Maximizing Shift Preference for Nurse Rostering Schedule Using Integer Linear Programming and Genetic Algorithm

Siti Noor Asyikin Binti Mohd Razali[1], Thesigan Achari A/L Tamilarasan[2], Batrisyia Binti Basri[3], Norazman bin Arbin[4]

Department of Mathematics and Statistics-Faculty of Applied Sciences and Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Edu Hub, 84600 Pagoh, Muar, Johor, Malaysia[1, 2, 3]

Department of Mathematics-Faculty of Sciences and Mathematics, Universiti Pendidikan Sultan Idris, 35900 Tanjong Malim, Perak, Malaysia[4]

***Abstract*—This study explores how scheduling methods can support work-life balance and overall job satisfaction by considering the preferences of the nursing staff. Creating a nurse rostering schedule that maximizes staff preferences for working shifts, off days, and hospital demands was the main goal. A Google Form that was distributed to the nursing staff is used to gather preference data. With the help of the LPSolve IDE, an integer linear programming (ILP) technique is used for the first datasets, and the Flexible Shift Scheduling System is utilized to facilitate the use of a genetic algorithm approach for the second dataset. The first dataset's result reveals that the proposed schedule's preference weight is 205.8 (73.35%), indicating an increase of 46.24 (16.48%) over the current schedule's 159.56 (56.87%) preference weight. According to the results of the second dataset, the preference weight for the current schedule is 589 (62.98%), whereas the preference weight for the proposed schedule is 619.2 (66.21%), indicating a 30.2 (3.23%) increase. This demonstrates that both proposed schedules have higher preference weight values than the current schedule, which satisfies the study's primary goal of optimizing staff preferences. The genetic algorithm is used in the second dataset since it has a high complexity problem and can produce a near-optimal solution. Flexible Shift Scheduling System generates quicker and easier schedules compared to manual schedules. This study emphasizes the importance of including nurse staff preferences into consideration when creating nurse rostering schedule procedures to support a happier and more engaged nursing team.**

Keywords*—Nurse rostering schedule; schedule optimization; metaheuristic techniques; complex scheduling; integer linear programming; genetic algorithm; shift; and off-day preference maximization

I. INTRODUCTION

Scheduling is known as the challenge of allocating finite resources to jobs across time to maximize one or more objectives. Scheduling is a popular method of making decisions that is mostly applied in the manufacturing and service industries [1]. Scheduling selects from a variety of plans and assigns resources and deadlines to every task to guarantee that the assignment complies with job time constraints and group resource capacity limitations [2]. According to [3], the scheduling problem is the assignment of the organization throughout time and numerous sets of constraints. According to [4], all feasible solutions typically satisfy several hard and soft constraints. The recruiting of nursing staff, the scheduling of nursing staff, and a few other nursing service duties are all significantly impacted by nursing staff [5]. Creating rosters that constantly provide adequate coverage while considering individual preferences is the overarching goal of the Nurse Rostering Schedule (NRS) problem. Despite the development of numerous approaches to address the issue of nurse scheduling, many large healthcare organizations worldwide continue to manually schedule nurses [6].

Each nurse staff member has the right to select the shifts and days off that work best for them. A common task for the chief nurse is to establish a schedule that meets both the nurses' preferences and hospital demands. This demonstrates how challenging it is to schedule nurses while meeting several goals with limitations. Because different staffing levels need to be assigned to different days and shifts and scheduling nurses manually involves a lot of work and intricacy. This is sometimes called "self-scheduling" in literature [6]. This must be resolved by using a systematic approach that results in higher quality which is important in producing the best schedules, particularly in the healthcare industry. Additionally, a fast and optimal schedule can be made by using a systematic approach.

In this study, the hospital is trying to resolve a difficult and drawn-out scheduling problem. To maximize the efficiency of the nursing staff, the manager of the Malaysia Specialists Centre (for the first dataset) and the Malaysia Hospital (for the second dataset) has a major responsibility to schedule the "right" nurses properly working for the day and night shift. Since scheduling becomes more complex as the number of nurses increases, the hospital does not follow a systematic process when creating the current nursing schedule, and it consistently disregards the preferences of nurses. Hence, the goal of this work is to use optimization and metaheuristic approaches for both the first and second datasets to construct a schedule that satisfies both hard and soft constraints that follows hospital policies and preference of nurses. Therefore, it is crucial to apply some scientific methods, which include integer linear programming and genetic algorithms. Since the number of nurses can be classified as a small dataset, this study used ILP for the first dataset, which allowed the algorithm to find the optimal solution. In the meantime, the second dataset, which has 100 data points, can make scheduling more difficult, which is appropriate for a genetic algorithm method. This study fills a gap left by earlier research that primarily focused on metaheuristic techniques only.

