IOP Conf. Series: Materials Science and Engineering **332** (2018) 012039 doi:10.1088/1757-899X/332/1/012039

Scheduling nurses' shifts at PGI Cikini Hospital

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Abstract. Hospitals play an essential role in the community by providing medical services to the public. In order to provide high quality medical services, hospitals must manage their resources (including nurses) effectively and efficiently. Scheduling of nurses' work shifts, in particular, is crucial, and must be conducted carefully to ensure availability and fairness. This research discusses the job scheduling system for nurses in PGI Cikini Hospital, Jakarta with Goal Programming approach. The research objectives are to identify nurse scheduling criteria and find the best schedule that can meet the criteria. The model has hospital regulations (including government regulations) as hard constraints, and nurses' preferences as soft constraints. We gather primary data (hospital regulations and nurses' preferences) through interviews with three Head Nurses and distributing questionnaires to fifty nurses. The results show that on the best schedule, all hard constraints can be satisfied. However, only two out of four soft constraints are satisfied. Compared to current scheduling practice, the resulting schedule ensures the availability of nurses as it satisfies all hospital's regulations and it has a higher level of fairness as it can accommodate some of the nurses' preferences.

1. Introduction

The healthcare industry is growing significantly in Indonesia. According to data from the Ministry of Health (MOH), the number of hospitals in Indonesia has increased annually in the average of 5.3% from 2013 to 2016 [1]. In the Jakarta province (the capital city of Indonesia), in particular, the number of hospitals is about 190 in 2016, consisting of general and specialized hospitals [1]. Concerning the number of patients, 39 state-owned hospitals in Indonesia serve about 6.8 million patients in 2016 [2]. As the number of patients is predicted to increase significantly, the availability of human resources, especially nurses, becomes crucial to ensure high-quality health services. The main challenge faced by healthcare service providers is how to allocate and manage resources efficiently to anticipate demand fluctuation [3].

Scheduling nurses' shifts are still considered as a complex problem [4]. According to Kumar et al., scheduling has not been able to provide an optimal solution to the hospital, that can minimize labor costs and satisfy nurses' preferences, as well as distribute well-balanced work shift among nurses, and meet workplace constraints [5].

Good scheduling will increase the quality of healthcare services provided to the customers, as well as increasing nurses' job satisfaction. Generally, shift scheduling is conducted by complying with hospitals' regulations related to workload and by considering nurses' preferences. Work shifts may influence employee's performance, personally, socially and psychologically [6]. Good scheduling allows nurses to have sufficient time for themselves and their families, and provide fairness as each nurse has a similar number of shifts, and thus, allows them to work optimally.

This research is concerned with scheduling nurses' shifts at PGI Cikini Hospital, a private hospital in Jakarta. In this hospital, the nurses' shifts scheduling is performed manually by the Head Nurse in each unit, at the end of every month. This task is still considered as tedious and challenging for the Head Nurse, and the resulting schedule has not been able to provide fairness to nurses. Furthermore, it has not been able to meet all hospital's regulations and accommodate nurses' preferences. Thus, there is a need for a scheduling approach that can provide a better shift schedule for the nurses in the hospital. As different hospitals may have different regulations and nurse preferences, existing nurse scheduling models cannot be directly applied to the problem.

Therefore, the objectives of this research are to identify factors that affect scheduling (hospital regulations and nurses' preferences), and then apply goal programming approach to schedule nurses' work shifts, and compare the resulting schedule with current schedule implemented by the hospital. Goal programming approach is used as it attempts to optimize multiple objective functions simultaneously [7], thus, it can be used to develop nurses' scheduling that must take into accounts hospital regulations and nurses' preferences.

The remainder of the paper is presented as follows. Section 2 discusses the methodology, while Section 3 shows the results and discussions, and Section 4 presents conclusions and recommendations.

