TECHNICAL REPORT

STAFF SCHEDULING FOR A LIBRARY AT A LOCAL UNIVERSITY USING BINARY INTEGER PROGRAMMING

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UNIVERSITI TEKNOLOGI MARA

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The staff scheduling process at a local university library was plagued by inefficiencies, including workload imbalances and operational challenges. In order to tackle these issues, this research project was dedicated to developing an automated scheduling system with the primary objective of optimizing staff allocation and workload distribution. The approach involved extensive data collection on number of staff, shifts and working hours, followed by the modification of a binary integer programming model tailored to library staff scheduling requirements. The system utilizes Excel Solver to generate optimized schedules. The outcomes demonstrated the efficacy of the automated solution, as it generated schedules that satisfy all model's constraints. This research project successfully achieves its objective of developing an automated scheduling system that significantly enhances efficiency and operational effectiveness in library staff scheduling. By replacing manual processes with automation, libraries can save time, improve resource utilization, and ensure optimal staffing levels, ultimately providing better services to library users.

1. INTRODUCTION

According to Afwan Mohamad et al. (2021) scheduling is a process allocating a resource to a specific process. A scheduling mathematical model is a formal representation of a scheduling problem, which can be used to compute optimal or near-optimal solutions. There are many different types of scheduling models, including linear and integer programming models, constraint programming models, and heuristic models. Common uses for scheduling mathematical models include workforce scheduling, transportation scheduling and machine scheduling.

Workforce scheduling refers to the process of organizing and planning the work schedule of employees in a company or organization. This can include determining when employees will work, assigning shifts, and ensuring that there are enough staff members scheduled to meet the demands of the business. Transportation scheduling, on the other hand, focuses on allocating jobs to available transport vehicles and determining optimal routes and stops to meet specific due dates (Ehm et al., 2016). This can include creating schedules for routes and stops, as well as determining the most efficient use of vehicles and drivers. Machine scheduling involves managing the allocation and utilization of industrial machines, such as production lines, manufacturing equipment, and robotics. The primary objective is to optimize machine utilization, increase productivity, minimize downtime, and reduce costs. Mathematical models using optimization techniques like linear programming, mixed-integer programming, or constraint programming can be formulated to address machine scheduling problems. The specific model chosen depends on the problem characteristics and the desired level of complexity.

As we only focus on workforce scheduling, it is also a well-known problem that appears in a wide range of different areas including health care, air lines, transportation services, and basically any organization that has to deal with workforces. The workforce scheduling problem (WSP) is a well-known decisional problem that refers to the assignment of workers to specific workstations or tasks (Rinaldi et al., 2022). Ultimately, the goal of scheduling a workforce is to ensure that there are enough employees on hand to meet the needs of the business, while also minimizing labor costs and ensuring that employees are fairly compensated for their time.

Numerous studies have been done with implementation of various mathematical models approaches. The most used mathematical models in scheduling are Linear Programming (LP), Mixed-Integer Linear Programming (MILP), and Integer Programming (IP). Working on LP models, Garaix et al. (2018) and Hochdörffer et al. (2018) include workers' work life balance in their objectives. Garaix et al. (2018) construct an algorithm to minimize the number of employees needed to cover a set of shifts while ensuring that all shifts are covered while Hochdörffer et al. (2018) tend to a planning system which generates job rotation schedules taking into consideration workers' qualifications.

Other than that, (Guo & Bard, 2022) used MILP to deploy the weighted sum method to minimize the uncovered demand and staff preference violations. The weighted sum method involves assigning weights to different 10 objectives and then combining them into a single objective function. This approach can be useful for scheduling problems that have multiple objectives and constraints. MILP can handle both continuous and integer variables and can optimize the problem with multiple objectives and constraints.

Apart from that, Rahimian et al. (2017) proposed a hybrid algorithm that combines Integer Programming (IP) and Constraint Programming (CP) to efficiently solve the Nurse Rostering Problem. The algorithm aims to exploit the strength of IP in obtaining lower-bounds and finding an optimal solution with the capability of CP in finding feasible solutions in a cooperative manner. For the Goal Programming (GP) model, Mohd Nasir et al. (2021) propose a cyclical nurse scheduling in the Coronary Care Unit (CCU) at Shah Alam hospital. The main objective of the model was to minimize the total payroll costs while ensuring that patients were satisfied with the level of care provided. The results showed that the GP model was able to produce schedules that were more cost-effective and fairer for the nurses compared to the current manual scheduling system.

