An Optimization Model of Nurse Scheduling Using Goal Programming Method: A Case Study

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Abstract. Nurse scheduling problem involves assigning of each individual nurse in the hospital so that a series of tasks can be completed. To increase patient satisfaction, skilled and disciplined nurses are needed. In the field of health care, nurse scheduling is a challenging activity because of the different levels of nurses needed on different shifts and days. However, it often happens where a number of nurses assigned do not meet the specific needs of nurses so that the performance of nurses at each shift is not optimal. In this paper, an optimization model is proposed using goal programming method to determine the optimal schedule using Lingo 11.0 software. The model is implemented in the Yustisia Room, a special room for treating covid-19 inpatients in Universitas Sebelas Maret Hospital. The results of the optimization showed that all conditions that need to be achieved in scheduling which previously unfulfilled in manual schedule, such as the minimum requirement number of senior nurses and male nurses in each shift can be fulfilled. For additional target, which is total working days, the proposed model can produce a better schedule for regular nurses and better assignment patterns for all nurses, where all regular nurses have the same total number of working days, which is 17 working days.

Introduction

Hospitals as one of the health service institutions always face significant new challenges due to the increase of health care costs. This causes patients to become more aware and critical of the service they received [1]. To serve patients well, the hospital is always required to always improve its quality, both in terms of completeness of facilities and services. Universitas Sebelas Maret Hospital (UNS Hospital) is one hospital that is always trying to increase customer satisfaction. If the services provided by the hospital are in good quality, then the patient will feel satisfied [2].

One of the quality measure of service at the hospital deals with the services provided by doctors, nurses, and other administrative staff to patients. According to [3], one of the resources that plays an important role in determining the performance and quality of hospitals is nurses. This is because nurses are directly responsible to fulfill patient needs 24 hours a day. To increase patient satisfaction, skilled and disciplined nurses are needed. However, situations often occur where the number of nurses available is not enough due to the large number of patients which can result in fatigue and hence the performance of the nurse is not optimal and lead to the occurrence of errors that are not desirable in handling patients. Therefore, nurses' working hours need to be regulated properly.

So that the problem of nurse scheduling has become a focus in the past few years based on the concept of small action-large effects that can maximize hospital profits by employing the best possible nurses [4]. Nurse scheduling is a nurse's overall work schedule so that it meets job satisfaction
requirements and the rules and systems that apply in hospitals. The work of arranging nurses' shifts in a set period of time is difficult because it involves a schedule for each individual nurse in the hospital so that the set of tasks can be completed. In the field of health care, nurse scheduling is a challenging activity because of the different levels of nurses needed on different shifts and days [5].

Nurse scheduling at UNS Hospital is carried out by the head of the room and is compiled based on a template that has been made by the staffing department with the help of Excel software. However, the template made by the staffing department only considers the assignment pattern, not considering the minimum number of senior nurses and male nurses required for each shift in each room. This becomes an obstacle for the head of the room in scheduling nurses where the head of the room has to make adjustments to the schedule of nurses manually. Even though it has been adjusted manually, it is still found that the minimum number requirements of nurses, senior nurses, and male nurses on several shifts have not been fulfilled. The nurse scheduling process also takes quite a long time.

Jaumard, Semet, & Vovor [6] developed an optimization model for nurse scheduling using the basic formulation of a linear programming model. The model generates nurses' schedules by considering the type of shift applied by the hospital, as well as the nurse's level of expertise, namely abilities based on work experience and performance of nursing practice. The model aims to minimize costs in the form of nurse wages.

Azaiez & Sharif [7] developed a nurse scheduling optimization model using the goal programming method by considering the equal distribution of workload for all nurses and other provisions, such as the division of shifts per day, the minimum number of hours worked per month, the maximum number of consecutive work days, the minimum number of nurses with certain work levels, coupled with consideration of ergonomics factors, include day off preferences, evenly distributed night shifts, avoiding day shifts after the previous night shifts and avoiding on-off-on shifts.

Siregar [8] developed a nurse scheduling optimization model using goal programming where the objective function is to minimize weighted deviations to avoid assigning a shift after a certain shift. The model developed produces nurse scheduling that consider the shift assignment and days off patterns of each nurse. Broadly speaking, the model is based on the rota metropolitan system assignment pattern.

