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Nurse Scheduling Model Strategy in Emergency Unit Using Integer Linear Programming

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ABSTRACT

The study purpose was to optimize the nurse scheduling system at Toto Hospital, Gorontalo, by minimizing total working shifts while fulfilling daily shift requirements and respecting rest constraints after night shifts. Nurse scheduling is a complex combinatorial problem that directly affects the quality of health services and nurse job satisfaction. This study employed an Integer Linear Programming (ILP) approach using the PuLP library in Python with the CBC solver. The model involved 25 nurses over a 30-day period, four shift types (morning, afternoon, night, day off), with minimum requirements of 8, 6, and 4 nurses for morning, afternoon, and night shifts respectively. The objective function minimized the number of working shifts (penalty 1 for work shifts, 0 for day off). Constraints ensured each nurse had exactly one assignment per day, prohibited morning/afternoon shifts immediately after a night shift, and met minimum shift coverage each day.

Materials and methods The ILP model was implemented using the Python programming language with the PuLP library. The model consisted of 25 × 30 × 4 = 3,000 binary decision variables and 1,910 constraints. The CBC solver was used to find the optimal solution**.**

Results. The solver found an optimal solution with a total objective value of 540, meaning 540 working shifts were assigned over 30 days (18 working shifts per day on average). Each of the 25 nurses received exactly 30 assignments (induding day off) over the period, with an average of 21.6 working days and 8.4 days off per nurse. All shift coverage constraints were satisfied, and no nurse was assigned a morning or afternoon shift after a night shift.

Conclusions. The ILP model successfully produced an optimal and feasible nurse schedule for Toto Hospital. The approach can be adapted to different numbers of nurses, shift requirements, and additional constraints such as maximum consecutive night shifts or workload balancing.

Keywords: *Nurse scheduling, integer linear programming, optimization, hospital management, shift assignment*

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INTRODUCTION

In today's competitive healthcare environment, every hospital must continuously improve service quality. One of the most critical factors influencing hospital performance is the human resource factor, especially nurses (Rosenbaum et al., 2024). Nurses are at the frontline of patient care, and their availability, fatigue level, and job satisfaction directly affect patient safety and treatment outcomes (Weaver & Wurmser, 2024). Many hospitals in Indonesia, including Toto Hospital in Gorontalo, still rely on manual or rule-of-thumb scheduling, which often leads to unfair workload distribution, excessive night shifts, and low job satisfaction (Abdullah et al., 2025).

Management of nurse scheduling is essential for achieving operational efficiency and maintaining quality of care. Generally, hospital leaders expect optimal nurse performance while ensuring that nurses have adequate rest and work-life balance (Schoenfelder et al., 2020). The hospital realizes that

nurses are the basic capital in patient care, therefore the quality of nurse scheduling must always be improved (Silalahi et al., 2022).

Nurse scheduling is a very important problem in hospital management. In daily reality, hospitals often face difficulties in creating schedules that meet minimum shift requirements, respect labor regulations, and accommodate nurse preferences (Alaouchiche et al., 2023). It is very important to use systematic optimization methods to generate feasible and efficient schedules. Improving scheduling fairness and efficiency will bring progress for the organization and reduce nurse burnout (Fourati et al., 2023).

Based on preliminary observations at Toto Hospital, Gorontalo, the current scheduling process often results in uneven distribution of night shifts among nurses, violations of rest periods after night shifts, difficulty in finding substitute nurses, and low nurse satisfaction (Badriyah et al., 2024). Thus, an optimization- based approach is needed. This study develops an Integer Linear Programming (ILP) model to generate optimal nurse schedules that satisfy all operational constraints and minimize total working shifts (i.e., maximizing day off allocation) (Ouda et al., 2023).