II. Related Work

A nurse scheduling model, according to [7], maximizes the preference satisfaction of the nursing staff with the shift schedule by working within the schedule's constraints, considering the different preference rankings for each shift, and taking historical data from previous schedule periods into account. Integer programming and constraint programming are the two approaches that [8] examined for a public hospital in France's anesthesia nurse scheduling issue (ANSP). The objective is to maximize the fairness of the timetable. This seeks to maximize nursing preferences, minimize pay costs, and satisfy coverage needs, all while preserving team cohesion. However, in different situations, scheduling involves a lot of variables and constraints and is difficult to solve optimally in a reasonable amount of time. Optimization methods such as integer programming or integer linear programming are only appropriate for a small number of datasets [9]. To get around this flaw, hybrid strategies that combine ILP with heuristic algorithms, metaheuristics like simulated annealing or genetic algorithms, or constraint programming are used to enhance computing efficiency and quality of scheduling issue solutions [9].

In [10], the authors describe how a genetic algorithm can be used to resolve a personnel scheduling conflict that occurred at a large United Kingdom hospital. A heuristic decoder generates schedules from nurse permutations, which are the basis of the indirect coding technique used here. Results show that the proposed approach is more flexible and faster, and can find high-quality solutions. Furthermore, genetic algorithms (GA) are a class of highly unpredictable computer programming algorithms that are grounded in the concept of biogenetics. The augmented genetic algorithm is suggested as the solution for the multi-objective optimization problem of college English class scheduling [11]. Studies show that, in terms of time and average fitness value, the modified genetic algorithm performs better than the standard genetic algorithm.

This study has three goals: first, to identify staff preferences for shifts to meet satisfaction; second, to produce a schedule that fully satisfies the demand of the nursing staff by maximizing their preferences using integer linear programming for the first dataset and a genetic algorithm for the second dataset; and lastly, to validate and compare the proposed schedule with the current schedule. This study is significant because it models and solves a difficult scheduling problem for nurses by utilizing optimization and metaheuristic techniques to provide the optimal timetable. These techniques, for example, can be used to effectively manage schedule conflicts and the requirement to uphold a high level of service. A well-designed timetable will result in better staff nursing performance and care.

The flow of this study starts with explanation on data collection method of nurse preferences and the decision variables of mathematical model used in the objective function to maximize the nurse's preferences, aligning with the constraints listed. The following part describes the details of methodology for ILP and GA, including the Flexible Shift Scheduling System. The next part discusses the results obtained, comparison with the current, and the proposed schedule. The last part shows the discussion and conclusion of this study.

III. Materials and Methods

A. Data Collection

The children's ward of Malaysia Specialists Centre and the admission ward of Malaysia Hospital are the case studies. The hospital's children's ward, which is assigned as the first dataset, has 24 nursing staff members, and the admissions ward, which is assigned as the second dataset, has 100 nursing staff members. Data on staff preferences is gathered via a Google Form that was sent to the nursing staff. Informal discussions with the unit manager helped in obtaining information about the one-week nurse work schedule. The data spans one week for both datasets, from August 7 to August 13, 2023.