2. Methodology

According to Azaiez and Al Sharif, human resources scheduling decisions in health institutions, such as hospitals, can be classified into four interrelated decisions, namely staffing, scheduling, allocation, and assignment decisions [7]. Nurse scheduling, in particular, is the process of determining the schedule for nurses so that the health institution can meet the customer demand [8]. Nurse scheduling is a complex problem that affects hospital personnel on a daily basis, and thus, it is essential to develop it efficiently, and to balance the workload among nurses, and to attempt to satisfy personal preferences [9].

Azaiez and Al Sharif [7] develop a 0-1 goal programming model for nurse scheduling. The model takes into account hospital objectives and nurses' preferences (which are obtained via a survey), and applied to a hospital in Saudi Arabia. The model assumes that a working day consists of two twelve-hour shifts, and the schedule is developed for every planning period. The model is applied to a case with 28 days scheduling period and 15 nurses. Jenal et al. [10] later modify model in [7], and develop a cyclical shift scheduling approach. A cyclic schedule consists of a set of work patterns that are rotated among a group of workers over a set of scheduling horizon [10]. The model by Jenal et al. assumes that one working day consists of three eight-hour shifts, and creates schedule patterns that will be used by Head Nurses to allocate shifts for nurses for the whole year. The model is applied to a case with 21 days scheduling period and 18 nurses.

In this paper, we develop the nurses' work shifts schedule for PGI Cikini Hospital using goal programming approach. The model has hospital regulations (including government regulations) as hard constraints, and nurses' preferences as soft constraints. We modify the model from [7] and [10] as hospital regulations and nurses' preferences in the PGI Cikini Hospital are slightly different from those discussed in the aforementioned models. The scheduling period is 28 days, and the model can be easily modified to a cyclic schedule as in [10]. We gather primary data (hospital regulations and nurses' preferences) through interviews with three Head Nurses and distributing questionnaires to fifty nurses.

2.1. Problem definition

In the current scheduling practice at PGI Cikini Hospital, the Head Nurse in each unit is responsible to create, implement, revise, and documenting the nurse schedule. As previously mentioned, the schedule is created manually at the end of each month, and the process is considered as challenging by the Head Nurse and takes a lot of time to complete. The created schedule often has work shifts distributed unevenly among nurses.

Thus, the objective of this research is to develop the work shift schedule that ensures availability and provides more fairness to the nurses. The schedule is created for 16 nurses in one unit. The main assumptions of the model are as follows: (1) The number of nurses is constant throughout the scheduling

period; (2) There are three shifts in a day, morning shift (07.00-14.00), evening shift (14.00-21.00), and night shift (21.00-07.00); (3) The number of minimum nurses in each shift is constant, namely 4 nurses in morning shift, 5 nurses in evening shift, and 3 nurses in night shift; (4) The number of shifts on weekdays (Monday-Saturday) is similar to weekend (Sunday); (5) The planning period is for 28 days (4 weeks), and the first day is Monday; (6) There is no public holiday in the planning period; (7) The schedule does not take into account nurses' skill level or experience.

2.2. Model Formulations

2.2.1. Hard constraints. The hard constraints of the model represent the hospital rules (obtained through interviews with three Head Nurses at the hospital), namely: (1) The number of nurses in each shift satisfies the minimum requirement; (2) A nurse can only work in one shift in a day; (3) If a nurse work two night-shifts in two consecutive days, he/she will get two days-off afterwards; (4) A nurse works 5 to 6 days in a week.

2.2.2. Soft constraints. The soft constraints represent the nurses' preferences (obtained from questionnaires). They are: (1) All nurses have similar workdays in the scheduling period; (2) Each nurse at least gets one day-off on weekend in the scheduling period; (3) The total number of morning and evening shits is more than the number of night shifts; (4) There is no working day in between days-off.

2.2.3. The model. The notations for indices, parameters, and decision variables are presented in Table 1, followed by the model formulations.