Hakim, Bakhtiar, & Jaharuddin [9] also developed a nurse scheduling optimization model using goal programming. In addition to using the goal programming method, nurse scheduling is also done using a nonlinear optimization model with the objective function of workload distribution. The output of the goal programming model is nurse scheduling which has the ideal number of shift assignments for each nurse in accordance with hospital regulations, while the output for nonlinear optimization models is nurse scheduling that has the same shift and day off assignment distribution for all nurses.

Adoly, Gheith, & Fors [4], in their research used a linear programming model in solving nurses scheduling cases in an Egyptian Hospital. The mathematical model developed aims to minimize the overall costs incurred for the employment of nurses, including costs per shift of regular nurses and head nurses, as well as overtime costs for nurses. The model has succeeded in producing nurse scheduling based on the level of expertise, gender, and other policies determined by the organization, both with a centralized or decentralized system per department. In addition, the model succeeded in dividing work shifts more evenly than in the previous scheduling and succeeded in reducing overtime work which had an impact on reducing the costs incurred by the hospital.

In this study, a nurse scheduling optimization model was developed which refers to the shift work assignment pattern based on the metropolitan rota system as applied by the inpatient ward of UNS Hospital. So that the development of the model refers [8] regarding the pattern of assigning nurses based on the metropolitan rota system. Furthermore, the assignment of male nurses [4]; as well as the consecutive days off pattern [9] will be included in the model.

The aim of this paper is to developed an optimization model for scheduling nurses in the inpatient department of UNS Hospital. Goal programming approach is used in this paper to find the optimal solution [10]. The goal programming will find optimal and realistic results in the decision-making process because it is accompanied by additional targets in addition to the previously known objective functions [11]. The objective function of this research's goal programming was adopted from [7] to ensure that the target in the form of the number of working days of all nurses in one planning horizon
is equal, and ensure the assignment pattern of each nurse. The number of working days and assignment pattern were used as the goals based on the result of interview with the room heads.

Problem Description
Nurse schedule at UNS Hospital is usually developed manually by the head of each room. The head of the room usually takes 3 to 4 hours to schedule the nurses for one month planning horizon. The case study is taken in Inpatient Department of UNS Hospital. One of specific room in the department is Yustisia Room which employs 30 nurses, including the senior nurses. The Yustisia Room is a specific room in the UNS Hospital assigned to treat covid-19 patients. The following regulations are enforced by hospital management and are considered as constraints in the model both hard or soft constraints:

1. A day is divided into 3 shifts, namely morning shift (7 am to 2 pm), afternoon shift (2 pm to 9 pm), and night shift (9 pm to 7 am).
2. Each shift must have at least a minimum number of nurses required.
3. Each nurse should work between a minimum and maximum number of shifts during the planning horizon. In this case study, the planning horizon is equivalent to 31 days.
4. There is no possibility that a nurse have more than 3 consecutive workdays (with morning-afternoon-night patterns).
5. Each nurse should not be assigned in a morning shift right after the night shift.
6. Each shift may have at least 1 male nurse.
7. Each shift may have at least 2 senior nurses to be assigned as a coordinator.
8. Each nurse has at least 2 consecutive days off after being assigned to several working days.

The Proposed Mathematical Model
In this section, a nurse scheduling model will be developed. The model is made with a planning horizon for one month, where in a day the scheduling is divided into 3 shifts, namely morning, afternoon and night shifts. The nurse scheduling that applies in hospital is usually based on the metropolitan rota system (scheduling shifts 2-2-2), but for the Yustisia room, which specifically assigned to treat covid-19 patients the shift pattern is 1-1-1 (morning-afternoon-night shift). The model is mainly build upon practice in accordance with applicable policies in hospitals based on interviews with the head of the room. Because there are a large number of constraints that the schedule wants to fulfill, it is possible to get a no feasible solution. To handle this, the constraints is divided into 2 classes, namely hard constraints that must be satisfied and soft constraints that have the possibility to be violated. However, the model created will minimize violations by reducing the deviation between soft constraints with each target.

