Research Article

Nurse's Shift Balancing in Nurse Scheduling Problem

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Abstract

In this study, a load balanced nurse-scheduling model is developed. A case problem of a local hospital in Ratchaburi province is used to test the model in order to improve the existing manual method. There are three working shifts, morning shift, afternoon shift and night shift in the hospital. The load balance is one of factors that affects the nurse's preferences. The objective of the study is to balance the load of each shift for all workers. The min-max objective is applied to minimize the maximum deviation of the average load of each shift. Goal constraints is applied to determine the plus and minus deviation from the average load of each shift. The proposed model is solved by the Premium Solver on Microsoft Excel. It was found that the balanced load is improved.

***Key Words*: Nurse scheduling problem; Load balancing**

Introduction

The nurses' timetabling problem exists in the periodic schedules for nursing staffs. These affect the performance and quality of a health care service. Generally, a nurse chief is responsible for assigning the shifts arrangement to nursing staffs. The manual scheduling process is time-consuming process. The nurse's schedule is often adjusted to meet the requirement and nurse satisfaction. There are many factors need to be considered in nurse scheduling problem, e.g. the fairness, balanced workloads, the difference of load requirement for senior and junior nurses and the personal requirement.

In the study, the mathematical model is applied to solve the problem. The study develops the nurse's schedule in monthly periodic with the objective to satisfy nurses' preferences and balance their workload. The nurses' workload is the total number of the working period time assigned to each nurse based on the hospital policy and also there are the workload limitations on each nurse which depend on seniority. The Premium Solver on Microsoft Excel is applied to solve the problem.

Theory and Literature Review

Integer Linear programming (ILP)

Optimization problem is the problem involving one or more decisions with restrictions. A goal or an objective is considered and represented by an objective function which identifies the function of the decision variables. The decision maker may want to either maximize or minimize the objective, e.g. minimizing cost and maximize profit. The constraint is represented in a mathematical model, e.g. $f(x_1,x_2,.., x_n) \leq b$, $f(x_1,x_2,.., x_n) \geq b$ (Ragsdale et al., 2004).

Linear programming (LP) involves an optimization problem with linear objective functions and linear constraints. LP model has three basic components (Taha, 2003).

1) Objective or goal that is aimed to optimize

2) Constraints or restrictions that are needed to comply with, e.g. a limited amount of raw materials or labors

3) Decision variables or the solutions, the non-negativity restrictions accounting for this requirement

Integer linear programming (ILP) is linear programming in which some or all the variables are restricted to integer value.

Goal programming

Goal programming is one of the techniques to solve multi-objective problem. It is applied when the problem has more than one objective. All objectives are converted into goals and they are transformed to be constraints. The idea of the technique is minimizing the 'distances' between the solution and the target goal. The general structure of the i-th goal can be expressed as:

$$g_i : f_i(x) + \eta_i - \rho_i = b_i \qquad , i = 1,2,\ldots,K$$

where K = Total number of goals.

$f_i(x)$: is the mathematical expression a linear function of decision variable x

b_i: is the target value for the i-th goal gi

η_i:is the negative deviational variable, i.e., quantification of the under achievement ofi-th goal.

ρ_i: is the positive deviational variable, i.e., quantification of the over-achievement of i-th goal.

All k number of goal will be formulated. The aim is to detect the deviation variables (η_i and ρ_i) which are the variable that we want to minimize.

Literature review

Scheduling deals with the timing operations. The research of scheduling decision applied in organizations e.g. hospitals, university, manufacturer, restaurant and airline. Wattanamano et al.(2011) proposed integer linear programming model to schedule courses and classroom assignment for a University. For hospital,there are many researchers that have formulated mathematical models for nurse staffing and scheduling problems. Nurses scheduling problems have been addressed in the literature for many years. Rosenbloon and Goertzen (1987) presented an integer programming technique to solve nurse scheduling problem. M'Hallah and Alkhabbaz (2013) investigated the problem of designing timetables for nurses. For the multi-objective problem, a variety of techniques have been used to solve the nurse scheduling problem including: goal programming, artificial intelligence techniques, heuristics and meta-heuristics, Berrada et al. (1996). Azaiez and Al Sherif (2005) used a 0-1 goal programming for nurse scheduling. The objective in goal programming is designed in different ways, e.g. assigning weights to the deviations based on their importance and then minimize the sum. In this paper, the min-max goal programming is applied. The maximum deviation among the weighted deviation is minimized. Umarusman (2013) proposed a Min-Max Goal programing approach for solving multi-objective problem. Wright and Mahar (2013) concerned the nurse satisfaction. They proposed a nurse scheduling model to achieve less overtime while reducing wage cost.