METHOD

This research uses a quantitative approach with a causal relationship design, implementing an optimization model into a computer program. The model was built using Python 3.10 with the PuLP library (version 2.7.0) and the CBC (Coin-or Branch and Cut) solver. The data used were obtained from the nursing department of Toto Hospital, Gorontalo, as of July 2025 (Anggraini et al., 2024).
Parameters: r = 25 nurses, h = 30 days, s = 4 shift types: morning (07:00–14:00), afternoon (14:00–21:00), night (21:00–07:00), day off. Minimum required nurses per shift: morning = 8, afternoon = 6, night = 4. Cost coefficients: [1, 1, 1, 0] (working shifts cost 1, day off costs 0).
Decision Variables: $Xijk \in \{0,1\}\, where\ i = 1..25, j = 1..30, k = 0..3, and\ Xijk = 1$ if nurse i is assigned shift k on day j.
Objective Function: $Minimize\ Z = \Sigma i, j, k\ cost_k \cdot Xijk.$

Constraints: (1) Exactly one assignment per nurse per day: $\Sigma k\ Xijk = 1$. (2) No morning/afternoon after night shift: $Xi, j-1,2 + Xi, j, 0 \leq 1\ and\ Xi, j-1,2 + Xi, j, 1 \leq 1$. (3) Minimum shift coverage: $\Sigma i\ Xij0 \geq 8, \Sigma i\ Xij1 \geq 6, \Sigma i\ Xij2 \geq 4$ for each day j.
The model was solved using the CBC solver with default settings. The solution was verified for feasibility and optimality.

FINDING AND DISCUSSION

Optimal Schedule Results

The ILP model was executed on a standard laptop (Intel Core i5, 8GB RAM). The CBC solver found an optimal solution in 0.34 seconds. The status was "Optimal" with an objective value of 540. This objective value represents the total number of working shifts (morning + afternoon + night) assigned over 30 days, because each working shift contributes 1 to the objective, while each day off contributes 0. Since each day requires 8+6+4 = 18 working shifts, over 30 days the total working shifts are exactly 18 × 30 = 540. The solver successfully achieved the theoretical lower bound, confirming optimality.

Table 1. Summary of Shift Assignments

Shift Type	Total Shifts (30 days)	Average per Day	Minimum Required	Met?
Morning	240	8.0	8	Yes
Afternoon	180	6.0	6	Yes
Night	120	4.0	4	Yes
Day off	210	7.0	-	-
Total assignments	750 (25 nurses × 30 days)			

Constraint Verifacation

All constraints were satisfied: (a) Exactly one assignment per day: every nurse-day cell had one shift (including day off). (b) No morning/afternoon after night: no occurrence where a nurse worked a night shift and then a morning/afternoon shift the next day. (c) Minimum coverage: each day had exactly 8 morning, 6 afternoon, and 4 night shifts (since extra working shifts would increase objective value, solver assigned exactly at minimum).

Discussion

Feasibility of the Model The ILP approach proved highly effective for Toto Hospital. With 3,000 binary variables and nearly 2,000 constraints, the CBC solver found the optimal solution instantly. This demonstrates that even with moderate computational resources, hospitals can implement optimization-based scheduling.

Comparison with Manual Scheduling. Previously, Toto Hospital used a rotating shift pattern that often violated night-shift rest rules. Manual scheduling took about 4-5 hours per month. The ILP model produces a verified optimal schedule in less than 1 second, eliminating human error and reducing administrative burden.

Flexibility of the Model. The current model can be easily adapted: adding constraints like maximum consecutive night shifts or minimum days off per week, including nurse preferences via penalty costs, or adjusting nurse numbers.

Limitations. The model does not consider individual preferences, seniority/skill levels, or maximum consecutive working days. These can be addressed in future extensions.

CONCLUSIONS

This study successfully developed and implemented an Integer Linear Programming model to optimize nurse scheduling at Toto Hospital, Gorontalo. The model generates a monthly schedule that meets minimum shift requirements (8 morning, 6 afternoon, 4 night nurses daily), respects mandatory rest after night shifts, assigns exactly one shift including day off per nurse per day, and minimizes total working shifts (maximizing day off). The optimal solution was obtained in less than one second with total working shifts of 540 over 30 days. Each nurse received a fair number of working days (21–23) and days off (7–9). It is recommended that Toto Hospital adopt this model. Future research should incorporate nurse preferences, consecutive night shift limits, and skill-based assignments.

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