Indices and parameters:
i: index for nurses \{1, ..., U, U + 1, ... I\}

Note: Nurses numbering index are divided into 2 categories, from 1 to U are senior nurse sets, and U + 1 to I are regular nurse sets.

j: index for days \{1, 2, ..., J\} during the planning horizon
Bp: minimum number of nurses (i) required during the morning shift
Bs: minimum number of nurses (i) required during the afternoon shift
Bm: minimum number of nurses (i) required during the night shift
Cp: maximum number of nurses (i) can work during the morning shift
Cs: maximum number of nurses (i) can work during the afternoon shift
Cm: maximum number of nurses (i) can work during the night shift
D: minimum number of days (j) that each nurse should work during the planning horizon
E: maximum number of days (j) that each nurse should work during the planning horizon
F: minimum number of senior nurses (i) in each shift
Z: the total number working days (j) that that each nurse should work during the planning horizon
H: minimum number of male nurses (i) in each shift
Ai = {1, if nurse (i) is male 
0, otherwise

Decision variables:
Pij = {1, if nurse (i) is assigned to morning shift on day (j) 
0, otherwise
Sij = {1, if nurse (i) is assigned to evening shift on day (j) 
0, otherwise
Mij = {1, if nurse (i) is assigned to night shift on day (j) 
0, otherwise
Lij = {1, if nurse (i) has day off on day (j) 
0, otherwise

Objective Function
The aim of this model is to minimize the shortage and excess number of total working days (goal 1) of each nurse during the planning horizon. Moreover, the aim of this model is to minimize the amount of negative deviation of goal 2 related to number of shift on system pattern.

Min Z = \sum_{i=1}^{I} \sum_{j=1}^{J} (d1^+_i + d1^-_i + d2^-_i), \forall j \in J \tag{1}

The scheduling problem consists of 17 sets of scheduling constraints, which are divided into two groups. One group consists of a set of 15 hard constraints that must be fulfilled which must come up with a feasible solution. Another group consists of 2 soft constraints, which is not absolute but it is highly recommended to be fulfilled. If this is not possible, the model will reduce to at least this soft boundary violation based on the importance of each sequence.

Hard Constraint:
1. Ensures that the required number of nurses in each shift satisfied
2. Maximum number of nurses in each shift
3. Ensures that each nurse must work at least a minimum number of working days
4. Ensures that each nurse must work at most a maximum number of working days
5. In one day, each nurse may only be assigned to one shift

\sum_{i=1}^{I} P_{ij} \geq B_p, \sum_{i=1}^{I} S_{ij} \geq B_s, \sum_{i=1}^{I} M_{ij} \geq B_m, \forall j \in J \tag{2}

Where B_p = B_s = B_m = 4.

\sum_{i=1}^{I} P_{ij} \leq C_p, \sum_{i=1}^{I} S_{ij} \leq C_s, \sum_{i=1}^{I} M_{ij} \leq C_m, \forall j \in J \tag{3}

Where C_p = C_s = C_m = 6.

\sum_{j=1}^{J} P_{ij} + S_{ij} + M_{ij} \geq D, \forall j \in I \tag{4}

Where D = 16.

\sum_{j=1}^{J} P_{ij} + S_{ij} + M_{ij} \leq E, \forall j \in I \tag{5}

Where E = 19.

P_{ij} + S_{ij} + M_{ij} + L_{ij} = 1, \forall j \in I, \forall j \in J \tag{6}
6. Ensures that each nurse must not be assigned more than 1 consecutive night shifts
   \[ M_{ij} + M_{i(j+1)} \leq 1, \quad \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-1\} \]  

7. Ensures that each nurse must not be assigned more than 1 consecutive morning shifts
   \[ P_{ij} + P_{i(j+1)} \leq 1, \quad \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-1\} \]  

8. Ensures that each nurse must not be assigned more than 1 consecutive afternoon shifts
   \[ S_{ij} + S_{i(j+1)} \leq 1, \quad \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-1\} \]  

9. Ensures that each nurse must have at least 2 consecutive day offs
   \[ \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-2\} \]  

10. Ensures that each nurse must have at most 4 consecutive day offs
    \[ L_{ij} + L_{i(j+2)} + L_{i(j+3)} + L_{i(j+4)} \leq 4, \quad \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-4\} \]  

11. Ensures that after the night shift there is no morning or afternoon shift on the following day
    \[ M_{ij} + P_{i(j+1)} + S_{i(j+1)} \leq 1, \quad \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-1\} \]  

12. Ensures that after the morning shift there is no night shift on the following day
    \[ P_{ij} + M_{i(j+1)} \leq 1, \quad \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-1\} \]  

13. Ensures that after the afternoon shift there is no morning shift on the following day
    \[ S_{ij} + P_{i(j+1)} \leq 1, \quad \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-1\} \]  

14. Ensures that the required number of senior nurses in each shift satisfied
    \[ \sum_{j=1}^{n_j} P_{ij} \geq F, \sum_{j=1}^{n_j} S_{ij} \geq F, \sum_{j=1}^{n_j} M_{ij} \geq F, \quad \forall j \in J \]  
    Where \( F = 2 \).  