Research Methodology

Interviewing and discussing the related persons

Fourteen nurses a local hospital in Ratchaburi province were interviewed and asked to fill in a questionnaire to determine the requirement of the nurse scheduling. The survey was conducted to obtain nurses' preferences.

Problem statement

There are 14 nurses operating in the In-patient department in a hospital , a head of In-Patient department and 13 registered nurses. Generally, the nurse scheduling is processed monthly, 2 weeks before the beginning of each month. The working period has 3 shifts in a day, i.e. morning shift (8.00-16.00), afternoon shift (16.00-24.00) and night shift (00.00-8.00). There are three seniority levels based on the working experience as shown in Table 1. For the scheduling requirement, each shift requires a variety in number of the nurse's seniority levels. For example, the morning shift on workdays requires 3 nurses in high-seniority level. The nurses in high-seniority level do not work on holiday. For all days, the morning shift requires 1 nurse with medium and low seniority levels. The afternoon shift and night shift require 2 nurses with medium-seniority level and 1 nurse in low seniority level for all days as shown in Table 2.

A nurse is able to work only one shift per day which is limited to 8 hours a day. Each nurse cannot work more than 8 hours continuously. For example a nurse which already worked on night shift on the first day cannot do the morning shift on the next day.

Table 1 The seniority levels

Seniority levels	Working Experience
High	>20 years
Medium	10-20 years
Low	1 – 10 years

Mathematical Model

To determine the nurse scheduling, an integer linear programming model is proposed. The objective of the model is to balance the load of each nurse. MINIMAX objective and Goal programming are applied. The requirements are added in form of constraints. In the development, the following notations are used.

Indices and sets

i index for days in a month, $i = 1,2,..I$

j index for periods in a day, $j = 1,2,3$ (1 = morning shift, 2 = afternoon shift, 3 = night shift)

k index for nurses, $k = 1,2,\ldots, K$

l index for seniority level of nurses , l = 1,2,3 (1 = high, 2 = medium, 3 = low)

Parameters and data

Z_{jl} = demand for seniority level l in shift j

N_{jk} = target value of load for each nurse k in shift j

W_1 = weighted value to set the priority for the overachieved deviational variable.

W_2 = weighted value to set the priority for the underachieved deviational variable

Decision variables

X_{ijk} = (binary) 1 if nurse k is assigned to shift j on day i, *0* otherwise

D_{jk}- = deviational variable, goal's target value is underachieved.

D_{jk}+ = deviational variable, goal's target value is overachieved.

Mload = the maximum deviational load for all nurses.

Objective function

Ideally, the work load should be equal. However, the scheduler expects the scheduling solutions having similar load or the smaller deviation load among nurses. In this study, the balance value is set in target number. The workers' load is expected to close to the target number. The deviation load of each nurse from the target should be small among nurses. To minimize the maximum deviation from the goal which is the target load, MINIMAX objective is applied. The variable (*Mload*) is the maximum load which is the highest deviational load for all nurses.The objective function is minimizing *Mload* in order to spread the maximum load to other nurses so that the load of each nurse will be similar.

Objective function:

Min *Mload*

Formulating model constraints

$$\sum_{k \in l} X_{ijk} = Z_{jl} \quad ; \forall i, \ \forall j, \forall l \qquad (1)$$

Constraint 1 states that the number of nurses k available during shift j of day i must be equal to the requirement.

$$\sum_{j=1}^{J} X_{ijk} \leq 1 \quad ; \forall i, \ \forall k \qquad (2)$$

Constraint 2 specifies that each nurse k is able to work only a shift j on day i.

$$X_{i,j=3,k} + X_{i+1,j=1,k} \leq 1 \quad ; \forall i, \ \forall k \qquad (3)$$

Constraint 3 requires that each nurse cannot work continually greater than 8 hours.

$$\sum_{i=1}^{I} X_{ijk} - D^{+}_{jk} + D^{-}_{jk} = N_{jk} \quad ; \forall j, \ \forall k \qquad (4)$$

Constraint 4 states the goal constraint which is the target load of each nurse. The deviation value from the target value is determined in this constraint.

$$(W_1 \times D^{+j}_{k}) + (W_2 \times D^{-}_{jk}) \leq Mload \quad ; \forall j, \ \forall k \qquad (5)$$

Constraint 5 determines the maximum deviation load. *Mload* must be greater than or equal to the values of all deviational variables. The underachieved deviational variable and the overachieved variable are weighted in order to set the priority.

