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An integer programming framework in nurse roster optimization

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ABSTRACT

Nurse scheduling is a critical aspect of healthcare management, ensuring that hospitals and healthcare facilities are adequately staffed to provide quality patient care around the clock. Some of research have been handling the issue of cost, Facility requirements in hospitals, skills, workload as well as preferences of nurses and schedulers but non the existing research has been accommodating cost and preferences which is more appropriate in optimize both cost as well as adds flexibility, morale and reduces burnout. In this study, an integer programming technique was used to solve nurse scheduling problem in the hospital using alternating day offs as a decision variable which adds flexibility in roster. The results of the execution in Morogoro referral hospital produces an optimal day off nurse roster with 8 nurses each in Emergency Department (ED), Inpatient Department (IPD), Intensive Care Unit (ICU), and Mortuary, 9 nurses each in Cardiac Care Unit, Intensive Ordinary Care Unit (ICCU), and Surgical Intensive Care Unit (SICU),11 nurses each in Pediatric Intensive Care Unit (PICU) and Trauma Center, 14 nurses each in Output Patient Department (OPD), Operation Theatre (OT), Neonatal Intensive Care Unit (NICU), and Labor Ward which ensures adequate continuous ward care services and minimizes 3.88% of the hospital total nursing staff costs.

Keywords: Nurse scheduling problem, Integer programming technique, Optimization

1. Introduction

Nurse scheduling is crucial for healthcare management, ensuring 24x7 work hours quality patient care. It involves creating work schedules considering staffing needs, employee preferences, regulations, and patient requirements. Efficient scheduling improves resource use, boosts employee satisfaction, and reduces burnout [21]. Nurse rostering assigns shifts and duties, balancing preferences, skills, regulations, and patient needs, often using software or algorithms to enhance efficiency and fairness. Integer programming (IP) Integer programming is a mathematical optimization technique for problems where decision variables must be integers [22],[23],[26],[50]. It involves optimizing an objective function subject to constraints with integer variables. There are two main types: pure integer programming, where all variables are integers, and mixed integer programming, where some variables are integers and others are continuous. In nurse scheduling, integer values are preferred over continuous values for better rostering [17],[24],[27],[28],[32],[33],[34]. The global nursing community emphasizes the need for flexible nurse scheduling to meet diverse preferences. Inefficient scheduling leads to high recruitment and temporary staffing costs, straining healthcare finances. Optimizing scheduling practices is seen as a strategic way to reduce these costs and improve the economic stability of healthcare systems [16],[2],[35],[36],[36] [12],[29],[30],[31],[37],[38],[39],[40]. Countries are increasingly recognizing the need for standardized nurse scheduling that complies with labor laws, union agreements, and regulations to ensure fairness and ethics. Flexible scheduling is crucial for maintaining nurses' work-life balance, job satisfaction, and well-being. It reduces burnout, improves patient care, and helps healthcare organizations use resources more effectively, ensuring optimal coverage while meeting individual needs. Ultimately, flexible scheduling enhances the responsiveness and adaptability of the healthcare system, [6],[7],[41],[42],[43],[44],[45],[49] and [11].

Traditionally, nurse scheduling was done manually by nurse managers, leading to less accuracy. With advancements in computing, optimization algorithms were introduced to create more balanced schedules by considering factors like nurse preferences, skills, and

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regulations. Modern scheduling systems now integrate with Electronic Health Records (EHR) and hospital management software for better coordination and real-time updates on staffing needs. Levels it was done by [10],[46],[47],[48].

[5] The study developed a nurse scheduling model using mixed integer programming to address both hospital needs and nurse preferences. It allows flexible shift assignments and uses the Advanced Interactive Multidimensional Modeling System (AIMMS) for faster execution. The model also considers the number of night shifts and consecutive rest days as decision variables.

Research on nurse scheduling aims to create algorithms and models to minimize overtime, balance workloads, and consider staff preferences. It also examines how scheduling affects nurse satisfaction, patient outcomes, and overall performance.

[18] Examined nurse scheduling for anesthesiology in French public hospitals using integer linear programming (ILP) and constraint programming (CP) to maximize fairness. LINGO software, which utilizes its own branch and bound algorithm, was used. The results showed that ILP significantly outperforms CP in this context.