B. Mathematical Model

A mathematical model that addresses the problem of NRS at a hospital is composed of three key elements: decision variables, objective functions, and constraints. Table I lists the symbols used to define the decision variables:

1) Decision variables:

TABLE I. Description of Decision Variable

Decision Variable	Description
q	Nurse staff
r	Nurse staff category where; 1=Senior Community Nurse, 2=Community Nurse, 3=Senior Registered Nurse, 4=Registered Nurse, 5=Senior Care Assistant, 6=Care Assistant, 7=Senior Licensed Practical Nurse and 8=Licensed Practical Nurse
s	Preferred shift
T	Day off of the week
Q	Set of nurse staff (i.e. q ϵQ)
R	Set of nurse staff categories (i.e. r ϵR)
S	Set of shift preference (i.e. s ϵS) 1 = morning shift, 2 = evening shift and 3 = night shift.
T	Set of the day off (i.e. t ϵT)
$\boldsymbol{D_{s,t}}$	Demand for shift *s* on the day *t*
$P_{q,r,s,t}$	Shift preference of nurse staff, *q* category, *r* shift, *s* day, *t* $P_{q,r,s,t}$: 0 as not preferred and 1 as preferred
$A_{q,r,s,t}$	Availability of nurse staff, *q* category, *r* shift, *s* day, *t*

Decision Variable	Description
	$A_{q,r,s,t}$: 0 as unavailable and 1 as available
$W_{q,r,s,t}$	Wight preference of nurse staff, q category, r shift, s day, t $W_{q,r,s,t}$: 0 as unavailable and 1 as available
$X_{q,r,s,t}$	$\begin{cases} 1, \text{staff } q \text{ of category } r \text{ for shift } s \text{ on day } t \\ 0, \text{otherwise} \end{cases}$

2) Objective function: Eq. (1) aims to optimize the overall preferences of the nursing staff regarding work shifts and their days off.

$$Max, Z = \sum_1^Q \sum_1^R \sum_1^S \sum_1^T (\Omega_{\theta,\rho,\sigma,\tau} . \Xi_{\theta,\rho,\sigma,\tau}) \qquad (1)$$

The preference weight for each nurse staff member is calculated using Eq. (2):

$$W_{q,r,s,t} = \begin{cases} 0, if\ A_{q,r,s,t} = 0, \\ 1 + \alpha, if\ A_{q,r,s,t} = 1, P_{q,r,s,t} = 1 \\ 1 - \beta, if\ A_{q,r,s,t} = 1, P_{q,r,s,t=}0 \end{cases} \qquad (2)$$

The α and β in the preference weight calculation are obtained from Eq. (3) and Eq. (4).

$$\alpha = \left(\frac{\sum A_{q,r,s,t} - \sum P_{q,r,s,t}}{\sum A_{q,r,s,t}}\right) \qquad (3)$$

$$\beta = \alpha \left(\frac{\sum P_{q,r,s,t}}{\sum A_{q,r,s,t} - \sum P_{q,r,s,t}}\right) \qquad (4)$$

3) Constraints: Eq. (5) to Eq. (7) indicate how many staff are needed for each shift in the children's ward, while Eq. (8) to Eq. (10) indicate how many staff are needed for each shift in the admission ward.

Staff needed for each shift in the children's ward:

$$D_{1,t} = 8 \qquad (5)$$

$$D_{2,t} = 7 \qquad (6)$$

$$D_{3,t} = 5 \qquad (7)$$

Staff needed for each shift in the admission ward:

$$D_{1,t} = 30 \qquad (8)$$

$$D_{2,t} = 25 \qquad (9)$$

$$D_{3,t} = 25 \qquad (10)$$

Eq. (11) mandates a constraint, where each staff has one day off per week.

$$X_t = 1 \qquad (11)$$

Eq. (12) states that staff must work within minimum and maximum shift limitations specified for each week.

$$5 \leq \sum X_{q,s} \leq 6 \qquad (12)$$

Eq. (13) mandates each staff will be assigned only one work shift for each day.

$$X_q = 1 \qquad (13)$$

Eq. (14) states that each member of the nursing staff will get a day of rest or a day off, when the staff work for two to three consecutive night shifts.

$$2 \leq \sum X_{3,t} \leq 3 \qquad (14)$$

C. Integer Linear Programming

For the first dataset, this study uses an integer linear programming approach to solve the nurse scheduling problem and produce a schedule that maximizes the preferences of the hospital's nursing staff while fully satisfying their demands. An optimization technique known as "integer linear programming" combines integer variables with linear goals and equations. Integer linear programming is the study of strategies for addressing optimization problems, which can involve either maximizing or minimizing. By providing a framework model which addresses discrete decision variable optimization problems, ILP enables the effective handling of several real-world situations [12]. The objective function and constraints are defined mathematically to produce an ILP issue. An ILP issue has feasible solutions when each constraint is met. These solutions must satisfy both the integer and linear constraints. In an ILP problem, an optimal solution is both feasible and enhances the objective function [13]. The first dataset is used to apply ILP using the LPSolve IDE, which is an integer linear programming software, to produce an optimal schedule that satisfies both nurses' preferences and hospital demands.