Table 1. Model notations

Symbols	Descriptions
n	Number of days in a scheduling period
m	Number of nurses available in the respective division/unit
i	Days, i = 1, 2, 3, ..., n
k	Nurses, k = 1, 2, 3, ..., m
P_i	Number of nurses required for morning shift on day i, i = 1, ..., n
T_i	Number of nurses required for evening shift on day i, i = 1, ..., n
M_i	Number of nurses required for night shift on day i, i = 1, ..., n
$X_{i,k}$	= 1, if nurse k gets morning shift on day i = 0, otherwise
$Y_{i,k}$	= 1, if nurse k gets evening shift on day i = 0, otherwise
$Z_{i,k}$	= 1, if nurse k gets night shift on day i = 0, otherwise
$C_{i,k}$	= 1, if nurse k gets day-off on day i = 0, otherwise

Based on the interview results, below are hospital regulations (hard constraints) that must be considered by the schedule:

1. The number of nurses on morning, evening and night shifts must meet the minimum requirement.
$$\sum_{k=1}^{m} X_{i,k} \geq P_i, i = 1,2, \dots, n \quad (1)$$
$$\sum_{k=1}^{m} Y_{i,k} \geq T_i, i = 1,2, \dots, n \quad (2)$$
$$\sum_{k=1}^{m} Z_{i,k} \geq M_i, i = 1,2, \dots, n \quad (3)$$
2. Each nurse may only work one shift in day:
$$X_{i,k} + Y_{i,k} + Z_{i,k} + C_{i,k} = 1, i = 1,2, \dots, n \text{ and } k = 1,2, \dots, m \quad (4)$$

3. Each nurse that gets two night-shifts in a row, will get two consecutive days-off afterwards:

$$Z_{1,k} + Z_{2,k} + C_{3,k} + C_{4,k} + Z_{11,k} + Z_{12,k} + C_{13,k} + C_{14,k} + Z_{21,k} + Z_{22,k} + C_{23,k} + C_{24,k} = 12, k = 1 \quad (5)$$

$$Z_{1,k} + Z_{2,k} + C_{3,k} + C_{4,k} + Z_{11,k} + Z_{12,k} + C_{13,k} + C_{14,k} + Z_{23,k} + Z_{24,k} + C_{25,k} + C_{26,k} = 12, k = 2 \quad (6)$$

$$Z_{1,k} + Z_{2,k} + C_{3,k} + C_{4,k} + Z_{13,k} + Z_{14,k} + C_{15,k} + C_{16,k} + Z_{23,k} + Z_{24,k} + C_{25,k} + C_{26,k} = 12, k = 3 \quad (7)$$

$$Z_{3,k} + Z_{4,k} + C_{5,k} + C_{6,k} + Z_{13,k} + Z_{14,k} + C_{15,k} + C_{16,k} + Z_{23,k} + Z_{24,k} + C_{25,k} + C_{26,k} = 12, k = 4 \quad (8)$$

$$Z_{3,k} + Z_{4,k} + C_{5,k} + C_{6,k} + Z_{13,k} + Z_{14,k} + C_{15,k} + C_{16,k} + Z_{25,k} + Z_{26,k} + C_{27,k} + C_{28,k} = 12, k = 5 \quad (9)$$

$$Z_{3,k} + Z_{4,k} + C_{5,k} + C_{6,k} + Z_{15,k} + Z_{16,k} + C_{17,k} + C_{18,k} + Z_{25,k} + Z_{26,k} + C_{27,k} + C_{28,k} = 12, k = 6 \quad (10)$$

$$Z_{5,k} + Z_{6,k} + C_{7,k} + C_{8,k} + Z_{15,k} + Z_{16,k} + C_{17,k} + C_{18,k} + Z_{25,k} + Z_{26,k} = 10, k = 7 \quad (11)$$

$$Z_{5,k} + Z_{6,k} + C_{7,k} + C_{8,k} + Z_{15,k} + Z_{16,k} + C_{17,k} + C_{18,k} + Z_{27,k} + Z_{28,k} = 10, k = 8 \quad (12)$$