Besides that, Alwadood et al. (2021) proposed a Binary Integer Programming (BIP) model for hotel housekeeping personnel scheduling during the pandemic. Their objective was to modify the BIP model to obtain the optimal number of staff for each shift in each housekeeping section for each day. The research demonstrated that the suggested mathematical model could effectively reduce the workforce size during the pandemic, indicating the potential benefits of using mathematical models in staff scheduling.

In the context of library operations, scheduling library staff plays a vital role in providing quality services to users and supporting the academic and research goals of universities. However, the current practice of manually generating schedules for library staff using Excel has several drawbacks. It is time-consuming, prone to errors, and challenging to modify when needed. Therefore, there is a clear need for a more efficient and effective solution for scheduling library staff. Despite the importance of scheduling library staff, there is a lack of research specifically focused on this area. While previous studies have addressed scheduling in various industries, such as scheduling for lecturer shifts and emergency services, not all of these studies may directly address the unique requirements of scheduling library staff. However, the concepts and techniques used in scheduling research can be adapted and applied to the specific problem of scheduling library staff.

To address these challenges, this project aims to develop and implement an automated scheduling system for library staff at a local university. The objectives of the study are to identify important components, such as the number of staff, number of shifts, and number of working days, in producing work schedules for library staff, to modify a binary integer programming model for scheduling library staff at the local university and to obtain an optimal schedule for the library staff. By achieving these goals, in turn, can help to increase the efficiency and accuracy of library staff scheduling. Additionally, it can save significant time for library managers and other staff members responsible for scheduling by quickly and easily collecting data on staff availability, skills, and preferences, compared to manual methods of collecting information. Furthermore, automating the scheduling process can improve staff satisfaction, ensure optimal staffing levels, and provide better and more efficient services to the community that relies on library services. The utilization of these novel approaches can help in reducing scheduling errors, improving overall efficiency, and ensuring optimal allocation of staff to meet the specific demands of library operations. Additionally, the implementation of an automated scheduling system brings various benefits, including time savings, improved resource utilization, and increased staff satisfaction.

2. METHODOLOGY

This section discusses the research flow of the study. It is split into three phases which are background study of the area, model development and obtaining solution.

Phase I: Background study

a) Conducting literature review

The initial phase involved conducting a comprehensive literature review within the field, focusing on key research areas and topics pertinent to our study. This encompassed identifying and exploring subjects such as mathematical modeling, automated scheduling systems, and best practices related to library staff scheduling. To gather relevant and reliable information, various databases, including JSTOR, Google Scholar, and others, were extensively searched for scholarly articles, books, and other credible sources.

b) Data acquisition.

Data acquisition played a crucial role in our staff scheduling methodology. Gathering relevant data was an essential step in understanding and addressing the needs of the library. This involved collecting information on various aspects, such as the number of staff, number of staff members, their working hours, and the number of shifts.

By acquiring this data, we were able to develop a comprehensive understanding of the staff scheduling requirements. This information served as the foundation for creating a mathematical model that could effectively generate schedules while considering all relevant factors. Furthermore, the data acquisition process involved gathering information about the current scheduling process in place. This included identifying any challenges or issues that required attention. By understanding the existing scheduling process, we were able to identify areas for improvement and guide the development of an automated scheduling system.

Phase II: Model development

a) Model references

A mathematical model developed by Alwadood et al. (2021) was utilized as a reference model that closely resembled our scenario. The model was adopted and modified to suit the specific characteristics and requirements of our library staff scheduling workforce.

With the reference model as a guide, necessary adjustments have been made to account for the distinct features of library staff scheduling. Libraries operate within certain constraints and factors such as the number of staff, operating hours and working days. Therefore, the model is modified accordingly to capture these key considerations and deliver a more accurate representation of the scheduling process. The adapted model helped us to analyze and optimize different aspects of library staff scheduling. By utilizing mathematical techniques and algorithms, we were able to generate schedules that met the requirements of the library's operations.

