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An Optimization Model For The Nurse Scheduling Problem Considering Workload Variance

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Abstract:

The Nurse Scheduling Problem (NSP) is a critical issue in healthcare management, involving the assignment of nurses to shifts while adhering to constraints such as hospital requirements, legal obligations, and nurse preferences. A key objective is to balance workloads among nurses, minimizing variance to prevent burnout and ensure high-quality patient care. Despite various models addressing NSP, such as goal programming and stochastic methods, a significant gap remains in balancing workloads within individual shifts, which is crucial for nurse well-being and operational efficiency. This study develops an optimized nurse scheduling model for the emergency department (ED) of Dr. Saiful Anwar Hospital (RSSA) in Malang, using data from January 2024. The model considers 21 nurses, including 4 chief nurses, and aims to minimize workload variance across shifts while ensuring each nurse works at least 21 days per month. The simulation results show that the optimized schedule achieves a more equitable distribution of shifts and days off compared to the actual January 2024 schedule. The optimized model ensures that all nurses, except chief nurses, are assigned 21 working days with evenly distributed rest days, reducing fatigue and enhancing nurse well-being. This study advances NSP research by focusing on workload balance within shifts, contributing to improved healthcare service quality and nurse satisfaction. Future research should explore adaptive scheduling and incorporate factors like nurse preferences and patient acuity to further enhance scheduling flexibility and efficiency.

Keywords: *Nurse Scheduling Problem, Optimization, Scheduling*

1. INTRODUCTION

The Nurse Scheduling Problem (NSP) is a critical issue in healthcare management, involving the assignment of nurses to various shifts each day while adhering to a complex set of constraints. These constraints include hospital requirements, such as maintaining a minimum staffing level for each shift, meeting legal and contractual obligations, and considering individual nurse preferences and availability. The primary objective in solving the NSP is to balance the workload among nurses, minimizing workload variance across shifts to prevent overworking and burnout. Achieving a balanced workload distribution is not only essential for maintaining nurse well-being but also for ensuring high-quality patient care. Studies have shown that overworking nurses can lead to reduced quality of care, poorer patient outcomes, and increased operational costs due to factors such as higher turnover rates and absenteeism (Rerkjirattikal, 2020; Dyrbye, 2019; Labrague et al., 2020; Tawfik et al., 2019). Moreover, recent research by Lee et al. (2024) highlights the heightened risk of burnout among nurses who are frequently assigned to night shifts, further underscoring the importance of equitable scheduling practices.

To address the NSP, various models and techniques have been proposed in the literature. For instance, Rehman et al. (2023) employed a goal programming approach to optimize hospital staff scheduling, focusing on the efficient allocation of resources such as doctors, nurses, and beds while maintaining high standards of patient care. Schoenfelder et al. (2019) utilized stochastic modeling techniques to minimize costs associated with nurse overtime, understaffing penalties, and patient transfers, thereby aiming to improve operational efficiency. Ramirez (2024) explored the NSP at Hospital Escuela Universitario in Honduras, with an emphasis on maximizing the number of shifts assigned to nurses within the constraints of shift limits, working hours, and holidays. Additionally, Fitriani et al. (2020) applied fuzzy goal programming to optimize nurse scheduling, taking into account multiple goals such as achieving required working hours, ensuring minimum days off, limiting evening shifts, and maintaining on-off patterns.

Despite the advances made in these studies, a significant limitation persists: the balancing of workloads between nurses within each individual shift has not been thoroughly examined. This gap is particularly critical because unequal workload distribution within shifts can lead to disparities in nurse fatigue, job satisfaction, and ultimately, patient care quality. While existing models effectively address the broader aspects of nurse scheduling, they often overlook the granular details of workload distribution within each shift, which can have profound implications for both nurse well-being and healthcare service delivery.

The present study seeks to address this gap by developing a scheduling model that not only optimizes nurse assignments but also ensures a balanced workload within each shift across all nurses. By focusing on minimizing workload variance at this more detailed level, the proposed model aims to enhance the overall quality of healthcare services while safeguarding the physical and mental health of the nursing staff. This approach represents a significant step forward in the ongoing effort to create more equitable and effective nurse scheduling practices in healthcare management.