D. Genetic Algorithm

Genetic algorithms (GA) are adept at resolving complex optimization problems, which is why scheduling problems have been extensively addressed by them. It is possible to find optimal or near-optimal scheduling solutions using a genetic algorithm. The population size, crossover rate, mutation rate, and selection strategy are some of the elements that affect a genetic algorithm's scheduling performance. These parameters must be correctly calibrated to produce the optimum outcomes. Common processes in tuning parameters include experimenting, adjusting settings, and evaluating the impact on the efficiency and caliber of schedules that are generated [14].

In a GA the process begins with the initialization phase, where a population of potential solutions, also known as chromosomes, is created with random traits. In this study, the researcher adopted integer value encoding for a weekly schedule. Subsequently, before the selection phase, the fitness of each solution is evaluated based on the weighted preference of each staff [Eq. (2)], and the fitness value is the only way to guide the selection phase in GA. Individuals with greater fitness exhibit a higher chance of becoming parents compared to those with lower fitness in the selection phase. This study adopted a tournament selection approach, where individuals compete in tournaments based on their fitness values.

Next, the crossover phase follows, where the traits of selected individuals are combined to create new solutions, mimicking genetic recombination. In this study, the 1-point crossover method is adopted, with a crossover rate of 0.82. Furthermore, the mutation phase introduces small random changes to the traits of some solutions, ensuring genetic diversity in the population. This study applied the swap mutation method, where two individuals are selected and swapped positions in the chromosomes to yield a better fittest value based on a 0.044 mutation rate. The evaluation phase then assesses the fitness of the newly formed solutions. This cycle of selection, crossover, mutation, and evaluation is repeated for several generations or until a predetermined termination criterion is met (refer Fig. 1).