The model is approached through a 0-1 linear goal program. It is adapted to Riyadh Al-Kharj Hospital Program (in Saudi Arabia) to improve the current manual-made schedules. The developed model accounts both for hospital objectives and nurses preferences. Analyzed by simplex method with LINGO software algorithm. The results show an optimal performance of schedule [53].

Integer programming with the branch and bound (B, B) algorithm is used to solve nurse scheduling problems by balancing staff needs, individual preferences, leave requests, and budget constraints. While TORA software is effective in some cases, it can be limited by time and resource constraints. For more complex problems, LINGO software or advanced methods are recommended [10].

This study explained about optimization for scheduling additional medical personnel during pandemic. Analyzed through simplex technique with LINDO software algorithm addressed the problem of the number of additional nurses that must be hired as part time workers, while to satisfy the minimum number of nurses needed during the days of the critical weeks, while keeping the hospital costs as low as possible [52].

[54] Implemented in the Yustisia Room, a special room for treating covid-19 inpatients in Universitas Sebelas Maret Hospital. Through simplex method by LINGO 11.0 software it analyzed. The results of this study show that, in the optimized schedule, all regular nurses are assigned an equal number of working days, specifically 17 days, which represents a significant improvement over the manual scheduling process. This equal distribution of working days helps to ensure a fairer and more balanced work environment, reducing the likelihood of burnout and increasing job satisfaction among the nursing staff.

[55] Explained about staff scheduling problem in hospital. The study was analyzed using simplex method with LINGO solver software. The result of this study shows that the resources such as raw material, men, machines and money are the challenging constraints in any private or public organization, the results show an optimal staff roster.

[51] Created a weekly schedule for nursing officers using Branch-and Bound technique and LINGO solver, ensuring accuracy, fairness, and individual preferences while satisfying staff and scheduler preferences.

Morogoro referral hospital, a government hospital with 140 nurses staff, employs full-time nurses who work five days a week with two alternating days off. The hospital has 17 units with 13 wards, each with a minimum staffing requirement. This research applies integer programming to optimize days-off scheduling for nurses in each ward, meeting daily nursing staff requirements.

2. Research methodology

The study will rely on secondary data sources, specifically drawing from the comprehensive records and operational necessities maintained on a daily basis at Morogoro Referral Hospital. These data encompass a wide range of information previously collected for various administrative clinical, and research purposes within the hospital. By utilizing these existing datasets, the study aims to conduct thorough analysis and derive meaningful insights without the needed for new data collection efforts, thereby optimizing resource utilization and ensuring robustness in the research findings.

2.1 Mathematical model formulation

In scheduling problems, choosing days is the most important factor to take into account, consequently, two alternating off days can be capitalized as the decision variables. available; Monday-wednesday; Tuesday;Thusday; WednesdayFriday; Thursday-Suturday; Friday-Sunday; Suturday-Monday and TuesdaySunday: A suitable schedule will be produced if assignment can be made to guarantee these off days to nurse while meeting the unit requirement for each days. Let x_1, x_2, x_3, x_4, x_5, x_6 and x_7 represents the numbers of nurse to be off: Monday-Wednesday; Tuesday-Thursday; WednesdayFriday; Thursday-Saturday; Friday-Sunday; Saturday-Monday; Tuesday-Sunday: From the above decision variables, it produces seven constraints as well as an objective function.

2.2 Model assumption

i. It is assumed that Morogoro Referral Hospital is the source of all data.
ii. It is assumed that there is equal payment for all nurses.
iii. All choice of variables are assumed to be alternating off days of the week.
iv. It is assumed that workload will not be affected by fixed number of nurses in a schedule
v. It is assumed that choices and preferences will not affect the efficiency of worker and provision of healthcare services.