Therefore, the utilization of the reference model developed by (Alwadood et al., 2021) provided a solid foundation for our own model development. By adopting and modifying their model, we were able to accommodate the characteristics of our library staff scheduling workforce and create a tailored solution that addressed our specific requirements effectively.

b) Model modifications

The model development process for scheduling library staff using a reference model involved adapting an existing model to meet the specific requirements of the library. The modifications were based on the data that was collected from the librarian at the local university, providing valuable insights into the unique constraints and requirements of the library. Based on the collected data, the model was systematically modified to accommodate the specific needs of the library. This included incorporating factors such as staff availability, shift patterns, days off, and other relevant constraints that were identified during the data collection process.

The purpose of these modifications was to ensure that the model accurately reflected the staffing requirements of the library. By customizing the model to the specific constraints and requirements, it became a more reliable tool for generating optimized staff schedules that met the library's needs. The modifications allowed for a more efficient allocation of resources, optimized shift assignments, and improved coverage during peak times. As a result, the model underwent successful modifications by incorporating the data provided by the librarian at the local university. These modifications resulted in a model that was specifically tailored to meet the unique constraints and requirements of the library. As a result, the staff schedules generated by the modified model became more accurate and effective. The adjustments made to the model also facilitated better resource allocation, leading to improved operational efficiency and enhanced service levels for both the library staff and patrons.

Phase III: Solution approach

The modified model will be solved using the exact method which is branch-and-cut. The branch-and-cut method is particularly suited for solving mathematical models as it aims to find the exact optimal solution to a given problem. It achieves this by systematically exploring the solution space and eliminating suboptimal solutions. Branch-and-cut is considered a powerful optimization method due to its ability to find the best possible solution. The branch-and-cut method is very successful and efficient for solving a variety of integer programming problems while still providing a guarantee of optimality (Castrignanò et al., 2020). However, it is important to note that this method can be computationally expensive, especially when dealing with large and complex scheduling models. It may require substantial computational resources to ensure an accurate and efficient solution.

To solve the modified model, we utilized Excel solver, a widely used tool in optimization and mathematical modeling. Excel solver provides a user-friendly interface for implementing the branch and cut method and obtaining the optimal solution for the given scheduling problem. It offers a range of features and functionalities to facilitate the optimization process and streamline the analysis. Once the optimal solution is obtained, we proceeded to analyze and review the results. This step involves examining the scheduling outcomes and evaluating their effectiveness and feasibility within the context of the library staff scheduling. By assessing the obtained solution, we can identify any potential issues or constraints that need to be addressed.

Based on the findings from the analysis, appropriate adjustments and conditions will be made to further refine the scheduling model. These modifications may include altering parameters, constraints, or decision variables to optimize the scheduling process and enhance its performance. The overall research process, from problem formulation to solution analysis and adjustment, can be summarized in a flowchart, as depicted in Figure 1.