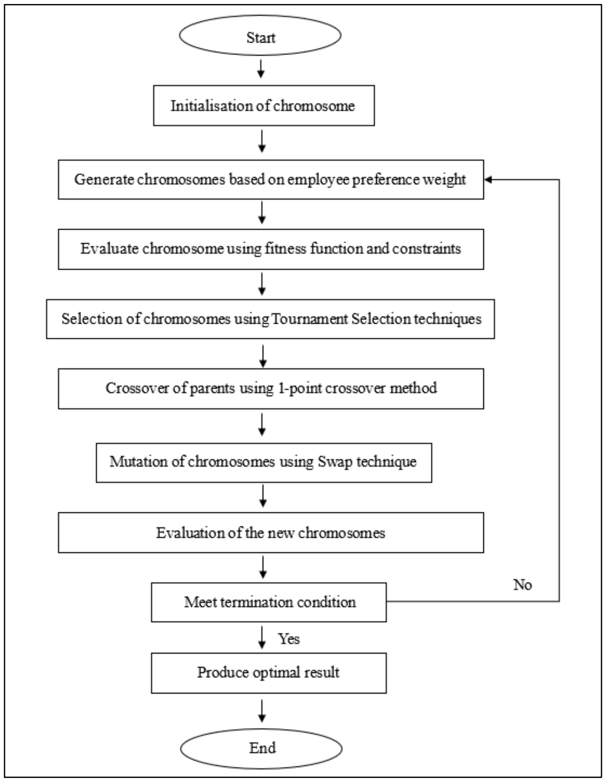

Fig. 1. Flowchart of genetic algorithm

The second dataset is used to apply GA method through the Flexible Shift Scheduling System to produce a near-optimal nursing staff's work schedule that satisfies both nurses' preferences and hospital demands. For better scheduling implementation, the Flexible Shift Scheduling System is developed based on the concept of the genetic algorithm as discussed in Fig. 1. The FSS system obtained a copyright certificate (LY2019007740) in 2019. The FSS system is built using Eclipse Java Oxygen, and the interface is set up in Visual Studio. In the interface (refer to Fig. 2), there are four selection buttons, which are "Add New Employee", "View/Edit Employee", "View/Edit Shift Demand", and "View Result". By clicking the "Add New Employee" button, the user is required to enter the name and the gender of the staff, as illustrated in Fig. 3. Following from there, the preferred shift and day off are keyed in by the user, who can recheck the details of the staff by clicking the "View/Edit Employee" button. Then, the user can edit or delete the staff details using the button "Delete" or "Edit", as shown in Fig. 4. In addition, the user inserts the demand of each shift, as illustrated in Fig. 5, by clicking the 'View/Edit Shift Demand' button. Finally, the user clicks the 'View Schedule' button, which then displays the near best or optimal solution.

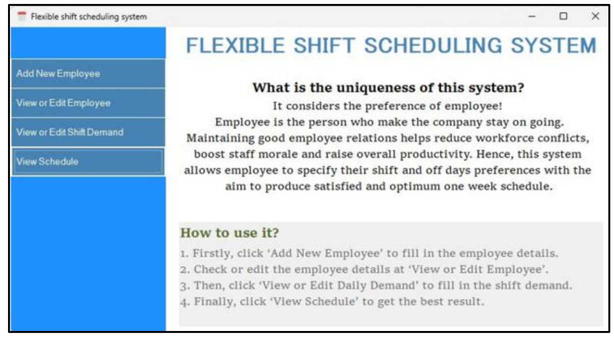

Fig. 2. Interface of Flexible Shift Schedule system.

Fig. 3. Interface to enter the staff details

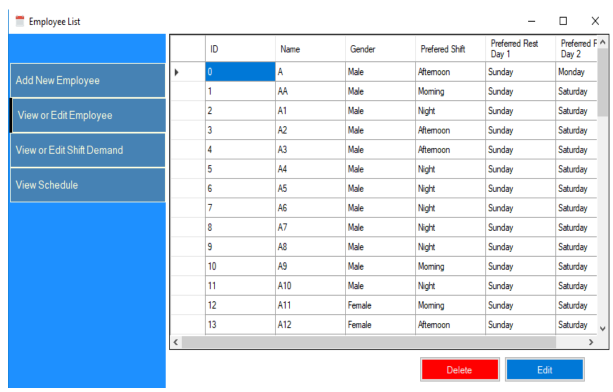

Fig. 4. Interface to edit the staff details

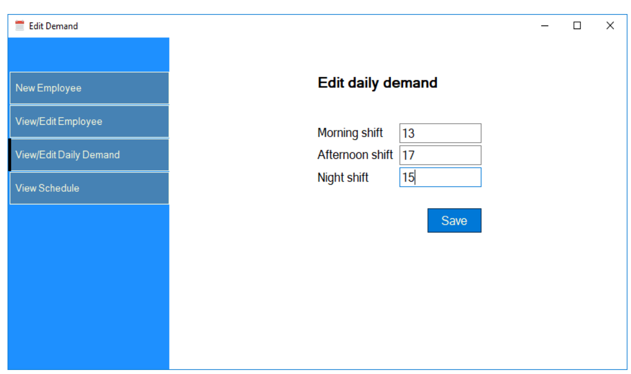

Fig. 5. Interface to enter the demand

IV. RESULT

This is the result of a nursing rostering schedule that was obtained for one week and produced using integer linear programming and genetic algorithms. The LPSolve IDE is used to implement integer linear programming, while the Flexible Shift Scheduling System is used to implement GA. This section presents a comparison between the hospital's current schedule and the schedule generated utilizing both methods.

A. Evaluation of Current One-Week Schedule for Children's Ward (Dataset 1)

The current schedule ran from August 7th to August 13th, 2023, for a total of one week, as shown in Table II. The letters "M" stands for morning shift, "A" for afternoon shift, "N" for night shift, and "OFF" for off-day.