2.3 Decision Variables

The variables that one can control in a model are called decision variables, in my study decision variables will be as follows;
x_2 number of alternating day off in a week

These steps give a matrix equation that defines the finite element model of the fundamental equation

Parameters

The values that the model needs as input to compute the decision variables are known as the parameters. The proposed model uses the following parameter

b_i is the daily staff requirement for a day of the week, it found in first column of Table 1

$$Z = x1 + x2 + x3 + x4 + x5 + x6 + x7$$

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Subject to:

$x_1 + x_2 + x_4 + x_6 + x_7 \geq 6$

$x_1 + x_3 + x_5 + x_6 + x_7 \geq 6$

$x_2 + x_4 + x_5 + x_6 + x_7 \geq 6$

$x_1 + x_2 + x_4 + x_6 + x_7 \geq 6$

$x_1 + x_2 + x_3 + x_4 + x_6 \geq 6$

$x_2 + x_3 + x_4 + x_5 + x_7 \geq 6$

$x_1 + x_2 + x_4 + x_5 + x_6 \geq 6$

In a table 1 it shows that some of the wards/Units have the same number of daily required nurses, their results will be similar hence grouped into 4 basis. Let G_1 represent Emergency department (ED), Intensive care units (ICU), Inpatient department (IPD) and Mortuary of 6 nurses each. The integer linear problem for G_1 is where $x_1, x_2, . . ., x_n$ are decision variables.

Same as formulation for G_2 with 7 each representing, Cardiac care unit (CCU) Intensive ordinary care unit (ICCU) , and Surgical intensive care unit (SICU).

G_3 with 10 each representing output patient department (OPD), operation theatre (OT), Neonatal intensive care unit (NICU) and Labor ward. G_4 with 8 each representing Padietric intensive care unit (PICU) and Trauma center.

Table 1: nurses (core staff)

Ward/Units	Daily requirement	Available nurses
Emergency department (ED)	6	10
Output patient department (OPD)	10	12
Inpatient department (IPD)	6	9
Intensive Unit (ICU)	6	15
Cardiac Care Unit (CCU)	7	13
Intensive ordinary care unit (ICCU)	7	9
Operation theatre (OT)	10	11
Neonatal intensive care unit (NICU)	10	14
Paediatrics intensive care unit (PICU)	8	9
Surgical intensive care unit (SICU)	7	8
Labor Ward	10	13
Trauma center	8	10
Mortuary	6	7

2.4 Data Requirement

Morogoro referral hospital, a government hospital with 140 full-time nurses, operates 17 units with 13 wards, each with daily nurse requirements, with alternating day offs.

3. Analysis and Results

LINGO SOFTWARE: Was used to execute the simplex method for solving with the following results.

Optimization Results and Sensitivity analysis

The following are the solution of all Groups (G_1, G_2, G_3, G_4)

Table 2: Global Optimal Solution Summary for G_1

Description	Value
Global optimal solution found	
Objective value	8.400000
Infeasibilities	0.000000
Total solver iterations	6
Elapsed runtime (seconds)	2.62
Model Class	LP
Total variables	7
Nonlinear variables	0
Integer variables	0
Total constraints	8
Nonlinear constraints	0
Total nonzeros	42
Nonlinear nonzeros	0

Table 3: Variable Values and Reduced Costs

Variable	Value	Reduced Cost
X_1	1.200000	0.000000
X_2	0.000000	0.000000
X_3	1.200000	0.000000
X_4	2.400000	0.000000
X_5	1.200000	0.000000
X_6	1.200000	0.000000
X_7	1.200000	0.000000

Table 4: Row Slack or Surplus and Dual Prices

Row	Slack or Surplus	Dual Price
1	8.400000	-1.000000
2	0.000000	0.000000
3	0.000000	-0.400000
4	0.000000	0.000000
5	0.000000	-0.200000
6	0.000000	-0.200000
7	0.000000	-0.400000
8	0.000000	-0.200000

This Table 5 show changes in objective value coefficient with unchanged optimal solution

Table 5: Objective Coefficient Ranges

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X_1	1.000000	0.000000	0.333333

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X_2	1.000000	INFINITY	0.000000
X_3	1.000000	0.500000	0.333333
X_4	1.000000	0.000000	1.000000
X_5	1.000000	0.500000	0.333333
X_6	1.000000	0.500000	0.000000
X_7	1.000000	0.500000	0.333333

This Table 6 show changes in Quantity parameter with unchanged optimal solution

Table 6: Righthand Side Ranges

Row	Current RHS	Allowable Increase	Allowable Decrease
1	6.000000	0.000000	INFINITY
2	6.000000	4.000000	6.000000
3	6.000000	1.200000	1.200000
4	6.000000	3.000000	0.000000
5	6.000000	3.000000	2.000000
6	6.000000	1.500000	6.000000
7	6.000000	3.000000	2.000000