2. RESEARCH METHOD

This section explores the research methodology employed in this study, along with the mathematical formulation. The proposed formulation aims to schedule nurses in a way that minimizes workload variance among them. The step-by-step process is as follows:

a. Data collection
   The collected data includes the following:
   - The number of nurses.
   - The number of working days in a month
   - The number of chief nurses
   - Minimum and maximum working hours per nurse in a month, and
   - Minimum working days required for each nurse in a month

b. Model Formulation

This study focuses on minimizing the variance in workload distribution among nurses. Each shift must include a number of nurses within a specified minimum and maximum range, and each nurse is required to work a minimum of minD days per month. The development of this model follows approach outlined by Hakim, et al (2017). Therefore, the nurse scheduling problem addressed in this research can be formulated as follows:

$$\min Z = \sum_{s \in S} V_s \qquad (1)$$

s.t.

$$V_s = \frac{\sum_{n \in N-T} \sum_{d \in D} \left(x_{n,d,s}\right)^2}{|N-T|} - \left(\frac{\sum_{n \in N-T} \sum_{d \in D} x_{n,d,s}}{|N-T|}\right)^2 \quad, \forall s \in S \qquad (2)$$

$$\sum_{s \in S} x_{n,d,s} = 1, \quad \forall\, n \in N, d \in D \tag{3}$$

$$\sum_{n \in T} x_{n,d,s} = 1, \quad \forall\, s \in \{1,2,3\}, d \in D \tag{4}$$

$$\sum_{n \in N} x_{n,d,s} \geq x_{min}, \quad \forall d \in D, s \in \{1,2,3\} \tag{5}$$

$$\sum_{n \in N} x_{n,d,s} \leq x_{max}, \quad \forall\, d \in D, s \in \{1,2,3\} \tag{6}$$

$$x_{n,d,3} + x_{n,d+1,1} \leq 1\,, \quad \forall n \in N, d \in \{1,2,\dots,D-1\} \tag{7}$$

$$\sum_{d \in D} \sum_{s=1}^{3} x_{n,d,s} \geq minD, \qquad \forall n \in N \tag{8}$$

$$\sum_{s \in S} \sum_{d \in D} x_{n,d,s} = |D|, \qquad \forall n \in N \tag{9}$$

Where:

N	:	Total Nurses (including chief of nurses)
D	:	Total workdays in a month
S	:	Shifts, in which 1: morning shift, 2: afternoon shift, 3: night shift, and 4: holiday shift
T	:	Total Chief of nurses
V_s	:	Variance workload of each nurses on shift s
$x_{n,d,s}$	:	1 if nurse *n* is assigned on shift *s* at day *d* and 0 otherwise
x_{min}	:	Minimum nurses working on each shift
x_{max}	:	Maximum nurses working on each shift
$minD$	:	Minimum working days for each nurses on a month

The objective function presented in Equation (1) aims to minimize the variance in the workload among nurses across shifts, with the variance for each shift defined in Equation (2). Constraint (3) ensures that each nurse is assigned to exactly one shift per day, while Constraint (4) guarantees that a chief nurse is assigned to each shift. Constraints (5) and (6) enforce that the number of nurses working per shift falls within a specified range. To mitigate fatigue and prevent burnout, Constraint (7) stipulates that a nurse assigned to a night shift cannot be scheduled for the following morning shift. Constraint (8) mandates that each nurse works a minimum of minD days per month, while Constraint (9) ensures that each nurse is scheduled every day within the month.

3. NUMERICAL RESULT

The model presented above then is solved with Python 3.11.4 and solver Gurobi 11.0.3. In this research, we modeled nurse scheduling for the emergency department (ED) of Dr. Saiful Anwar Hospital (RSSA) in Malang. The data was collected in January 2024. The department has 21 nurses, including 4 chief nurses. The work shifts consist of morning, afternoon, night, and holiday shifts each day. The number of nurses working in each shift should range from 3 to 6, including one chief nurse. Additionally, each shift must include one chief nurse. The minimum number of workdays for each nurse per month is 21 days. Nurses assigned to a night shift cannot be scheduled for the morning shift the following day. In this study, we consider a 30-day work period. The objective is to minimize the variance in workload for each nurse across all shifts.

The numerical simulation results demonstrate that each nurse, except for the chief nurses, is scheduled to work over a 21-day period. The detailed breakdown of shifts for each nurse is presented in Table 1. The table illustrates the distribution of morning, afternoon, night shifts, and days off across the 21-day working schedule. While the data in Figure 1 highlights the variability in shift assignments among the nurses. This variability is crucial for maintaining a balanced workload, ensuring adequate rest periods, and optimizing the overall efficiency of the nursing staff. Specifically, the shift distribution is categorized into four types: morning, afternoon, night, and days off. The total number of working days for each nurse is also indicated.

