assigned day and shift. The probability of medical error is obtained by multiplying the performance coefficient of each team member in each shift. The performance coefficient of personnel has been determined by nursing managers. The model is solved and the optimum solution for the first goal is 228; the results are shown in Table 9.

Table 9. Assigning personnel to teams considering goal 1

	t1	**t2**	**t3**	**t4**
RNs	5	6	2	1
	10	8	7	9
NAs	11	14	13	12
LPN	20	17	16	18
US	24	21	25	22

Numbers in the table represent the assigned number of the personnel. Shift assignment is also shown in Table 10.

Table 10. Assigning teams to shifts considering goal 1

		Days						
Teams	Shifts	1	2	3	4	5	6	7
1	1							
	2							
	3	✓	✓	✓	✓	✓	✓	
2	1		✓	✓	✓	✓	✓	✓
	2							
	3							
3	1							
	2	✓		✓	✓	✓	✓	✓
	3							
4	1	✓						
	2		✓					
	3							✓

Next, the model is solved for the second goal considering the optimum solution of goal 1; the optimum answer is 135 and the result is shown below:

Table 11. Assigning personnel to team considering goals 1 and 2

	t1	**t2**	**t3**	**t4**
RNs	2	5	8	1
	7	10	9	6
NAs	13	12	11	14
LPN	16	20	17	18
US	23	25	22	21

Table 12. Assigning teams to shifts considering goals 1and2

		Days						
Teams	**Shifts**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	1							
	2	✓						✓
	3		✓		✓	✓	✓	
2	1			✓	✓			✓
	2		✓				✓	
	3	✓						
3	1	✓	✓					
	2				✓	✓		
	3			✓				
4	1					✓	✓	
	2			✓				
	3							✓

Now, the model is solved according to the third goal in a way that the two previous goals do not get worse. The obtained solution is 50.6; 25.2 of which is related to the cost of assigning personnel to teams and 25.4 is related to the cost of assigning teams to shifts. Details are presented in the following tables.

Table 13. Assigning personnel to team considering goals 1, 2 and 3

	t1	**t2**	**t3**	**t4**
RNs	2	3	8	6
	5	4	10	9
NAs	15	13	11	12
LPN	20	16	18	17
US	23	25	21	22

Table 14. Assigning teams to shifts considering goals 1, 2 and 3

		Days						
Teams	**Shifts**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	1							
	2	✓						✓
	3		✓		✓	✓	✓	
2	1			✓	✓			✓
	2		✓				✓	
	3	✓						
3	1	✓	✓					
	2				✓	✓		
	3			✓				
4	1					✓	✓	
	2			✓				
	3							✓

As it can be seen, assigning personnel to teams is changed; but, assigning teams to shifts is fixed. This result is reasonable because the cost depends on teams and type of personnel, and working shifts are fixed. Now, the last goal is solved and the optimum solution is 2; the violation happened in the first soft constraint. In the following table, the 2 nights in which violation happens are highlighted in red.

Table 15. Assigning personnel to team considering all the goals

	t1	**t2**	**t3**	**t4**
RNs	3	4	1	5
	10	7	8	6
NAs	14	13	15	12
LPN	20	19	18	17
US	24	23	21	22

Table 16. Assigning teams to shifts considering goals 1, 2, 3 and 4

		Days						
Teams	Shifts	1	2	3	4	5	6	7
1	1							
	2	✓						✓
	3		✓		✓	✓	✓	
2	1			✓	✓			✓
	2		✓				✓	
	3	✓						
3	1	✓	✓					
	2				✓	✓		
	3			✓				
4	1					✓	✓	
	2			✓				
	3							✓

Sensitivity analysis

Now, we solve the numerical example in the last section with different decision-making styles for NAs, RNs, UAs, and LPNs. Three different combinations of decision-making styles were considered. Then, the model was solved using these parameters and compared with the results obtained from the last section. Details of the data are available in Appendix 1. The results showed that the optimum amount of the first goal was different and teams were formed with different personnel. Also, assigning teams to shifts was different as well.

Table 17. Assigning teams to shifts considering goals 1, 2, 3, and 4

		Days						
Teams	Shifts	1	2	3	4	5	6	7
1	1							
	2	✓						✓
	3		✓		✓	✓	✓	
2	1			✓	✓			✓
	2		✓				✓	
	3	✓						
3	1	✓	✓					
	2				✓	✓		
	3			✓				
4	1					✓	✓	
	2			✓				
	3							✓

But, when the model was solved for goals 2 to 4, the order of assigning teams to shifts was equal in all 4 different sets of decision-making styles, although the personnel of the teams was different. With further study, it was concluded that the obtained results were reasonable because, in the second goal, the percent of error did not depend on persons. Also, the costs were constant and the number of each kind of nurse in the teams was equal to the optimum solution obtained for assigning teams to shifts.