Table 2 The data input

Seniority levels	No. Available
High	3
Medium	7
Low	4

Shift(j)	Morning (j = 1)			Afternoon (j = 2)			Night (j = 3)		
Seniority levels	**High**	**Medium**	**Low**	**High**	**Medium**	**Low**	**High**	**Medium**	**Low**
Workload Req. (Z_{jl}) (workday)	3	1	1	0	2	1	0	2	1
Workload Req. (Z_{Ff}) (holiday)	0	1	1	0	2	1	0	2	1
Target load (N_{jk})	20	4	8	-	8	8	-	8	8

Illustrative Example

The following constraints show the example of the constraint 1 to 5. The constraint 6 shows that three nurses in high seniority have to work on 1st day on day shift. The 1st nurse can work on any shift in the 1st day (constraint 7).The constraint 8 presents that if the 1st nurse is assigned the night shift on the 1st day, the nurse cannot do the day shift on the 2nd day. In constraint 9, the 4th nurse has workload equal to the target load (8 days) in 1 day on afternoon shift.

$$X_{1,1,1} + X_{1,1,2} + X_{1,1,3} = 3 \quad \text{(No. nurses required)} \quad (6)$$

$$X_{1,1,1} + X_{1,2,1} \ldots X_{1,3,1} \leq 1 \quad \text{(Shift selection)} \quad (7)$$

$$X_{1,3,1} + X_{2,1,1} \leq 1 \quad \text{(Limit the workload)} \quad (8)$$

$$X_{1,2,4} + X_{2,2,4} + \ldots + X_{k,i,4} + D^{-}_{jk} - D^{+}_{jk} = 8 \quad \text{(Deviation to the target)} \quad (9)$$

Results and discussion

The questionnaire indicated that most nurses preferred working in morning shift to other shifts. With this information, the nurses'expectation is to balance each shift assigned among them. And also the day-off assigned should be equal for all nurses. Fairness among nurses is one of important factors that they concern. The existing scheduling process was investigated and the data was also gathered and analyzed. Figure 1 shows the unbalanced workload among nurses in a month.

The study develops the nurse's schedule in monthly periodic with the objective to satisfy nurses' preferences and balance their workload. To test the model, five tests were designed with the 5 levels weighted as shown in Table 3. For example, in test 2 the constraint 5 in the model will be $(0.6 \times D^{+}_{jk}) + (0.4 \times D^{-}_{jk}) \leq Mload$. The software Excel's Premium Solver version 11.0 from Frontline Systems, Inc.was applied to determine the solution as shown in Figure 2. With the requirement in the problem statement, the problem consists of 526 binary decision variables. The computational results based on the collected data illustrated that the test with weighted w1= 0.8 and w2 = 0.2 gave the lowest maximum workload (*Mload*) as shown in Table 3. The solution from the model was compared to the solution from the practical application. Figure 1 shows the workload in number of the assigned shift which was the solution from manual process. Nurse M7 (medium seniority) in night shift and L1 (Low seniority) for afternoon shift had higher load than the others. After the test, it was found the workload