$$Z_{5,k} + Z_{6,k} + C_{7,k} + C_{8,k} + Z_{17,k} + Z_{18,k} + C_{19,k} + C_{20,k} + Z_{27,k} + Z_{28,k} = 10, k = 9 \quad (13)$$

$$Z_{7,k} + Z_{8,k} + C_{9,k} + C_{10,k} + Z_{17,k} + Z_{18,k} + C_{19,k} + C_{20,k} + Z_{27,k} + Z_{28,k} = 10, k = 10 \quad (14)$$

$$Z_{7,k} + Z_{8,k} + C_{9,k} + C_{10,k} + Z_{17,k} + Z_{18,k} + C_{19,k} + C_{20,k} = 8, k = 11 \quad (15)$$

$$Z_{7,k} + Z_{8,k} + C_{9,k} + C_{10,k} + Z_{19,k} + Z_{20,k} + C_{21,k} + C_{22,k} = 8, k = 12 \quad (16)$$

$$Z_{9,k} + Z_{10,k} + C_{11,k} + C_{12,k} + Z_{19,k} + Z_{20,k} + C_{21,k} + C_{22,k} = 8, k = 13, 14 \quad (17)$$

$$Z_{9,k} + Z_{10,k} + C_{11,k} + C_{12,k} + Z_{21,k} + Z_{22,k} + C_{23,k} + C_{24,k} = 8, k = 15 \quad (18)$$

$$Z_{11,k} + Z_{12,k} + C_{13,k} + C_{14,k} + Z_{21,k} + Z_{22,k} + C_{23,k} + C_{24,k} = 8, k = 16 \quad (19)$$

4. Each nurse works 5 to 6 days in a week:

$$\sum_{i=1}^{n}(X_{i,k} + Y_{i,k} + Z_{i,k}) \geq 5, k = 1,2, \dots, m \quad (20)$$

$$\sum_{i=1}^{n}(X_{i,k} + Y_{i,k} + Z_{i,k}) \leq 6, k = 1,2, \dots, m \quad (21)$$

Based on the questionnaire results, the following are nurses' preferences (soft constraints):

1. All nurses have similar number of workdays in every scheduling period:

$$\sum_{i=1}^{n}(X_{i,k} + Y_{i,k} + Z_{i,k}) = 22, k = 1,2, \dots, m \quad (22)$$

2. Each nurse at least has one day-off on weekend in every scheduling period:

$$C_{7,k} + C_{14,k} + C_{21,k} + C_{28,k} \geq 1, k = 1,2, \dots, m \quad (23)$$

3. The number of morning and evening shifts must be larger than the number of night shifts for each nurse in every scheduling period:

$$\sum_{i=1}^{n}(X_{i,k} + Y_{i,k}) - \sum_{i=1}^{n} Z_{i,k} \geq 1, k = 1,2, \dots, m \quad (24)$$

4. Avoid workday in between days-off:

$$C_{i,k} + X_{i+1,k} + Y_{i+1,k} + Z_{i+1,k} + C_{i+2,k} \leq 2, i = 1,2, \dots, n-2 \text{ and } k = 1,2, \dots, m \quad (25)$$

According to the Head Nurse, all nurses' preferences have the same priority. Thus, the goals in the model are as follows:

- Goal 1: all nurses have similar number of workdays in each scheduling period. Thus, the goal is to minimize the positive and negative deviations from the Goal 1. The negative deviation for nurse k is $\eta 1_k$, while $\rho 1_k$ is its positive deviation.

$$\sum_{i=1}^{n}(X_{i,k} + Y_{i,k} + Z_{i,k}) + \eta 1_k - \rho 1_k = 22, k = 1,2, \dots, m \quad (26)$$

- Goal 2: Each nurse has at least one day-off on weekend. Thus, the goal is to minimize negative deviation from Goal 2. The negative deviation for nurse k is $\eta 2_k$, while $\rho 2_k$ is its positive deviation.