To verify the proposed model, the model was solved using the same parameter in Section 4.1, but the second goal was ignored and the model was solved only for the first, third, and fourth goals. In this case, first, the model was solved for the first goal and the answer for the first goal was the same as the answer obtained in Section 4.2. Next, the model was solved for goal 3 considering the first goal's optimum solution and again, the solution gained 50.6. Finally, the model was solved for goal 4; this time, the optimum solution obtained was zero, i.e. no violation happened from soft constraint and the final optimum solution was changed to the following tables.

Table 18. Assigning personnel to team considering goals 1, 3 and 4

	t1	**t2**	**t3**	**t4**
RNs	5	4	1	6
	7	10	8	9
NAs	13	14	12	11
LPN	19	20	17	18
US	24	23	22	21

Table 19. Assigning teams to shifts considering goals 1, 3 and 4

		Days						
Teams	Shifts	1	2	3	4	5	6	7
1	1		✓					✓
	2	✓			✓			
	3			✓		✓		
2	1	✓		✓			✓	
	2		✓					✓
	3				✓			
3	1							
	2						✓	
	3		✓					✓
4	1				✓	✓		
	2			✓				
	3	✓					✓	

It could be concluded that, when the error is applied as a goal with higher priority, the error function doesn't allow the soft constraint to be 100% satisfied. If we compute the value of the error function for the above solution, the achieved value will be 225, which is more than 135 calculated in Section 4.2.

Conclusion

The aim of this study was to present an optimal nurse scheduling model to maximize job satisfaction. For achieving job satisfaction, team working was applied and it was tried to minimize incompatibility among the team members. In this study, we proposed a new model for nurse scheduling; first, we established nurse teams considering decision-making style. Then, each team was assigned to shifts in the planning horizon. A multi-objective model was proposed considering the inconsistency of each person's decision making style, team's reliability, allocation costs, and penalty for violation of soft constraints as objectives that must be optimized, simultaneously. Finally, the multi-objective approach was utilized for calculating the objective. Numerical examples were solved with GAMS to verify the model's solution approach. Then, sensitivity analysis was applied by changing decision-making style to test the efficiency of the solution approach.

According to the results, the proposed model assigns nurses to the teams in a way to minimize decision-making style inconsistency value, while cost and reliability of assignment are also considered. The proposed model of this study would help the managers to employ personnel with compatible personalities, or to assign the current staff to the teams to minimize possible inconformity. This would increase both patients' and nurses' satisfaction and in this way, the quality of healthcare services can be improved. In future research, decision-making style can be used to allocate nurses to different departments of hospitals.

Compliance with Ethical Standards

Authors declare that they have no conflict of interest.
Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

References

[1] Kalisch, B. J., and Lee, K. H. (2013). Variations of nursing teamwork by hospital, patient unit, and staff characteristics. *Applied Nursing Research, 26*(1), 2-9.