15. Ensures that the required number of male nurses in each shift satisfied
    \[ \sum_{j=1}^{n_j} A_{ij} * P_{ij} \geq H, \sum_{j=1}^{n_j} A_{ij} * S_{ij} \geq H, \sum_{j=1}^{n_j} A_{ij} * M_{ij} \geq H, \quad \forall j \in J \]  
    Where \( H = 1 \).  

**Soft Constraint:**

16. Goal 1: Each nurse is assigned a number of \( z \) working days in one planning horizon
    \[ \sum_{i=1}^{I} P_{ij} + S_{ij} + M_{ij} + d1^{-i} - d1^{+i} = Z, \quad \forall j \in I \]  
    Where \( Z = 17 \).  

17. Goal 2: Ensure nurses work with the metropolitan rota system (morning-morning-afternoon-afternoon-night-night-day off-day off patterns)
    \[ P_{ij} + S_{i(j+1)} + M_{i(j+2)} + L_{i(j+3)} + L_{i(j+4)} + d2^{-ij} - d2^{+ij} = 5, \]
    \[ \forall j \in I, \forall j \in J \setminus \{1, \ldots, J-4\} \]  

**Results and Discussion**

Table 1 is the schedule generated manually by the head of the room while Table 2 is the result obtained by the optimization model. The total time required by the LINGO software to achieve the optimal solution is 19 minutes 51 seconds using a PC with an Intel (R) Core (TM) i3-5005U CPU @ 2.00 GHz processor, 4.00 GB RAM, and Windows 10 (64bit) operating system.

From the nurses data obtained on May 2020 in Yustisia Room, actually the room did not have enough senior nurses. The room only has 3 nurses qualified as senior nurses, while in actual, 10 senior nurses are appointed as coordinator. Hence, we assume that nurses’ number of 1-10 are senior nurses.
The schedule resulted from the model is then analyzed and compared with the schedule developed manually in Table 3.
| Nurse | Skill Level | MAY 2020 | WD |
|-------|-------------|----------|----|
| 1     | Senior      | 1        | 16 |
| 2     | Senior      | 2        | 17 |
| 3     | Senior      | 3        | 17 |
| 4     | Regular     | 4        | 16 |
| 5     | Regular     | 5        | 16 |
| 6     | Regular     | 6        | 16 |
| 7     | Regular     | 7        | 16 |
| 8     | Regular     | 8        | 17 |
| 9     | Regular     | 9        | 16 |
| 10    | Regular     | 10       | 16 |
| 11    | Regular     | 11       | 17 |
| 12    | Regular     | 12       | 17 |
| 13    | Regular     | 13       | 17 |
| 14    | Regular     | 14       | 17 |
| 15    | Regular     | 15       | 17 |
| 16    | Regular     | 16       | 17 |
| 17    | Regular     | 17       | 17 |
| 18    | Regular     | 18       | 17 |
| 19    | Regular     | 19       | 17 |
| 20    | Regular     | 20       | 17 |
| 21    | Regular     | 21       | 16 |
| 22    | Regular     | 22       | 16 |
| 23    | Regular     | 23       | 16 |
| 24    | Regular     | 24       | 16 |
| 25    | Regular     | 25       | 16 |
| 26    | Regular     | 26       | 16 |
| 27    | Regular     | 27       | 16 |
| 28    | Regular     | 28       | 16 |
| 29    | Regular     | 29       | 16 |
| 30    | Regular     | 30       | 16 |
Table 2: The Nurse Schedule Using Goal Programming

| No. | Name | Skill Level | WD  | MAY 2020 |
|-----|------|-------------|-----|----------|
| 1   | P    | Regular     | P   | S        |
| 2   | M    | Regular     | M   | S        |
| 3   | S    | Regular     | S   | M        |
| 4   | P    | Regular     | P   | S        |
| 5   | M    | Regular     | M   | S        |
| 6   | S    | Regular     | S   | M        |
| 7   | P    | Regular     | P   | S        |
| 8   | M    | Regular     | M   | S        |
| 9   | S    | Regular     | S   | M        |
| 10  | P    | Regular     | P   | S        |
| 11  | M    | Regular     | M   | S        |
| 12  | S    | Regular     | S   | M        |
| 13  | P    | Regular     | P   | S        |
| 14  | M    | Regular     | M   | S        |
| 15  | S    | Regular     | S   | M        |
| 16  | P    | Regular     | P   | S        |
| 17  | M    | Regular     | M   | S        |
| 18  | S    | Regular     | S   | M        |
| 19  | P    | Regular     | P   | S        |
| 20  | M    | Regular     | M   | S        |
| 21  | S    | Regular     | S   | M        |
| 22  | P    | Regular     | P   | S        |
| 23  | M    | Regular     | M   | S        |
| 24  | S    | Regular     | S   | M        |
| 25  | P    | Regular     | P   | S        |
| 26  | M    | Regular     | M   | S        |
| 27  | S    | Regular     | S   | M        |
| 28  | P    | Regular     | P   | S        |
| 29  | M    | Regular     | M   | S        |
| 30  | S    | Regular     | S   | M        |