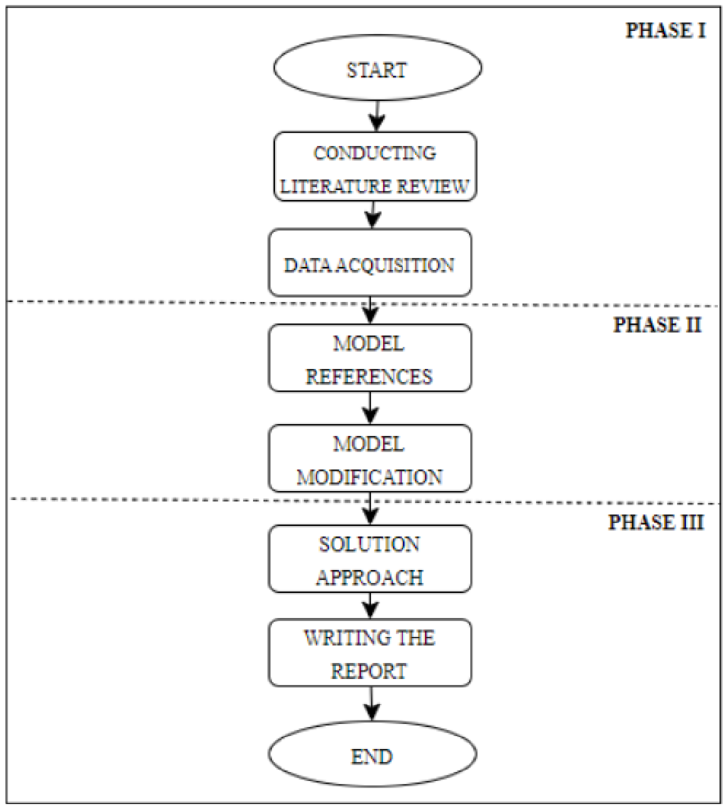

Figure 1 The Flowchart of Methodology

3. IMPLEMENTATION

Phase I: Data Collection

During the preliminary interview with the person in charge, it was revealed that the library operates every day except for public holidays. Out of the three available services, our focus is towards the customer service counter. To facilitate the smooth operation of the customer service counter, a team of six staff members has been designated. These staff members follow a rotating schedule on a weekly basis, allowing for fair distribution of workload and providing opportunities for each staff member to gain experience across different shifts and days.

The library staff who work at the customer service counter are organized into three different shifts to ensure coverage throughout the day. These shifts are carefully structured to accommodate the library's operational hours and cater to the needs of its patrons. Morning shift is from 8 am to 12 pm. The afternoon shift begins at 12 pm and continues until 5 pm. Lastly, the evening shift starts at 5 pm and concludes at 10 pm, encompassing the library's evening hour. However, it is important to note that on weekends rather than maintaining three separate shifts, it operates with a single shift that spans from 8 am to 5 pm. This adjustment allows the library to provide continuous service to its patrons while optimizing staffing resources during the weekend period. By employing this shift arrangement, the library ensures that trained staff members are available throughout the day. Whether it's during the morning, afternoon, or evening hours, the staff are dedicated to delivering excellent service and creating a welcoming environment for library users.

Table 1 below explains the work schedule for library staff who work on customer service counters for the first three weeks of January 2023 from 1/1/2023 to 22/1/2023. It includes information such as staff’s number, working days and shift timings. This table provides a clear overview of the schedule for each staff member during these specific weeks. From Table 1, Staff 1 work schedule is on week 1, from Tuesday until Friday during the morning shift, with working hours from 8 am to 12 pm.

Table 1 Current 3 Weeks Schedule for Library Staff

STAFF NUMBER	WEEK 1																	WEEK 2																	WEEK 3																
	M			T			W			T			F			S	S	M			T			W			T			F			S	S	M			T			W			T			F			S	S
	M	A	E	M	A	E	M	A	E	M	A	E	M	A	E	M	M	M	A	E	M	A	E	M	A	E	M	A	E	M	A	E	M	M	M	A	E	M	A	E	M	A	E	M	A	E	M	A	E	M	M
1	NEW YEAR PUBLIC HOLIDAY			√			√			√			√				√		√			√			√			√			√		√				√			√			√			√			√		CHINESE NEW YEAR
2				√			√			√			√			√			√			√			√			√			√			√			√			√			√			√			√		
3					√			√			√			√		√				√			√			√			√			√			√			√			√			√			√			√	
4					√			√			√			√			√			√			√			√			√			√			√			√			√			√			√				
5						√			√			√			√			√			√			√			√			√				√		√			√			√			√			√			
6						√			√			√			√			√			√			√			√			√			√			√			√			√			√			√		√	

Phase II: Modified model

Phase II focused on modifying the scheduling model to incorporate specific constraints identified as important for the library staff schedule. These constraints were designed to address various operational requirements and considerations. By incorporating the insights and methodologies from Alwadood et al. 's model from 2021, the framework can be adapted and tailored to meet the specific requirements of library staff scheduling. Necessary modifications were made to account for factors such as the number of staff, shift patterns, days off, and other relevant constraints that are specific to our project.

The model sets refer to the set of data that will be used in the process of developing the mathematical model. The set *i* indicates the number of staff where *i* = 1, 2, …,6 is the index of staff who work at the counter service. The subscript *j* represents the working shifts available throughout the week. During weekdays, there are three shifts available to accommodate the operational needs of the library. The morning shift is denoted by *j* = 1, the afternoon shift by *j* =2, and the evening shift by *j* = 3. This allows for a flexible scheduling arrangement that covers different periods of the day and caters to the varying levels of library activity. However, on weekends, the staffing requirements may differ, and as a result, there is only one shift available. This is reflected in the model by setting *j* = 1 for Saturday and Sunday, indicating the single shift available on those days. On top of that, the index *k* =1 represents Monday and *k* = 7 represents Sunday.