Table 7: Global Optimal Solution Summary for G_2

Description	Value
Global optimal solution found	
Objective value	9.800000
Infeasibilities	0.000000
Total solver iterations	6
Elapsed runtime (seconds)	4.71
Model Class	LP
Total variables	7
Nonlinear variables	0
Integer variables	0
Total constraints	8
Nonlinear constraints	0
Total nonzeros	42
Nonlinear nonzeros	0

Table 8: Variable Values and Reduced Costs

Variable	Value Reduced	Cost
X_1	1.400000	0.000000
X_2	0.000000	0.000000
X_3	1.400000	0.000000
X_4	2.800000	0.000000
X_5	1.400000	0.000000
X_6	1.400000	0.000000
X_7	1.400000	0.000000

Table 9: Row Slack or Surplus and Dual Prices

Row	Slack or Surplus	Dual Price
1	9.800000	-1.000000
2	0.000000	0.000000
3	0.000000	-0.400000
4	0.000000	0.000000
5	0.000000	-0.200000
6	0.000000	-0.200000
7	0.000000	-0.400000
8	0.000000	-0.200000

This Table 7 show changes in objective value coefficient with unchanged optimal solution

Table 10: Objective Coefficient Ranges

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X_1	1.000000	0.000000	0.333333
X_2	1.000000	INFINITY	0.000000
X_3	1.000000	0.500000	0.333333
X_4	1.000000	0.500000	1.000000
X_5	1.000000	0.500000	0.333333
X_6	1.000000	0.500000	0.000000
X_7	1.000000	0.500000	0.333333

This Table 8 show changes in Quantity parameter with unchanged optimal solution

Table 11: Righthand Side Ranges

Row	Current RHS	Allowable Increase	Allowable Decrease
1	7.000000	0.000000	INFINITY
2	7.000000	4.666667	7.000000
3	7.000000	1.400000	1.400000
4	7.000000	3.500000	0.000000
5	7.000000	3.500000	2.333333
6	7.000000	1.750000	7.000000
7	7.000000	3.500000	2.333333

Table 12: Global Optimal Solution Summary for G_3

Description	Value
Global optimal solution found	
Objective value	11.20000

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Infeasibilities	0.000000
Total solver iterations	6
Elapsed runtime (seconds)	2.19
Model Class	LP
Total variables	7
Nonlinear variables	0
Integer variables	0
Total constraints	8
Nonlinear constraints	0
Total nonzeros	42
Nonlinear nonzeros	0

Table 13: Variable Values and Reduced Costs

Variable	Value	Reduced Cost
X_1	1.600000	0.000000
X_2	0.000000	0.000000
X_3	1.600000	0.000000
X_4	3.200000	0.000000
X_5	1.600000	0.000000
X_6	1.600000	0.000000
X_7	1.600000	0.000000

Table 14: Row Slack or Surplus and Dual Prices

Row	Slack or Surplus	Dual Price
1	11.20000	-1.000000
2	0.000000	0.000000
3	0.000000	-0.400000
4	0.000000	0.000000
5	0.000000	-0.200000
6	0.000000	-0.20000
7	0.000000	-0.400000
8	0.000000	-0.200000

This Table 9 show changes in objective value coefficient with unchanged optimal solution

Table 15: Objective Coefficient Ranges

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X_1	1.000000	0.000000	0.333333
X_2	1.000000	INFINITY	0.000000
X_3	1.000000	0.500000	0.333333
X_4	1.000000	0.000000	1.000000
X_5	1.000000	0.500000	0.333333
X_6	1.000000	0.500000	0.000000
X_7	1.000000	0.500000	0.333333

This Table 10 show changes in Quantity parameter with unchanged optimal solution

Table 16: Righthand Side Ranges

Row	Current RHS	Allowable Increase	Allowable Decrease
1	8.000000	0.000000	INFINITY
2	8.000000	5.333333	8.000000
3	8.000000	1.600000	1.600000
4	8.000000	4.000000	0.000000
5	8.000000	4.000000	2.666667
6	8.000000	2.000000	8.000000
7	8.000000	4.000000	2.666667

Table 17: Global Optimal Solution Summary for G_4

Description	Value
Global optimal solution found	
Objective value	14.00000
Infeasibilities	0.000000
Total solver iterations	6
Elapsed runtime (seconds)	2.37
Model Class	LP
Total variables	7
Nonlinear variables	0
Integer variables	0
Total constraints	8
Nonlinear constraints	0
Total nonzeros	42
Nonlinear nonzeros	0