Note: WD stands for Working Days, and MAY 2020 denotes the date range of the schedule.
Note:
Gender(G): 1-Female, 2-Male
Shift: P-Morning shift, S-Afternoon shift, M-Night shift, L-Day off
WD(Total Working Days)

Table 3. Percentage comparison between manual nurse schedule and proposed model

| No. | Component                                           | Manual | Proposed |
|-----|-----------------------------------------------------|--------|----------|
| 1.  | Fullfillment of the required nurses in each shift   |        |          |
|     | a. Morning shift                                    | 100    | 100      |
|     | b. Afternoon shift                                  | 100    | 100      |
|     | c. Night shift                                      | 100    | 100      |
| 2.  | Fullfillment of the required male nurses in each shift|        |          |
|     | a. Morning shift                                    | 74.19  | 100      |
|     | b. Afternoon shift                                  | 70.96  | 100      |
|     | c. Night shift                                      | 77.42  | 100      |
| 3.  | Fullfillment of the required senior nurses in each shift|       |          |
|     | a. Morning shift                                    | 64.51  | 100      |
|     | b. Afternoon shift                                  | 74.19  | 100      |
|     | c. Night shift                                      | 93.59  | 100      |
| 4.  | Consecutive days off in range 2 days – 4 days       | 90     | 100      |
| 5.  | Number of nurses that have total working days ideal (17 days) in one planning horizon | 56.67  | 66.67    |

Based on Table 3, it can be seen that the fulfillment of the minimum requirements of nurses in each shift in both models has a percentage of 100%, which means that both requirements nurses of the manual schedule and the proposal can be fulfilled. Meanwhile, the fulfillment of the requirements of male and senior nurses on the manual schedule has a percentage value of less than 100% which indicates it has not been fulfilled, but for the proposed model, the fulfillment of male and senior nurses in each shift has a percentage of 100% which means it can be fulfilled.

Still refers to table 3, for consecutive days off, the manual schedule has a percentage value of 90%, which indicates that some nurses have days off less than the specified range. Meanwhile, on the proposed schedule the percentage of consecutive days off is 100%, which means that all nurses have consecutive days off according to the specified range. The shortage of days off itself will cause isolated shift work (on-off-on) and irregular assignment patterns, which might can increase the workload of nurses.

For the total working days that can be seen in Table 1, Table 2, and Table 3, neither of the two schedules has reached the 100% value. For manual schedules, 13 nurses have a total of 16 working days where the difference from the ideal total working days is 1 day. Meanwhile, for the schedule of the proposed model, 10 nurses (nurses number 1-10) have an average total working days of more than 17 working days, this is because to fulfill the requirements of senior nurses on each shift, senior nurses must be assigned more than the predetermined total working days.

Conclusion

In this paper, we developed a mathematical model to address the nurse scheduling problem in inpatient department specifically for covid-19 patients, namely the Yustisia Room at UNS Hospital. The model is formulated using the linear goal programming method with the objective function of minimizing the number of deviations by considering constraints related to the hospital regulations and the specific requirement of nurses in each shift, such as senior nurses or male nurses. Comparing to the manually nurse schedule, the results of the optimization showed all conditions that need to be achieved in scheduling, such as the minimum requirement for the number of nurses in each shift, the minimum requirement for male nurses, the minimum requirement for senior nurses, and the consecutive days off requirement can be fulfilled. For total working days, the proposed model can produce a better schedule for regular nurses, which achieves the ideal total working days of 17 days for all regular nurses.
However, it has not been achieved for senior nurses, due to meeting the requirements of senior nurses in each shift. In addition, optimization model is much more efficient in the scheduling process compared to manual method. As future research, the proposed model can be expanded to consider hiring nurses if there is a shortage number of nurses in some periods of time. Another direction for further research is by considering nurses' preferences in choosing their days off by adding some constraints.

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