[2] Hall, P., and Weaver, L. (2001). Interdisciplinary education and teamwork: a long and winding road. *Medical education, 35*(9), 867-875.
[3] Driver, M. J., Brousseau, K. R., and Hunsaker, P. L. (1998). *The dynamic decision maker: Five decision styles for executive and business success*: iUniverse.
[4] Azadeh, A., Rezaei-Malek, M., Evazabadian, F., and Sheikhalishahi, M. (2015). Improved design of CMS by considering operators decision-making styles. *International Journal of Production Research, 53*(11), 3276-3287. doi:10.1080/00207543.2014.975860
[5] Simmons, D., and Sherwood, G. (2010). Neonatal Intensive Care Unit and Emergency Department Nurses' Descriptions of Working Together: Building Team Relationships to Improve Safety. *Critical Care Nursing Clinics of North America, 22*(2), 253-260. doi: http://dx.doi.org/10.1016/j.ccell.2010.03.007
[6] Apker, J., Propp, K. M., Ford, W. S. Z., and Hofmeister, N. (2006). Collaboration, credibility, compassion, and coordination: professional nurse communication skill sets in health care team interactions. *Journal of Professional Nursing, 22*(3), 180-189.
[7] Utriainen, K., and KyngÄS, H. (2009). Hospital nurses' job satisfaction: a literature review. *Journal of Nursing Management, 17*(8), 1002-1010. doi:10.1111/j.1365-2834.2009.01028.x
[8] Kalisch, B. J., Lee, H., and Rochman, M. (2010). Nursing staff teamwork and job satisfaction. *Journal of nursing management, 18*(8), 938-947.
[9] Mahon, M. M., and Nicotera, A. M. (2011). Nursing and conflict communication: avoidance as preferred strategy. *Nursing Administration Quarterly, 35*(2), 152-163.
[10] Brunetto, Y., Farr-Wharton, R., and Shacklock, K. (2011). Supervisor-nurse relationships, teamwork, role ambiguity and well-being: Public versus private sector nurses. *Asia Pacific Journal of Human Resources, 49*(2), 143-164.
[11] Burtscher, M. J., and Manser, T. (2012). Team mental models and their potential to improve teamwork and safety: A review and implications for future research in healthcare. *Safety science, 50*(5), 1344-1354.
[12] Poghosyan, L., Boyd, D., and Knutson, A. R. (2014). Nurse Practitioner Role, Independent Practice, and Teamwork in Primary Care. *The Journal for Nurse Practitioners, 10*(7), 472-479.
[13] Dietz, A. S., Pronovost, P. J., Mendez-Tellez, P. A., Wyskiel, R., Marsteller, J. A., Thompson, D. A., and Rosen, M. A. (2014). A systematic review of teamwork in the intensive care unit: What do we know about teamwork, team tasks, and improvement strategies? *Journal of critical care, 29*(6), 908-914.
[14] Ferland, J., Berrada, I., Nabli, I., Ahiod, B., Michelon, P., Gascon, V., and Gagné, É. (2001). Generalized Assignment Type Goal Programming Problem: Application to Nurse Scheduling. *Journal of Heuristics, 7*(4), 391-413. doi:10.1023/A:1011392328632
[15] Azaiez, M. N., and Sharif, S. S. A. (2005). A 0-1 goal programming model for nurse scheduling. *Comput. Oper. Res., 32*(3), 491-507. doi:10.1016/s0305-0548(03)00249-1
[16] Topaloglu, S. (2006). A multi-objective programming model for scheduling emergency medicine residents. *Computers and Industrial Engineering, 51*(3), 375-388.
[17] Maenhout, B., and Vanhoucke, M. (2010). Branching strategies in a branch-and-price approach for a multiple objective nurse scheduling problem. *Journal of Scheduling, 13*(1), 77-93.
[18] Topaloglu, S., and Selim, H. (2010). Nurse scheduling using fuzzy modeling approach. *Fuzzy Sets and Systems, 161*(11), 1543-1563.
[19] Yilmaz, E. (2012). A mathematical programming model for scheduling of nurses' labor shifts. *Journal of Medical Systems, 36*(2), 491-496.
[20] Nelsey, L., and Brownie, S. (2012). Effective leadership, teamwork and mentoring–Essential elements in promoting generational cohesion in the nursing workforce and retaining nurses. *Collegian, 19*(4), 197-202.
[21] M'Hallah, R., and Alkhabbaz, A. (2013). Scheduling of nurses: a case study of a Kuwaiti health care unit. *Operations Research for Health Care, 2*(1), 1-19.
[22] Wright, P. D., and Mahar, S. (2013). Centralized nurse scheduling to simultaneously improve schedule cost and nurse satisfaction. *Omega, 41*(6), 1042-1052. doi:http://dx.doi.org/10.1016/j.omega.2012.08.004
[23] Güler, M. G., İdi, K., and Güler, E. Y. (2013). A goal programming model for scheduling residents in an anesthesia and reanimation department. *Expert Systems with Applications, 40*(6), 2117-2126.

[24] Güler, M. G. (2013). A hierarchical goal programming model for scheduling the outpatient clinics. *Expert Systems with Applications*, *40*(12), 4906-4914.
[25] Meskens, N., Duvivier, D., and Hanset, A. (2013). Multi-objective operating room scheduling considering desiderata of the surgical team. *Decision Support Systems, 55*(2), 650-659.
[26] Wong, T., Xu, M., and Chin, K. (2014). A two-stage heuristic approach for nurse scheduling problem: A case study in an emergency department. *Computers and Operations Research, 51*, 99-110.
[27] Legrain, A., Bouarab, H., and Lahrichi, N. (2015). The nurse scheduling problem in real-life. *Journal of Medical Systems*, *39*(1), 1-11.
[28] Jafari, H., and Salmasi, N. (2015). Maximizing the nurses' preferences in nurse scheduling problem: mathematical modeling and a meta-heuristic algorithm. *Journal of Industrial Engineering International*, *11*(3), 439-458.
[29] Hamid, M., Nasiri, M.M. Frank Werner., Sheikhahmadi, F. and Zhalechian, M. (2019). Operating room scheduling by considering the decision-making styles of surgical team members: a comprehensive approach, *Computers and Operations Research*, 108: 166-181.
[30] Cetin, E., and Sarucan, A. (2015, 27-29 May 2015). *Nurse scheduling using binary fuzzy goal programming.* Paper presented at the Modeling, Simulation, and Applied Optimization (ICMSAO), 2015 6th International Conference on.