The model decision variable that best represents the solution to the model is the binary variable, denoted as x_{ijk}. The decision variable value 1 indicates the staff *i* works on shift *j* on day *k*. On the contrary, the value 0 indicates otherwise. Therefore, the decision variable for the model is denoted by:

$$x_{ijk} = \begin{cases} 1, \text{ staff } i \text{ works on shift } j \text{ on day } k \\ 0, \text{ otherwise} \end{cases}$$

The full modified BIP model for the staff scheduling is stated as:

$$\text{Minimize staff, Z} = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} x_{ijk} \tag{1}$$

Subject to

$$\sum_{j=1}^{3} x_{ijk} \leq 1 \qquad \forall i, k \tag{2}$$

$$\sum_{i=1}^{6} x_{ijk} \leq 2 \qquad \forall j, k \tag{3}$$

$$\sum_{i=1}^{i} \sum_{j=1}^{j} \sum_{k=1}^{k} x_{ijk} \geq 30 \qquad \forall i, j, k \tag{4}$$

$$x_{i35} + x_{i16} + x_{i17} = 1 \qquad \forall i \tag{5}$$

$$\sum_{i=1}^{6} x_{i1k} \leq 2 \qquad \forall i \quad \text{for } k = 6, 7 \tag{6}$$

The objective function (1) intends to minimize the count of staff members assigned to a single shift within a day. By minimizing this number, the model seeks to optimize staff utilization and workload distribution, ensuring that staff members are not overburdened with excessive work hours. Constraints (2) enforce the rule that each staff member can only be assigned to one shift per day. It helps to maintain a fair and balanced workload distribution among the staff members, preventing any individual from being overloaded with multiple shifts in a single day. Constraint (3) outlines a specific requirement whereby the counter can accommodate a maximum of two staff members per shift. It ensures sufficient staffing levels to handle the customer service demands and operational needs during each shift, promoting efficient service delivery and avoiding staff shortages. Constraint (4) ensures that a minimum of 30 shifts are scheduled specifically for weekdays. By setting a minimum of 30 shifts, the scheduling model ensures that there is an adequate number of staff available to handle the workload and provide quality service to library patrons throughout the weekdays.

While the scheduling model includes 3 constraints for weekdays, there are 2 additional constraints specifically designed to cater to the scheduling needs for weekends. Constraint (5) ensures that staff members who have worked the night shift on Friday are given time off during the weekend. It recognizes the importance of providing sufficient rest and recovery time for staff members after working during the night. By implementing this constraint, the scheduling model acknowledges the need to avoid consecutive shifts that may adversely affect staff performance and well-being. On top of that, constraint (6) ensures that there is a maximum of two staff members assigned to work on one shift during weekends.

Constraint (2): $\sum_{j=1}^{3} x_{ijk} \leq 1$ $\forall i, k$

For *i* =1, *k* =1

$$x_{111}, x_{121}, x_{131} \leq 1$$

Constraint 2 shows that each staff only works on 1 shift per day. For example, on Monday staff 1 can only work for 1 shift on the counter.

Similarly, for different combinations of *i* and *k*, the constraints will be expanded accordingly. For instance, when *i* = 1 and *k* = 2, the constraint will be $x_{112}, x_{122}, x_{132} \leq 1$ representing the assignment of staff 1 to shifts 1 on Tuesday. For a complete overview of how the constraints are expanded for all combinations of *i* = 1, *k* = 2 to *i* = 6, *k* = 6, it can be referred to the appendix section of the project, where additional samples and explanations are provided.

Constraint (3): $\sum_{i=1}^{6} x_{ijk} \leq 2$ $\forall j, k$

For *j* =1, *k* =1

$$x_{111}, x_{211}, x_{311}, x_{411}, x_{511}, x_{611} \leq 2$$

Constraint 3 shows the number of staff that can work on the counter for each shift is 2. For example, only 2 staff will be assigned to work on the counter for the morning shift on Monday.