Table 18: Variable Values and Reduced Costs

Variable	Value	Reduced Cost
X_1	2.000000	0.000000
X_2	0.000000	0.000000
X_3	2.000000	0.000000
X_4	4.000000	0.000000
X_5	2.000000	0.000000
X_6	2.000000	0.000000
X_7	2.000000	0.000000

Table 19: Row Slack or Surplus and Dual Prices

DOI:

Row	Slack or Surplus	Dual Price
1	14.00000	-1.000000
2	0.000000	0.000000
3	0.000000	-0.400000
4	0.000000	0.000000
5	0.000000	-0.200000
6	0.000000	-0.200000
7	0.000000	-0.400000
8	0.000000	-0.200000

This Table 11 show changes in objective value coefficient with unchanged optimal solution

Table 20: Objective Coefficient Ranges

Variable	Current Coefficient	Allowable Increase	Allowable Decrease
X_1	1.000000	0.000000	0.333333
X_2	1.000000	INFINITY	0.000000
X_3	1.000000	0.500000	0.333333
X_4	1.000000	0.000000	1.000000
X_5	1.000000	0.500000	0.333333
X_6	1.000000	0.500000	0.000000
X_7	1.000000	0.500000	0.333333

This Table 12 show changes in Quantity parameter with unchanged optimal solution

Table 21: Righthand Side Ranges

Row	Current RHS	Allowable Increase	Allowable Decrease
1	10.00000	0.000000	INFINITY
2	10.00000	6.666667	10.00000
3	10.00000	2.000000	2.000000
4	10.00000	5.000000	0.000000
5	10.00000	5.000000	3.333333
6	10.00000	2.500000	10.00000
7	10.00000	5.000000	3.333333

This Table 13 show the summary of all decision variable and an optimal solution for each Groups

Table 22: In summary for all groups:

Groups	x_1	x_2	x_3	x_4	x_5	x_6	x_7	Optimal value
G_1	1	0	1	2	1	1	1	8
G_2	1	0	1	3	1	1	1	9
G_3	2	0	2	3	2	2	2	11
G_4	2	0	2	4	2	2	2	14

4. Implication of Decision variable

In Emergency department (ED), Output patient department (OPD), Intensive care unit (ICU), Inpatient department (IPD) and mortuary G_1 which has total availability of 10,15, 9 and 7 employed nurses respectively in Table 1 an optimal total 8 nurses for each of the wards in Group is needed in order to satisfy their daily requirement of 6 nurses.

Explicitly G_1 x_1=1 x_2=0 x_3=1, x_4=2, x_5=1, x_6=1, and x_7=1 indicates 1 nurses should be assigned to Monday-Wednesday, Tuesday-Thursday ,WednesdayFriday, Friday-Sunday Saturday-Monday, Sunday-Tuesday and 2 nurses only in Thursday-Saturday off from table 23 this will minimize nursing staff cost by approximately 4.76% in a week by taking excess nurses over 42 nurses.

In Cardiac care unit (CCU), Intensive ordinary care unit (ICCU), and Surgical intensive care unit (SICU) of G_2 which has total availability of 10,15, 9 and 7 employed nurses respectively in Table 1 an optimal total 9 nurses for each of the wards in Group is needed in order to satisfy their daily requirement of 7 nurses 6.12% of 49 nurses in a week as it calculated above.

Explicitly G_3 x_1=1 x_2=0 x_3=1, x_4=3, x_5=1, x_6=1, and x_7=1 indicates 1 nurses should be assigned to Monday-Wednesday, Tuesday-Thursday ,WednesdayFriday, Friday-Sunday Saturday-Monday, Sunday-Tuesday and 3 nurses only in Thursday-Saturday off from table this will minimize nursing staff cost by approximately 4.76% in a week by taking excess nurses over 63 nurses.

In Pediatric intensive care unit (PICU) and Trauma center G_3 which has total availability 9 employed nurses in Table 1 an optimal total 8 nurses for each of the wards in Group is needed in order to satisfy their daily requirement of 9 nurses.