TABLE II. CURRENT MANUALLY CONSTRUCTED SCHEDULE OF CHILDREN'S WARD FOR WEEK 1 (7TH AUGUST 2023 TO 13TH AUGUST 2023)

Staff	**Shift schedule**					**Weekly preference weight**
	7	**8**	**9**	**…**	**13**	
	Mon	**Tue**	**Wed**	**…**	**Sun**	
Staff 1	A	A	M	...	A	
Staff 2	A	OFF	A	...	M	
Staff 3	N	N	OFF	...	A	
⋮	⋮	⋮	⋮	⋮	⋮	
Staff 24	M	M	OFF	...	M	
Preference weight	23.08	21.08	26.08	...	21.08	**159.56**

A manually designed nurse schedule by the head nurse of Malaysia Specialists Centre for one week is shown in Table II. The overall weekly nurse staff preference weight, Z, is 159.56 (56.87%), as can be observed from the result. However, the hospital is still looking for improvement to figure out how to maximize nurse staff preferences by considering their demand for working shifts and days off. In addition, every staff member is granted one day off every week, as shown in Table II.

B. Proposed One-Week Schedule for Children's Ward

The integer linear programming software, LPSolve IDE, is used to produce the nursing staff's work schedule. The letter "SD" stands for the sleeping day, which the related staff should have for working two or three days of night shift continuously. A schedule can be completed more quickly, and allocating shifts to each member of staff can be done easily with the aid of LPSolve IDE. One-week results are displayed in Table III.

The manually created nurse schedule for a week by the head nurse of Malaysia Hospital, created without the use of any systematic software, is shown in Table IV. However, the real-life case study does not include a large number of nurses in one department; hence, simulated data is required to achieve the objective of this study. Based on Table IV, the preference weight, Z, of the nursing staff, is 589. Every member of staff has at least one day off every week, as Table IV demonstrates. Furthermore, as the table illustrates, each member of staff is assigned to a single shift every day, and most importantly, there is a sufficient number of staff for each shift. These are the hard constraints that need to be met to have a feasible schedule.

TABLE III. SCHEDULE FOR CHILDREN'S WARD USING LPSOLVE IDE IN A WEEK

Staff	**Shift schedule**					**Weekly preference weight**
	7	**8**	**9**	**…**	**13**	
	Mon	**Tue**	**Wed**	**…**	**Sun**	
Staff 1	OFF	N	N	...	N	
Staff 2	OFF	N	N	...	N	
Staff 3	OFF	N	N	...	N	
⋮	⋮	⋮	⋮	⋮	⋮	
Staff 24	M	M	M	...	OFF	
Preference weight	32.40	29.40	26.40	...	29.40	**205.80**

Table III shows an optimal nurse rostering schedule for a week that was created using an integer linear programming method. The preferred working shift of the nursing staff is represented by the green zone, which has been maximized to suit their demands. The blue zone represents the nursing staff's preference for days off that have been completed.

C. Evaluation of Current One-Week Schedule for Admission Ward (Dataset 2)

The manually designed weekly schedule for the hospital's admissions ward is shown in Table IV.

TABLE IV. CURRENT MANUALLY CONSTRUCTED SCHEDULE OF ADMISSION WARD FOR A WEEK (7TH AUGUST 2023 TO 13TH AUGUST 2023)

Staff	**Shift schedule**					**Weekly preference weight**
	7	**8**	**9**	···	**13**	
	Mon	**Tue**	**Wed**	···	**Sun**	
Staff 1	M	A	M	···	A	
Staff 2	OFF	M	A	···	M	
Staff 3	A	N	N		A	
⋮	⋮	⋮	⋮	⋮	⋮	
Staff 100	M	M	OFF	···	M	
Preference weight	77.00	80.00	88.00	···	94.00	**589.00**

D. Proposed One-Week Schedule for Admission Ward (Dataset 2)

The Flexible Shift Scheduling System sets the work schedule for the nursing staff. This system facilitates the process of allocating shifts to staff so that schedules can be quickly created. The weekly results are displayed in Table V.

TABLE V. WEEK 1 SCHEDULE FOR ADMISSION WARD BY USING THE FLEXIBLE SHIFT SCHEDULING SYSTEM

Staff	**Shift schedule**					**Weekly preference weight**
	7	**8**	**9**	···	**13**	
	Mon	**Tue**	**Wed**	···	**Sun**	
Staff 1	M	N	OFF	···	M	
Staff 2	A	A	A	···	A	
Staff 3	M	M	M	···	OFF	
⋮	⋮	⋮	⋮	⋮	⋮	
Staff 100	N	N	OFF	···	OFF	
Preference weight	91.60	95.60	85.60	···	79.60	**619.20**

The nearly optimal result that the genetic algorithm approach produced for one week of the second dataset is shown in Table V. According to the result, from Monday through Sunday, the proposed schedule satisfies every hard constraint as stated above for the one-week schedule of the first dataset that was obtained.