Appendix A

In this section, the final solution of different sets of decision-making styles used in Section 4.3 is presented.

- The first set of decision making style and its results used in sensitivity analysis:

Table A.1. Decision making style of RNs 1 to 10

1	2	3	4	5	6	7	8	9	10
Flexible	Hierarchic	Systemic	Integrative	Hierarchic	Integrative	Flexible	Systemic	Hierarchic	Hierarchic

Table A.2. Decision making style of NAs 11 to 15

11	12	13	14	15
Integrative	Decisive	Integrative	Systemic	Systemic

Table A.3. Decision making style of LNAs 15 to 20

16	17	18	19	20
Integrative	Flexible	Hierarchic	Hierarchic	Decisive

Table A.4. Decision making style of USs 20 to 25

21	22	23	24	25
Flexible	Hierarchic	Integrative	Systemic	Systemic

Table A.5. Assigning personnel to team considering all the goals

	t1	t2	t3	t4
RNs	1	5	2	4
	3	10	9	8
NAs	11	14	12	13
LPN	20	16	18	17
US	21	22	25	23

- The second set of decision making style and its results used in sensitivity analysis:

Table A.6. Decision making style of RNs 1 to 10

1	2	3	4	5	6	7	8	9	10
Flexible	Hierarchic	Systemic	Integrative	Hierarchic	Integrative	Flexible	Systemic	Hierarchic	Hierarchic

Table A.7. Decision making style of NAs 11 to 15

11	12	13	14	15
Integrative	Decisive	Integrative	Systemic	Systemic

Table A.8. Decision making style of LNAs 15 to 20

16	17	18	19	20
Integrative	Flexible	Hierarchic	Hierarchic	Decisive

Table A.9. Decision making style of USs 20 to 25

21	22	23	24	25
Flexible	Hierarchic	Integrative	Systemic	Systemic

Table A.10. Assigning personnel to team considering all the goals

	t1	**t2**	**t3**	**t4**
RNs	5	3	1	4
	10	8	7	6
NAs	14	15	12	11
LPN	18	19	17	16
US	22	25	21	23

Table A.11. Assigning teams to shifts considering goals 1, 2, 3 and 4

						Days		
Teams	**Shifts**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	1							
	2	✓						✓
	3		✓		✓	✓	✓	
2	1			✓	✓			✓
	2		✓				✓	
	3	✓						
3	1	✓	✓					
	2				✓	✓		
	3			✓				
4	1					✓	✓	
	2			✓				
	3							✓

- The third set of decision-making style and its results used in sensitivity analysis:

Table A.12. Decision making style of RNs 1 to 10

1	2	3	4	5	6	7	8	9	10
Flexible	Flexible	Systemic	Flexible	Flexible	Systemic	Integrative	Systemic	Hierarchic	Integrative

Table A.13. Decision making style of NAs 11 to 15

11	12	13	14	15
Hierarchic	Flexible	Integrative	Decisive	Decisive

Table A.14. Decision making style of LNAs 15 to 20

16	17	18	19	20
Systemic	Flexible	Systemic	Systemic	Decisive

Table A.15. Decision making style of USs 20 to 25

21	22	23	24	25
Flexible	Decisive	Integrative	Hierarchic	Systemic

Table A.16. Assigning personnel to team considering all the goals

	t1	t2	t3	t4
RNs	6	1	7	2
	8	4	10	5
NAs	13	12	11	15
LPN	18	17	19	20
US	25	21	23	22

Table A.17. Assigning teams to shifts considering goals 1, 2, 3 and 4

		Days						
Teams	**Shifts**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	1							
	2	✓						✓
	3		✓		✓	✓	✓	
2	1			✓	✓			✓
	2		✓				✓	
	3	✓						
3	1	✓	✓					
	2				✓	✓		
	3			✓				
4	1					✓	✓	
	2			✓				
	3							✓

Appendix B

Table B.1. Probability of medical error of teams in different shifts

		Days						
Teams	**Shifts**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	1	4	7	5	9	7	1	8
	2	10	11	4	2	3	7	5
	3	30	7	11	9	8	16	12
2	1	1	8	7	1	9	7	5
	2	9	3	6	12	8	3	20
	3	9	26	28	23	18	11	24
3	1	3	4	3	9	9	8	10
	2	14	17	1	10	6	16	17
	3	24	13	7	26	21	27	29
4	1	6	5	10	8	1	3	6
	2	15	10	2	19	1	2	10
	3	30	27	9	16	17	13	16