For different combinations of j and k, the constraints will be expanded accordingly. For example, when *j* = 1 and *k* = 2, the constraint will be $x_{112}, x_{212}, x_{312}, x_{412}, x_{512}, x_{612} \leq 2$ representing there are a maximum of 2 staff members that can be assigned to the counter for the afternoon shift on Monday. Further illustrations of the constraints for various combinations of j and k, specifically ranging from *j* = 1, *k* = 2 to *j* = 3, *k* = 5, can be found in the appendix section of the project.

Constraint (4): $\sum_{i=1}^{i}\sum_{j=1}^{j}\sum_{k=1}^{k} x_{ijk} \geq 30 \quad \forall i,j,k$

$x_{111}, x_{211}, x_{311}, \ldots, x_{633}, x_{634}, x_{635} \geq 30$

Constraint 4 shows the total number of working staff for 3 shifts on weekdays is at least 30.

Constraint (5): $x_{i35} + x_{i16} + x_{i17} = 1 \quad \forall i$

For *i* = 1

$$x_{135} + x_{116} + x_{117} = 1$$

Constraint 5 shows that if the staff work at night shift on Friday, as a reward, they will be off duty on weekends.

The constraint is expanded for different combinations of i. For example, for *i* = 2, the expanded constraint would be $x_{235} + x_{216} + x_{217} = 1$. Additional samples and expansions for *i* = 2 to *i* = 6 can be found in the appendix section of the project, providing a detailed explanation of how the constraints are expanded for each specific staff member.

Constraint (6): $\sum_{i=1}^{6} x_{i1k} \leq 2 \quad \forall i$ for *k* = 6, 7

For *k* =6

$$x_{116}, x_{216}, x_{316}, x_{416}, x_{516}, x_{616} \leq 2$$

Constraint 6 shows the number of staff who work on weekends is at most 2 people.

Similarly, when k = 7, the same constraint applies, restricting the number of staff members working on Sunday to a maximum of 2. The variables are $x_{117}, x_{217}, x_{317}, x_{417}, x_{517}, x_{617} \leq 2$.

Phase III: Obtaining solution

An efficient solution for scheduling library staff was achieved using Excel Solver. The utilization of Excel Solver enabled the optimization problems to be solved and the optimal solution to be found, which met the specified constraints and objectives. By incorporating constraints, an optimized schedule that fulfilled the requirements of the library was created. To utilize Excel Solver, an Excel spreadsheet of library staff schedules was set up with the necessary data and variables. This included information such as staff availability, shift requirements, and other relevant factors. Decision variables representing the staff assignments for each shift and day were defined, and a binary value of 1 or 0 was assigned to indicate whether a staff member was scheduled for a particular shift or not.

By defining the necessary components and utilizing Excel Solver, an optimized schedule was generated for library staff, meeting the specified constraints and minimizing the number of staff working on one shift per day. The utilization of Excel Solver streamlined the scheduling process and ensured an efficient allocation of staff resources to meet the operational needs of the library.