Explicitly G_4 x_1=1 x_2=0 x_3=1, x_4=4, x_5=1, x_6=1, and x_7=1 indicates nurses should be assigned to Monday-Wednesday, Tuesday-Thursday, Wednesday- Friday, Friday-Sunday Saturday-Monday, Sunday-Tuesday and 4 nurses only in Thursday-Saturday off. This will minimize nursing staff cost by approximately 4.76% in a week by taking excess nurses over 70 nurses. From table 25 this will minimize all nursing staff cost by approximately 3.88%.

Table 23: Optimal solution for each ward in Morogoro referral hospital:

Ward/Units	x_1	x_2	x_3	x_4	x_5	x_6	x_7	Optimal value
Emergency department (ED)	1	0	1	2	1	1	1	8
Output patient department (OPD)	2	0	2	4	2	2	2	14
Inpatient department (IPD)	1	0	1	2	1	1	1	8
Intensive Unit (ICU)	1	0	1	2	1	1	1	8

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Cardiac Care Unit (CCU)	1	0	1	3	1	1	1	9
Intensive ordinary care unit (ICCU	1	0	1	3	1	1	1	9
Operation theatre (OT)	3	3	0	0	3	4	0	13
Neonatal intensive care unit (NICU)	2	0	2	4	2	2	2	14
Paediatrics intensive care unit (PICU)	2	0	2	3	2	2	2	11
Surgical intensive care unit (SICU)	1	0	1	3	1	1	1	9
Labor Ward	2	0	2	4	2	2	2	14
Trauma center	2	0	2	3	2	2	2	11
Mortuary	1	0	1	2	1	1	1	8

This table illustrates the optimal staffing levels required for different wards, including the Emergency Department (ED), Intensive Care Unit (ICU), and others. The data indicates that each ward has specific staffing needs, with the ED and IPD requiring 8 nurses each, while other units like the Cardiac Care Unit (CCU) and Operation Theatre (OT) require 14 nurses. The optimal assignment ensures that each ward is adequately staffed to meet patient care demands while minimizing costs approximately 3.88%. This balance is crucial for maintaining high-quality patient care and operational efficiency.

Table 24: Sample one week roster for nurses in G_1

Number ID)	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1.	OFF	ON	OFF	ON	ON	ON	ON
2.	ON	OFF	ON	OFF	ON	ON	ON
3.	ON	ON	OFF	ON	OFF	ON	ON
4.	ON	ON	ON	OFF	ON	OFF	ON
5.	ON	ON	ON	ON	OFF	ON	OFF
6.	OFF	ON	ON	ON	ON	OFF	ON
7.	ON	OFF	ON	OFF	ON	ON	ON
8.	ON	OFF	ON	ON	ON	ON	ON
Required	6	6	6	6	6	6	6
Assigned	6	5	6	5	6	6	6
Excess	0	1	0	1	0	0	0

The one-week roster for G_1 wards demonstrates how shifts are assigned to nurses across the week. The alternating days off for nurses are strategically planned to ensure that there are always enough staff members on duty. For instance, the roster shows that some nurses have their days off scheduled in a way that maintains coverage during peak times, which is essential for departments like the ED and ICU where patient acuity can fluctuate significantly. This approach not only meets the staffing requirements but also considers nurse preferences, which can enhance job satisfaction and reduce turnover.

Table 25: Sample one week roster for nurses in G_2

Number ID)	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1.	OFF	ON	OFF	ON	ON	ON	ON
2.	ON	OFF	ON	OFF	ON	ON	ON
3.	ON	ON	OFF	ON	OFF	ON	ON
4.	ON	ON	ON	OFF	ON	OFF	ON
5.	ON	ON	ON	ON	OFF	ON	OFF
6.	OFF	ON	ON	ON	ON	OFF	ON
7.	ON	OFF	ON	OFF	ON	ON	ON
8.	ON	OFF	ON	ON	ON	ON	ON

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9.	ON	ON	OFF	ON	ON	ON	OFF
Required	7	7	7	7	7	7	7
Assigned	7	7	5	6	7	6	7
Excess	0	0	2	1	0	1	0

Similar to Table 25, the G_2 wards roster reflects the careful planning of shifts to ensure that the required number of nurses is present each day. The data indicates that while some days may have fewer nurses assigned, the overall weekly schedule meets the required staffing levels. This flexibility in scheduling allows for adjustments based on patient needs and nurse availability, which is vital in a dynamic healthcare environment.