$$C_{7,k} + C_{14,k} + C_{21,k} + C_{28,k} + \eta 2_k - \rho 2_k \geq 1, k = 1,2, \dots, m \quad (27)$$

- Goal 3: The number of morning and evening shifts must be larger than the number of night shifts for each nurse in every scheduling period. Thus, the goal is to minimize negative deviation from the Goal 3. The negative deviation for nurse k is $\eta 3_k$, while $\rho 3_k$ is its positive deviation.

$$\sum_{i=1}^{n}(X_{i,k} + Y_{i,k}) - \sum_{i=1}^{n} Z_{i,k} + \eta 3_k - \rho 3_k \geq 1, k = 1,2, \dots, m \quad (28)$$

- Goal 4: Avoid workday in between days-off. Thus, the goal is to minimize positive deviation from the Goal 4. The negative deviation for nurse k is $\eta 4_k$, while $\rho 4_k$ is its positive deviation.
$C_{i,k} + X_{i+1,k} + Y_{i+1,k} + Z_{i+1,k} + C_{i+2,k} + \eta 4_k - \rho 4_k \leq 2, i = 1,2,\dots,n-2$ and $k = 1,2,\dots,m$ (29)

Hence, the goal programming formulations are like the following:

Minimize $(\sum_{k=1}^{m}(\eta 1_k + \rho 1_k), \sum_{k=1}^{m} \eta 2_k, \sum_{k=1}^{m} \eta 3_k, \sum_{k=1}^{m} \rho 4_k)$ (30)

Subject to:

Formulations (1) - (21);
Formulations (26) - (29);
$X_{i,k}$, $Y_{i,k}$, $Z_{i,k}$, $C_{i,k}$ are 0 or 1, for all i and k (31)
$\eta 1_k, \rho 1_k, \eta 2_k, \rho 2_k, \eta 3_k, \rho 3_k, \eta 4_k, \rho 4_k \geq 0$, for all k (32)

2.3. Solution Method

The model is formulated using MS. Excel, and solved with Open Solver. The goal programming model is solved to satisfy the hard and soft constraints, and the objective is to minimize the deviations from the nurses' preferences. All preferences have similar priority. So, the model is solved by alternately making each preference as the main priority.

3. Results and discussions

The results show that the best schedule is obtained when the objective function is minimizing positive deviation from Goal 4 subject to hard and soft constraints. Figure 1 presents the best schedule. The sixteen columns in the middle of the figure present the 28-day schedule for 16 nurses, while the three columns on the far right explain the number of nurses in morning, evening, and night shifts in each day. Lastly, the five rows on the bottom of the figure give the total number of morning, evening, and night shifts, along with the total number of workdays and days-off for each nurse. The best schedule indicates that:

	Nurse																Number of Nurses in Each Shift		
Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Morning (M)	Evening (E)	Night (N)
1	N	N	N	E	M	M	M	E	E	M			E	E		M	5	5	3
2	N	N	N	E	M	M	M	M	M	E	E	E	M	E	E	E	6	7	3
3				N	N	N	E	E	M	M	M	M		E	E	E	4	5	3
4				N	N	N	E	M	M		E	M	M	E	E	E	4	5	3
5	E	M	M				N	N	N	M	M	E	E	E	E	M	5	5	3
6	M	E	E				N	N	N	E	E	E	M	M	M		4	5	3
7	E	E	E	M	E	M				N	N	N	E		M	M	4	5	3
8	M	M		E	E	M				N	N	N	E	E	E	M	4	5	3
9	M	E	E	E	E	M	M	E	E				N	N	N	M	4	6	3
10	M	E	E		E	M	M	M	E				N	N	N	E	4	5	3
11	N	N	E		E	M	M	E	M	M	E	E				N	4	5	3
12	N	N	M	E		E	E	M	M	E	E	M				N	4	5	3
13			N	N	N	E	E	M		E	E	E	M	M	M		4	5	3
14			N	N	N		M	M	M	E	M	E	E	E	E		4	5	3
15	E	E				N	N	N	E	E	E	M	M	M		M	4	5	3
16	E	E				N	N	N	E	E	E	M	M	M	M	M	5	5	3
17		M	E	E	E				N	N	N	E	M	M	M	E	4	5	3
18	E		E	M	E				N	N	N	E	M	M	M	E	4	5	3
19	M	E	E	M	E	M	E	E				N	N	N	M		4	5	3
20	E	E	E	E	M	M	M	E				N	N	N	M	M	5	5	3
21	N	E	M	E	E	E	E	M	M	M	E				N	N	4	6	3
22	N	M	E	E	E	M	E		E	M	M				N	N	4	5	3
23		N	N	N	E	E	E	M		M	M	M	E				4	5	3
24		N	N	N	M	E	E	M	M	M	E	E	E	E			4	6	3
25	M				N	N	N	E		M	E	E	M	M	E	E	4	5	3
26	E				N	N	N	E	M	M	E	E	M	M	M	E	5	5	3
27	E	E	E	E				N	N	N		E	M	M	M	M	4	5	3
28	E	E	E	M				N	N	N	M	M		E	E	M	4	5	3
Total Morning Shifts	6	4	3	4	4	10	7	8	10	9	6	7	12	9	10	10			
TotalEvening Shifts	9	11	12	10	11	5	9	9	6	7	12	12	6	10	8	8			
Total Night Shifts	6	6	6	6	6	6	6	6	6	6	4	4	4	4	4	4			
Total Workdays	21	21	21	20	21	21	22	23	22	22	22	23	22	23	22	22			
Total Days-off	7	7	7	8	7	7	6	5	6	6	6	5	6	5	6	6			

Figure 1. The best schedule

- Goal 1 is not achieved: 9 out of 16 nurses do not have similar number workdays, which is 22 days. Their number of workdays are in the range of 20-23 days.
- Goal 2 is not achieved: The negative deviation is 5, which means there will be 5 nurses that will not have a day-off on weekends.
- Goal 3 is achieved: All nurses will have larger number of morning and evening shifts than night shifts.
- Goal 4 is achieved: There is no workday in between days-off for all nurses.

These mean that in the best schedule, all hard constraints are satisfied, however, only soft constraints number 3 (the number of morning and evening shifts must be larger than the number of night shifts for each nurse) and number 4 (avoid workday in between days-off) are satisfied.

Compared to current scheduling practice that the Head Nurse does (by creating the schedule manually at the end of each month), the resulting schedule ensures the availability of nurses because it satisfies all hospital's regulations and it has higher level of fairness to all nurses as it can accommodate some of the nurses' preferences (see figure 2).