V. Discussion

A. Scheduling Comparison Between Existing Schedule and LPSolve IDE for Children's Ward (Dataset 1)

Overall, the findings showed that by utilizing the LPSolve IDE software, the preferred weight, Z for a week, could be raised by 46.24, from Z = 159.56 (56.87%) for the current schedule to Z = 205.8 (73.35%) for the proposed plan. It is possible to optimize the preference of nursing staff for shift work and days off.

TABLE VI. Comparison between Existing Schedule and LPSolve IDE-Generated Schedule for One Week

Comparison criteria	Scheduling type	
	Existing schedule	LPSolve IDE-generated schedule
Completely assigned to the preferred shift	0%	66.67%
Partially allocated to a preferred shift	83.33%	33.33%
Completely not assigned to the preferred shift	16.67%	4.17%
Completely assigned to preferred days off	12.5%	12.50%
Partially allocated to preferred days off	0%	0%
Completely not assigned to preferred days off	87.5%	87.5%
The duration needed to create the schedule	More than a day	3 hours
Total preference weight, Z	159.56	205.80

Table VI displays a comparison between the existing schedule and the proposed schedule generated by the LPSolve IDE software. It is interesting to note that the percentage of workers fully assigned to their desired shifts increased significantly from 0% to 66.67% according to the newly created shift plan. The newly designed schedule shows a significant improvement over the current timetable, which has 0% coverage. Rather than requiring a whole day, the scheduler now just needs three hours to generate the shift schedule. In just one week, the total preference weight increased significantly from 159.56 (56.87%) to 205.8 (73.35%). In conclusion, integer linear programming is a good approach to design an optimal shift schedule that uses fewer workers and computer time. Furthermore, it successfully satisfies both hard and soft constraints while optimizing staff preferences for working shifts and off days.

B. Scheduling Comparison Between Existing Schedule and Flexible Shift Scheduling System for Admission Ward (Dataset 2)

Overall, results demonstrated that the preference weight, Z, for a week could be increased by 30.2 by using the Flexible Shift Scheduling System, from Z = 589 (62.98%) for the current schedule to Z = 619.2 (66.21%) for the proposed plan. The results of the study demonstrate that the genetic algorithm approach can satisfy both soft and hard constraints. The preferences of nursing staff regarding shift work and days off can be optimized.

TABLE VII. Comparison between Existing Schedule and Flexible Shift Scheduling System Schedule for One Week

Comparison criteria	Scheduling type	
	Existing schedule	Flexible shift schedule system
Completely assigned to the preferred shift	0%	2%
Partially allocated to preferred shift	66%	61%
Completely not assigned to the preferred shift	34%	37%
Completely assigned to preferred days off	16%	24%
Partially allocated to preferred days off	0%	25%
Completely not assigned to preferred days off	84%	51%
The duration needed to create the schedule	3 days	2 m 45 s
Total preference weight, Z	589.00	619.20

The increase from 0% to 2% in the proportion of staff assigned to their chosen shifts is a noteworthy observation. The percentage of staff who fully allocated their desired days off increased from 16% to 24% in terms of off-day preferences, which is a noteworthy accomplishment. While the current schedule offers no coverage (0%) on desired days off, the proposed schedule demonstrates progress by partially allocating 25% of workers to those days. Additionally, there is a notable decline in the number of staff who are completely unallocated to their chosen days off, from 84% to 51%. The GA approach produced a near-optimal timetable of 2 minutes and 45 seconds, a significant reduction over the three workdays required for hand construction. The overall preference weight increased from 589 (62.98%) to 619.2 (66.21%) in just one week, indicating a significant improvement. The GA approach demonstrated its efficacy by producing a virtually optimal schedule with significantly less staff and computation time needed once all hard constraints had been satisfied.