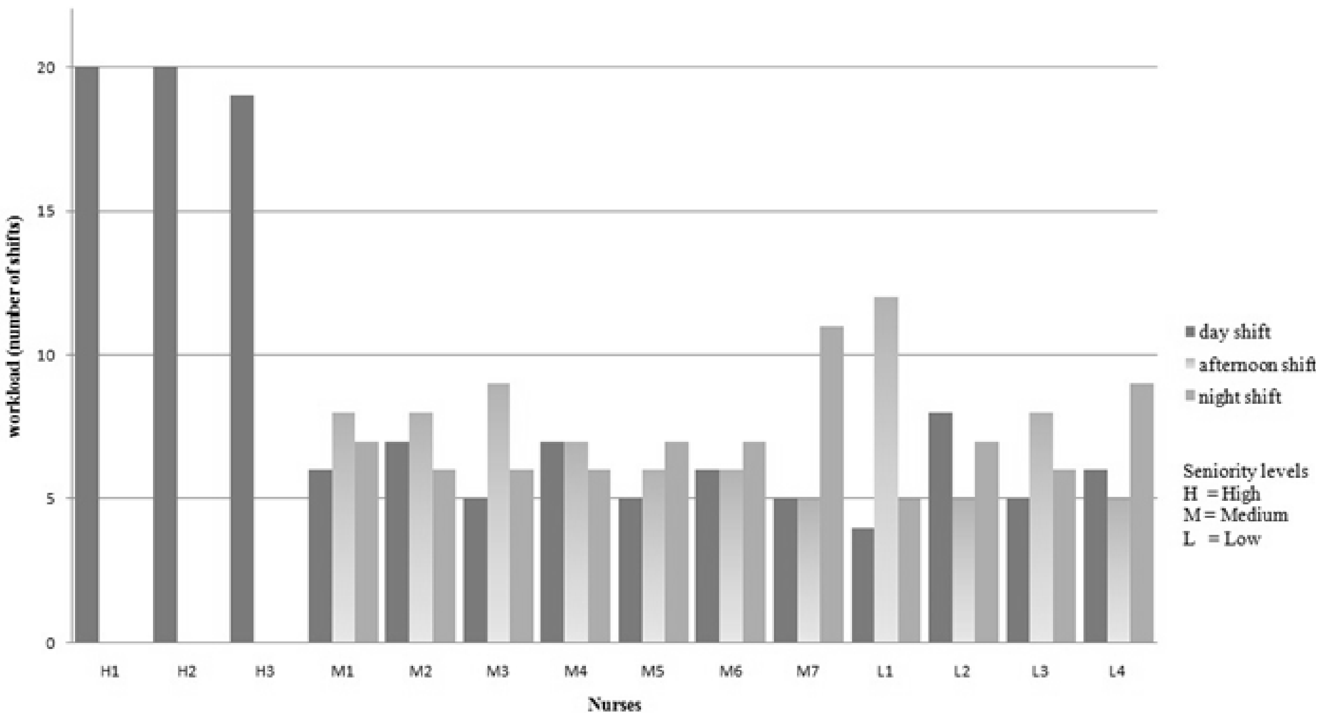

Figure 1 Workload in number of the assigned shift which is the solutions from manual-made.