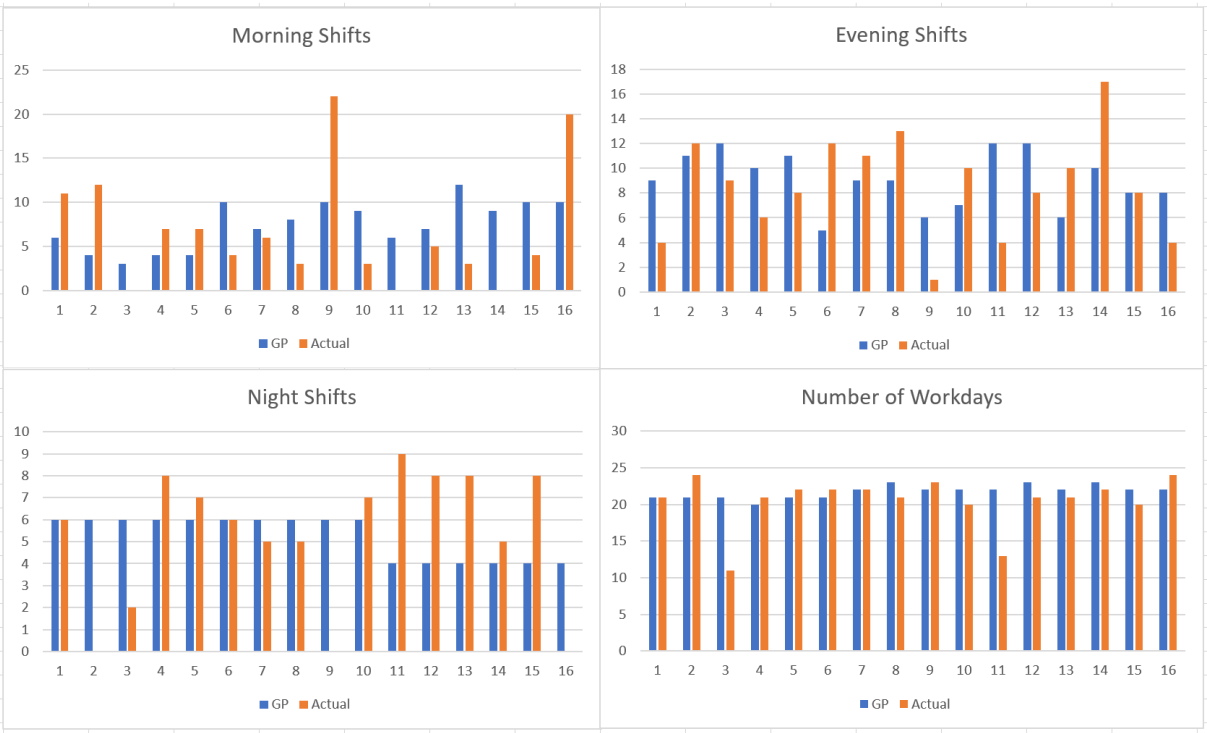

Figure 2. Comparisons of actual and GP schedules

As can be seen in figure 2, the actual schedule (Actual) shows little fairness to the nurses as the numbers of workdays across nurses are in the range of 13 to 24 days. The distribution of shifts also shows little fairness as there are nurses that do not get morning or night shifts at all. These conditions may affect nurses' quality of work and job satisfaction. The resulting schedule (GP) on the other hand, is relatively consistent and has a high level of fairness to nurses. Even though nurses do not get similar number of workdays, the total number of workdays is in the range of 20-23 days with more evenly distributed shifts.

4. Conclusions

Scheduling nurses is a very important task in the hospital and must be done repetitively. Current scheduling practice at PGI Cikini Hospital indicates unfairness and uneven distribution of shifts as the

schedule is created manually. Thus, it is very difficult to create a balanced schedule that has the same number of shifts or workdays for all nurses.

The paper presents nurses scheduling at the hospital using goal programming approach. The scheduling is conducted by considering the hospital's regulations/requirements to ensure that the number of minimum nurses available in each shift is sufficient, each nurse gets one shift in a day, nurses that are assigned two night-shifts in a row will get two consecutive days-off, and each nurse works for five to six days in a week. The proposed scheduling approach also considers four nurses' preferences which are obtained from the questionnaires.

The best schedule satisfies all the hospital's regulations, however, only two out of four nurses' preferences can be met. Compared to the manually-created schedule, the proposed schedule offers more fairness to all nurses as the shifts are more evenly distributed, and the differences in the number of workdays between nurses are smaller.

The proposed scheduling approach has some limitations. Firstly, in this approach, nurses are assumed to have similar level of skill. They are not classified based on their educational background and experience. In reality, in each shift, nurses are assigned based on their experiences. Secondly, we also assume that the nurses' preferences have similar priority that may not be the actual condition. The future research may address these limitations by taking into account the levels of skill of nurses, as a set of different nurse skills may be required in each shift. Furthermore, the rank of nurses' preferences can be obtained through a survey, so that the priority of each preference can be set, and the resulting schedule will better represent the nurses' preferences priority.

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