VI. Conclusion

Manual scheduling used to be quite difficult and time-consuming due to the multiple requirements that had to be met. This study used an integer linear programming approach with the aid of the LPSolve IDE software for the first dataset and a genetic algorithm with the assistance of the Flexible Shift Scheduling System for the second dataset. A feasible and optimal nurse rostering schedule was produced by the findings. The objectives of this study have all been achieved. Additionally, this study makes a contribution by providing a nurse rostering schedule that takes hospital demands, work shift preferences, and off-day preferences into account. Furthermore, this research is the first to utilize integer linear programming in conjunction with a genetic algorithm to account for various sample sizes, which highlights the gap in research on scheduling problems. The limitation of this research is that it was primarily focused on the preferences of nurses, excluding the hospital cost and budget. Therefore, it is recommended to consider the daily expenses of the hospital as a significant component of future studies, which might contribute to the finance team's discoveries of optimized hospitals' profits. Also, validation of this work could be enhanced in future study to highlight the contribution of this findings into the real situation.

ACKNOWLEDGMENT

The research was supported by the Ministry of Higher Education (MOHE) through the Fundamental Research Grant Scheme (FRGS) (FRGS/1/2024/STG06/UTHM/02/4) and Universiti Tun Hussein Onn Malaysia (UTHM) through Geran Penyelidikan Pascasiswazah (GPPS) (No. Q646).

REFERENCES

[1] M. L. Pinedo, Scheduling: Theory, Algorithms, and Systems, 4th ed, Springer, 2014.

[2] D. G. Rajpathak, Intelligent scheduling - A Literature Review, KMi Technical Report Knowledge Media, 2014.

[3] S. J. Kim, Y. W. Ko, S. Uhmn, J. Kim, A Strategy to Improve Performance of Genetic Algorithm for Nurse Scheduling Problem, vol. 8, International Journal of Software Engineering and Its Applications, pp. 53-62, 2014.

[4] S. Satheeshkumar, S. Nareshkumar, and S. Kumaraghuru, Linear programming applied to nurses shifting problems for six consecutive days per week, Vol. 6, International Journal of Current Research, pp. 5862-5864, March 2014.

[5] A. Y. M. Al-Rawi, T. Mukherjee, Application of Linear Programming in Optimizing Labour Scheduling, vol. 9, Journal of Mathematical Finance, pp. 272-285, 2019.

[6] E. K. Burke, P. De Causmaecker, G. V. Berghe, H. V. Landeghem, The State of the Art of Nurse Rostering, Journal of Scheduling, vol. 7, pp. 441–499, 2004.

[7] J. J. (J. H.) Park, Y. Pan, C. Kim, Y. Yang, A Mathematical Model for Nurse Scheduling with Different Preference Ranks, Lecture Notes in Electrical Engineering, pp 11-17 January 2015.

[8] L. Cheng-Hao, W. Y. Hong, Q. J. Wei, D. W. Zhao, S. Rui, Product Service Scheduling Problem with Service Matching Based on Tabu Search Method, Journal of Advanced Transportation, vol.18, pp. 1-9, February 2020.

[9] Halfpap, Stefan, Hybrid index selection using integer linear programming based on cached cost estimates of heuristic approaches, Proceedings of the 1st Workshop on Simplicity in Management of Data (SiMoD '23). Association for Computing Machinery, 17 July 2023.

[10] U. Aickelin, K. A. Dowsland, An Indirect Genetic Algorithm for a Nurse Scheduling Problem, Computers & Operations Research, vol. 31, issue 5, pp. 761-778, April 2004.

[11] J. Xu, Improved Genetic Algorithm to Solve the Scheduling Problem of College English Courses, vol. 3, pp. 1-11, June 2021.

[12] N. Mahmud, S. H. Jamaluddin, I. S. Hamidun, N. S. M. Pazil, Optimization of Workforce Scheduling using Integer Goal Programming Approach, Jurnal Intelek, vol. 13, issue 2, pp. 27-36, 2018.

[13] Optimization of Staff Schedule in Production Factory. Universiti Tun Hussein Onn Malaysia: Undergraduate's Project Report. Unpublished.

[14] D. Thilak, L. Devi, C. Shanmuganathan, K. Kalaiselvi, Meta-heuristic Algorithms to Optimize Two-Stage Task Scheduling in the Cloud, SN Computer Science, October 2023.