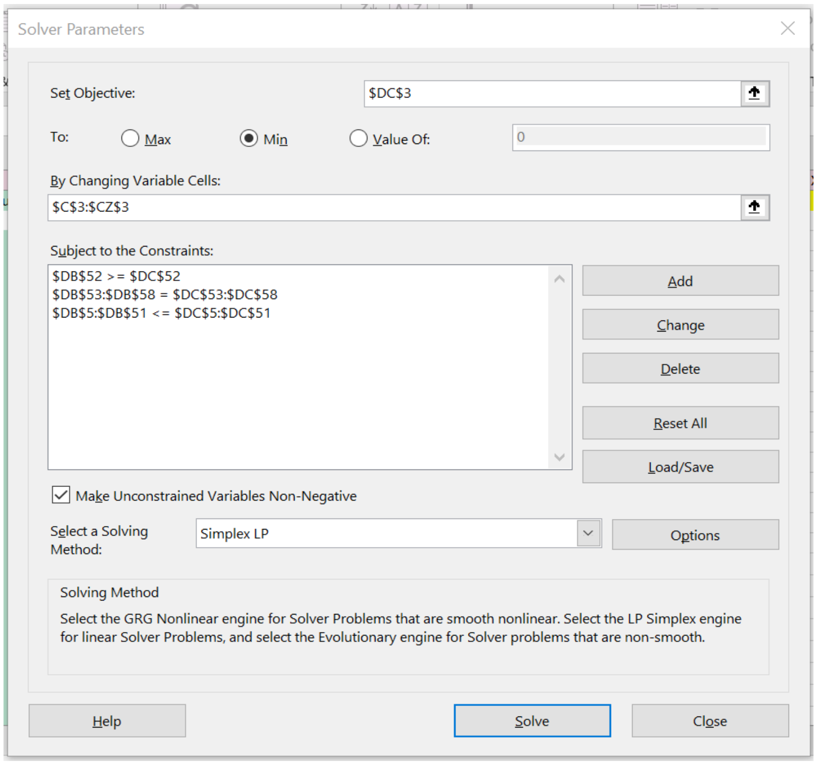

Figure 2 Windows for excel solver

Figure 2 shows the windows pop-up for excel solver. The value that was keyed in the Figure 2 was linked with the content on Table 2.

Table 2 showcases how Excel Solver can be utilized to schedule staff members based on specific constraints and ultimately obtain the optimum solution. To set up the spreadsheet in Excel, each cell representing a staff assignment was assigned a decision variable. These decision variables were binary, with a value of 1 indicating that the staff member was assigned to the shift, and a value of 0 indicating that the staff member was not assigned to the shift.

In this scenario, the coefficient variance was set as 1. The goal was to minimize the count of staff members assigned to a single shift within a day. Constraints were then applied to ensure the scheduling requirements were met. For instance, for constraint (2), each staff member could only work on one shift per day. This constraint was enforced by allowing a maximum value of 1 for the sum of decision variables per staff member per day. Another constraint (3) specified the maximum number of staff members allowed to work on the counter for each shift. It was implemented by limiting the sum of decision variables for each shift to a maximum value of 2. Constraint (4) limited the number of staff members working on weekends to a maximum of 2. The sum of decision variables for the weekends was set to be less than or equal to 2. Constraint (5) ensured a minimum number of staff members scheduled across the three shifts on weekdays. The sum of decision variables across the three shifts on weekdays was set to be greater than or equal to 30. Constraint (6) indicated that if a staff member worked the night shift on Friday, they would be off duty on weekends. This constraint was implemented by setting the decision variables for the weekends to 0 if the decision variable for the Friday night shift was 1.

The cell references in Excel Solver were obtained by using the sumproduct formula, which multiplied the binary decision variable values (1 or 0) with the corresponding coefficients representing the staff assignments. For instance, the cell reference value for the case where $i = 1$ and $k = 1$ was obtained by employing the formula SUMPRODUCT($C$3:$CZ$3*C5:CZ5). This formula involved multiplying the corresponding elements in the arrays $C$3:$CZ$3 and C5:CZ5 and then summing up the products. The range $C$3:$CZ$3 represented the optimum values for the specified constraints, while the range C5:CZ5 represented the constraint values for the staff assignments. By applying the SUMPRODUCT formula to these ranges, the cell reference value for $i = 1$ and $k = 1$ was determined. The formula took into account the specific constraints and optimum values for the staff scheduling problem, providing a cell reference value that met the desired criteria.

To sum up, Excel Solver effectively solved the staff scheduling problem by adjusting binary decision variable values and satisfying the set constraints. By setting up the spreadsheet with decision variables, the objective function to minimize the count of staff members assigned to a single shift, and the constraints, Excel Solver determined the optimum value and corresponding cell references, leading to an optimal staff scheduling solution based on the constraints for weekdays and weekends.