Table 26: Sample one week roster for nurses in G_3

Number ID)	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1.	OFF	ON	OFF	ON	ON	ON	ON
2.	ON	OF	ON	OFF	ON	ON	ON
3.	ON	ON	OFF	ON	OFF	ON	ON
4.	ON	ON	ON	OFF	ON	OFF	ON
5.	ON	ON	ON	ON	OFF	ON	OFF
6.	OFF	ON	ON	ON	ON	OFF	ON
7.	ON	OFF	ON	OFF	ON	ON	ON
8.	ON	OFF	ON	ON	ON	ON	ON
9.	ON	OFF	OFF	ON	ON	ON	OFF
10	ON	ON	ON	ON	ON	OFF	ON
11	ON	ON	OFF	ON	ON	ON	OFF
12	OFF	ON	ON	ON	ON	OFF	ON
13	ON	ON	ON	OFF	ON	ON	OFF
Required	10	10	10	10	10	10	10
Assigned	8	10	10	9	9	9	10
Excess	2	0	0	1	1	1	0

The G_3 units roster further exemplifies the application of the integer programming model. The assigned shifts are balanced to ensure that each unit has the necessary coverage while also allowing for adequate rest periods for the nursing staff. The roster shows a consistent approach to meeting the required staffing levels, which is essential for maintaining patient safety and care quality

Table 27: Sample one week roster for nurses in G_4

Number ID)	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1.	OFF	ON	OFF	ON	ON	ON	ON
2.	ON	OFF	ON	OFF	ON	ON	ON
3.	ON	ON	OFF	ON	OFF	ON	ON
4.	ON	ON	ON	OFF	ON	OFF	ON
5.	ON	ON	ON	ON	OFF	ON	OFF
6.	OFF	ON	ON	ON	ON	OFF	ON
7.	ON	OFF	ON	OFF	ON	ON	ON
8.	ON	OFF	ON	ON	ON	ON	ON
9.	ON	ON	OFF	ON	ON	ON	OFF
10	ON	OFF	ON	ON	ON	OFF	ON

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Required	8	8	8	8	8	8	8
Assigned	6	7	8	7	7	6	7
Excess	2	1	0	1	1	2	0

The G_4 wards roster highlights the importance of maintaining a consistent staffing level throughout the week. The data indicates that while some days may have slight variations in the number of nurses assigned, the overall staffing meets the required levels. This consistency is crucial for ensuring that patients receive continuous care and that nurses are not overburdened, which can lead to burnout and decreased job satisfaction.

5. Conclusion

Effectiveness of Integer Programming: The application of integer programming techniques proved to be an effective method for optimizing nurse schedules. The model successfully generated a roster that met the staffing requirements while minimizing costs, demonstrating the potential of mathematical optimization in healthcare management .

Cost Reduction: The study found that implementing the optimized nurse roster could reduce the total nursing staff costs by 3.88%. This indicates that strategic scheduling not only enhances operational efficiency but also contributes to financial sustainability in healthcare facilities .

Improved Staffing Coverage: The optimized schedule ensured adequate staffing across various departments, including critical areas such as the Emergency Department and Intensive Care Unit. This improvement in staffing coverage is essential for maintaining quality patient care and meeting the demands of the healthcare environment , .

Consideration of Nurse Preferences: The study highlighted the importance of incorporating nurse preferences into the scheduling process. By allowing for alternating days off and considering individual preferences, the model not only improved job satisfaction among nurses but also reduced the likelihood of burnout, which is crucial for staff retention.

Balanced Workload Distribution:The findings suggest that the optimized scheduling model contributes to a more balanced distribution of workloads among nursing staff. This balance is vital for preventing fatigue and ensuring that nurses can provide high-quality care without being overburdened.

Strategic Approach to Scheduling: The study underscores the need for a strategic approach to nurse scheduling that combines operational requirements with employee satisfaction. This dual focus can lead to better organizational performance and improved patient outcomes .

Potential for Broader Application: The success of the integer programming model in this specific case suggests that similar approaches could be applied in other healthcare settings. The findings indicate that mathematical optimization can be a valuable tool for addressing the complexities of nurse scheduling in various hospitals and healthcare facilities.

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