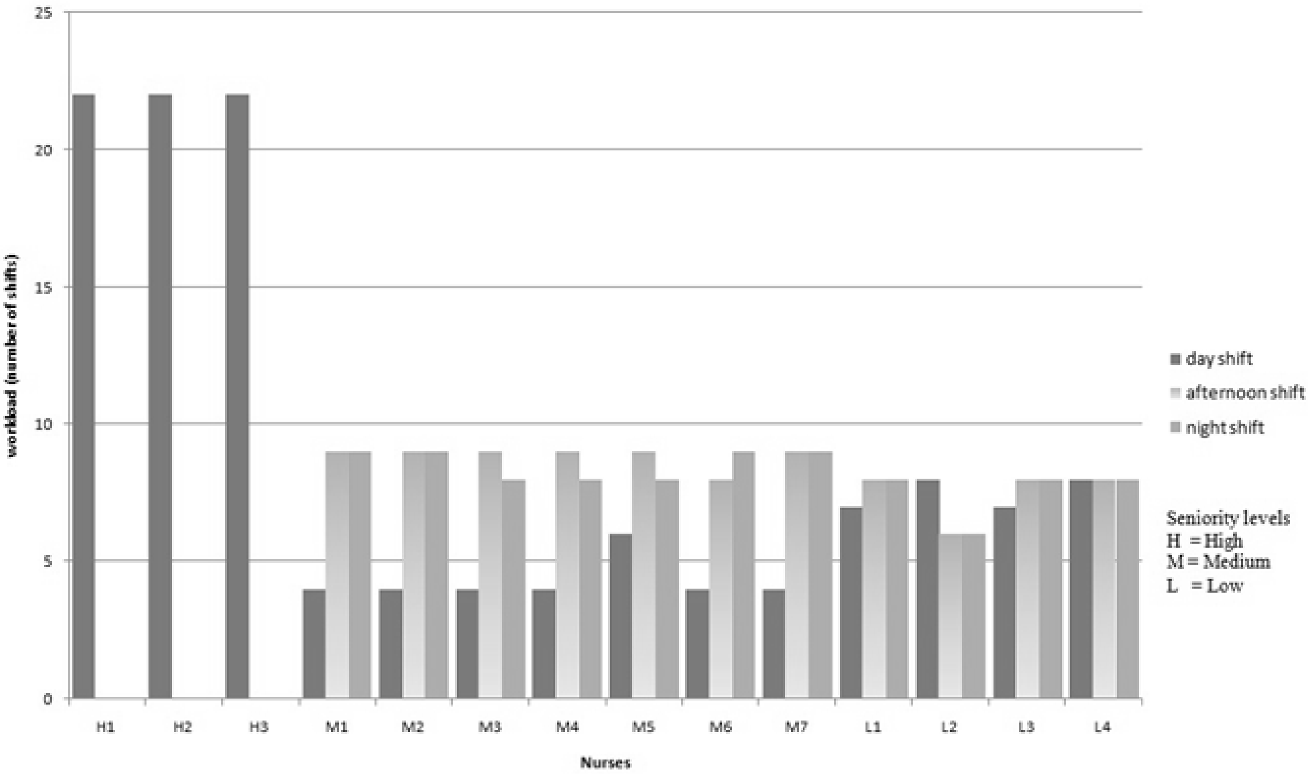

Figure 2 The workload solution from the proposed model

balance is improved. Table 4 presents the example of workload solution from the proposed model.

In this study, a goal programming with min-max objective is developed for nurse scheduling. Since the manual scheduling does not satisfy criteria, e.g. the balanced schedules, nurse preferences and fairness consideration. The proposed model met the quantitative of nurse requirement. Nurses grouped by seniority have been given the similar amount of load in day shift, afternoon shift and night shift. For health concern, the night shift before the day shift in the next day is excluded in the model. The developed model provides the improved solution. However, there are other factors in real situation, e.g. the nursing expertise, proportion between weekends and day on. Further study may focus on the nurse scheduling with nursing expertise or skill and also developing computer graphical user interface (GUI) for Excel Solver.

Table 3 The objective value (*Mload*)

Test	W_1	W_2	*Mload*
1	0.5	0.5	2
2	0.6	0.4	1.6
3	0.7	0.3	1.2
4	0.8	0.2	0.8
5	0.9	0.1	0.9

Table 4 The results of the nurse scheduling

		High			Medium							Low			
DAY	SHIFT	B1	B2	B3	M1	M2	M3	M4	M5	M6	M7	L1	L2	L2	L3
MON	Morning	1	1	1	0	0	0	0	1	0	0	0	0	0	1
	Afternoon	0	0	0	0	1	0	0	0	1	0	0	0	1	0
	Night	0	0	0	0	0	0	1	0	0	1	1	0	0	0
TUE	Morning	1	1	1	1	0	0	0	0	0	0	0	0	0	1
	Afternoon	0	0	0	0	0	1	0	0	1	0	1	0	0	0
	Night	0	0	0	0	0	0	0	1	0	1	0	1	0	0
WED	Morning	1	1	1	1	0	0	0	0	0	0	0	0	0	1
	Afternoon	0	0	0	0	1	1	0	0	0	0	1	0	0	0
	Night	0	0	0	0	0	0	1	0	0	1	0	0	1	0
THU	Morning	1	1	1	0	1	0	0	0	0	0	0	1	0	0
	Afternoon	0	0	0	1	0	0	0	0	1	0	0	0	1	0
	Night	0	0	0	0	0	1	0	1	0	0	0	0	0	1
FRI	Morning	1	1	1	0	0	0	0	0	0	1	1	0	0	0
	Afternoon	0	0	0	1	0	1	0	0	0	0	0	0	1	0
	Night	0	0	0	0	0	0	0	1	1	0	0	1	0	0
SAT	Morning	0	0	0	0	0	1	0	0	0	0	1	0	0	0
	Afternoon	0	0	0	0	0	0	0	1	0	1	0	1	0	0
	Night	0	0	0	1	1	0	0	0	0	0	0	0	0	1
SUN	Morning	0	0	0	0	0	0	0	0	1	0	0	0	1	0
	Afternoon	0	0	0	0	1	0	1	0	0	0	1	0	0	0
	Night	0	0	0	0	0	0	0	1	0	1	0	0	0	1

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