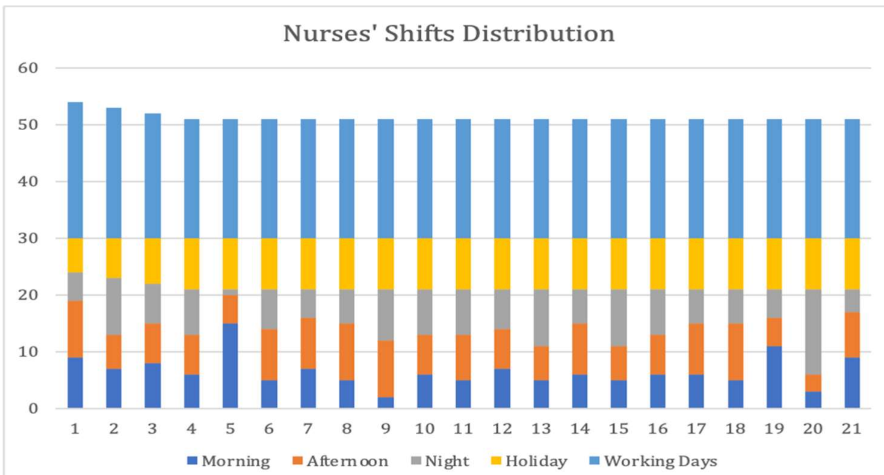

Figure 1: Nuses' Shifts Distribution

Table 1: Scheduled for Chief Nurses Nurses

ID	Day														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0	2	2	1	2	2	3	1	1	3	2	1	0	0
2	0	1	1	1	3	0	1	2	3	0	0	0	3	2	1
3	3	3	0	0	2	1	3	1	0	2	1	3	0	1	2
4	2	2	3	3	0	3	0	0	2	3	2	1	2	3	3

ID	Day														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	1	0	2	2	1	2	2	3	1	1	3	2	1	0	0
2	0	1	1	1	3	0	1	2	3	0	0	0	3	2	1
3	3	3	0	0	2	1	3	1	0	2	1	3	0	1	2
4	2	2	3	3	0	3	0	0	2	3	2	1	2	3	3

Table 2: Actual Schedule for Chief Nurses in January 2024

ID	Day														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	2	2	0	0	3	3	3	1	2	2	0	0	3
2	2	2	0	0	3	3	3	1	2	2	0	0	3	3	1
3	0	0	3	3	1	1	2	2	0	0	3	3	1	1	2
4	3	3	1	1	3	3	0	0	3	3	1	1	2	2	0

ID	Day														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	3	1	1	2	2	0	0	3	3	1	1	2	2	0	0
2	1	2	2	0	0	3	3	1	1	2	2	0	0	3	3
3	2	0	0	3	3	1	1	2	2	0	0	3	3	3	1
4	0	3	3	1	1	2	2	0	0	3	3	1	1	2	2

Table 1 presents the schedule for the chief nurses generated by the model, while Table 2 displays the actual schedule for the chief nurses in January 2024. The result shows the difference on distribution of schedule among chief nurses.

4. DISCUSSION

The numerical results of the model have been presented earlier. When we compare the optimized nurse schedule obtained in Figure 1 with the actual schedule from January 2024 depicted in Figure 2, it becomes evident that the distribution of workdays and days off in the actual schedule is uneven. Specifically, some nurses, such as Nurse 6, are assigned fewer than 21 working days. Additionally, the allocation of days off is inconsistent, with some nurses receiving as many as 11 days off while others only receive 7.

In contrast, the optimized schedule presented in Figure 1 demonstrates a more equitable distribution of both working days and days off. All nurses, except for the chief nurses, are assigned 21 working days. Chief nurses have a slightly varying number of working days, ranging from 21 to 24. Importantly, thedays off are evenly distributed, with each nurse receiving 9 days off.

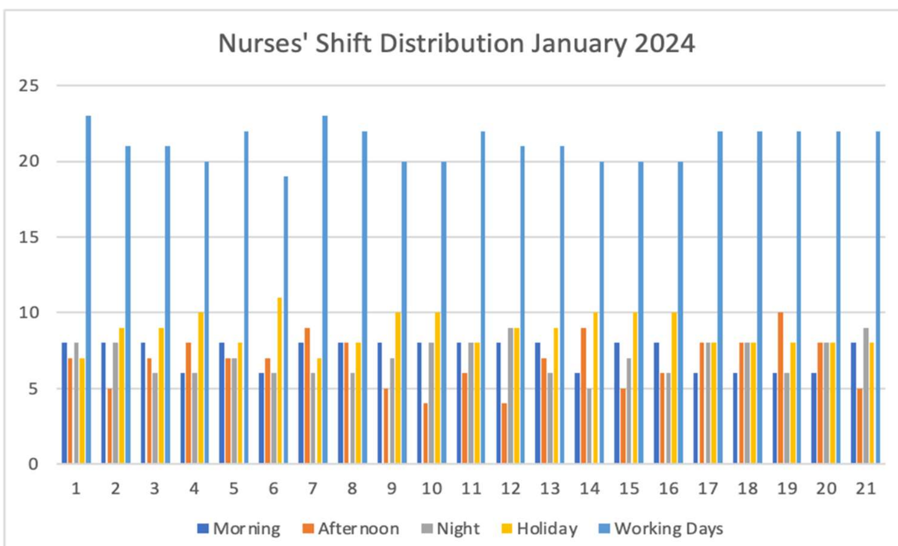

Figure 2: Nurses' shifts distribution on January 2024

The comparison between the optimized schedule presented in Table 1 and the actual schedule from January 2024 depicted in Table 2 reveals significant differences in the distribution of shifts and days off among chief nurses. In Table 1, the scheduling of four chief nurses over a 30-day period demonstrates a balanced and equitable allocation of morning (0), afternoon (1), and night (2) shifts, along with evenly distributed days off (3). This systematic rotation ensures that no single nurse is disproportionately assigned to a particular shift type, promoting fairness and reducing the risk of fatigue through regular rest periods interspersed throughout the month.

On the other hand, Table 2 illustrates a less balanced approach in the actual scheduling practices. There are noticeable instances where certain nurses experience consecutive identical shifts or clustered days off, leading to potential imbalances in workload and rest. For example, Nurse 1 has multiple occurrences of back-to-back days off followed by stretches of consecutive working days, which may contribute to irregular work-rest cycles and increased fatigue. Such patterns suggest a lack of uniformity in shift assignments and rest periods, potentially impacting the overall efficiency and well-being of the nursing staff.

Overall, the optimized schedule in Table 1 exemplifies a structured and methodical distribution of work responsibilities and rest, which is essential for maintaining high levels of performance and job satisfaction among chief nurses. In contrast, the actual schedule in Table 2 highlights areas where scheduling practices could be improved to achieve greater balance and equity. Implementing optimization strategies similar to those used in Table 1 could enhance the effectiveness of nurse scheduling by ensuring fair workload distribution and adequate rest, ultimately contributing to better healthcare service delivery.

Table 3: Variance of working days

Method	***Variance***
Manual	**1.13**
Model	**0.00**

Moreover, The results in table 3 demonstrate a significant difference in workload distribution between manual scheduling and the proposed model-based scheduling. The manual scheduling method yields a variance of 1.13, indicating an uneven distribution of workload among nurses, where some are assigned considerably more or fewer shifts than others. This imbalance can lead to dissatisfaction, burnout, and inefficiencies in healthcare service delivery as explained in Lee et al. (2024). Research indicates that an uneven workload can adversely affect nurses' mental health and job satisfaction, contributing to high turnover rates and poor patient outcomes (Khalili et al., 2020; Malekian et al., 2021).

In contrast, the model-based scheduling achieves a variance of 0.00, representing a perfectly balanced workload among nurses. This outcome highlights the model's effectiveness in ensuring equity in nurse scheduling, which can enhance job satisfaction, reduce fatigue, and improve the overall quality of healthcare services.

The implementation of model-based scheduling not only reduces workload variance but also enhances job satisfaction and reduces fatigue aming nurses. Studies have shown that optimized scheduling can lead to improved healthcare service quality by ensuring that nurses are well-rested and motivated (Khalili et al, 2020). This particularly important in high-stress environments like emergency departments, where effective staffing directly impacts patient care outcomes.

5. CONCLUSSION

This research effectively demonstrates the benefits of an optimized nurse scheduling model for the emergency department of Dr. Saiful Anwar Hospital. The optimized schedule ensures a more equitable distribution of workdays and days off compared to the actual schedule from January 2024. By assigning each nurse, except for chief nurses, to a consistent 21-day work period and evenly distributing days off, the optimized schedule reduces variability and promotes a balanced workload. This approach not only improves the efficiency of nursing staff but also enhances their overall well-being by providing adequate rest periods and preventing overwork. Implementing such optimization strategies can significantly contribute to better healthcare service delivery and nurse satisfaction.

Future research could explore the integration of real-time data and adaptive scheduling algorithms to further enhance the flexibility and responsiveness of nurse scheduling. Additionally, incorporating factors such as nurse preferences, skill levels, and patient acuity could lead to more personalized and efficient scheduling solutions. Expanding the model to consider multi-department or hospital-wide scheduling, as well as the impact of emergency or high-demand situations, could provide valuable insights for broader applications in healthcare management.

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