Table 2 Library Staff Schedule with Specified Constraints

		x_{111}	x_{112}	x_{113}	…	…	x_{633}	x_{634}	x_{635}			
	Objective Function Value	1	1	1	…	…	1	1	1			
	Optimum Value	0	0	0	…	…	0	0	0			34
										Cell Reference		Constraint
Constraint (2)	i = 1, k = 1	1	0	0	…	…	0	0	0	1	≤	1
	i = 1, k = 2	0	1	0	…	…	0	0	0	1	≤	1
	i = 1, k = 3	0	0	1	…	…	0	0	0	1	≤	1
	…	…	…	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…	…	…
	i = 6, k = 3	0	0	0	…	…	1	0	0	1	≤	1
	i = 6, k = 4	0	0	0	…	…	0	1	0	1	≤	1
	i = 6, k = 5	0	0	0	…	…	0	0	1	1	≤	1
Constraint (3)	j = 1, k = 1	1	0	0	…	…	0	0	0	2	≤	2
	j = 1, k = 2	0	1	0	…	…	0	0	0	2	≤	2
	j = 1, k = 3	0	0	1	…	…	0	0	0	2	≤	2
	…	…	…	…	…	…	…	…	…	…	…	…
	…	…	…	…	…	…	…	…	…	…	…	…
	j = 3, k = 3	0	0	0	…	…	1	0	0	2	≤	2
	j = 3, k = 4	0	0	0	…	…	0	1	0	2	≤	2
	j = 3, k = 5	0	0	0	…	…	0	0	1	2	≤	2
Constraint (4)	j = 1, k = 6	0	0	0	…	…	0	0	0	0	≤	2
	j = 1, k = 7	0	0	0	…	…	0	0	0	0	≤	2
Constraint (5)		1	1	1	…	…	1	1	1	30	≥	30
Constraint (6)	i = 1	0	0	0	…	…	0	0	0	1	=	1
	i = 2	0	0	0	…	…	0	0	0	1	=	1
	i = 3	0	0	0	…	…	0	0	0	1	=	1
	i = 4	0	0	0	…	…	0	0	0	1	=	1
	i = 5	0	0	0	…	…	0	0	0	1	=	1
	i = 6	0	0	0	…	…	0	0	1	1	=	1

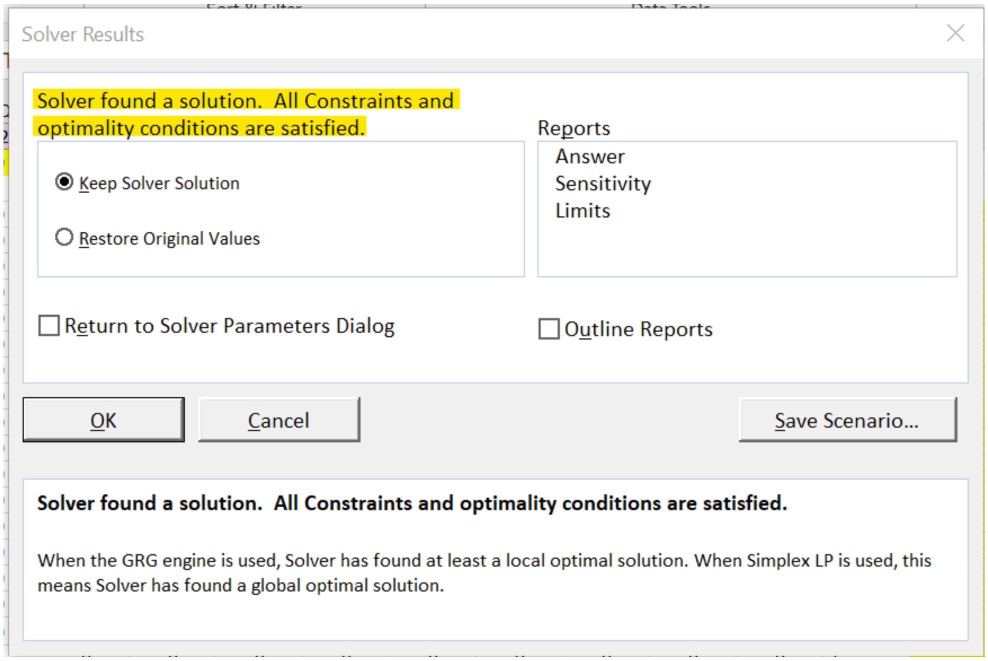

Figure 3 Windows for Excel Solver Results

Figure 3 shows the pop-up windows where the solver has found the optimum solution. The resulting schedule reflects a balanced allocation of staff members, meeting operational needs and enhancing the overall efficiency and effectiveness of the library's operations.

Ultimately, based on Figure 2 and 3, the scheduling problem is solved within the defined limitations. Solver takes these constraints into account while optimizing the objective function, ensuring that the generated staff schedule adheres to the specified requirements. The constraints ensure that staff members are assigned to suitable shifts, the counter has the appropriate number of staff members, and there is an adequate workforce available for the weekdays' shifts.

4. RESULTS AND DISCUSSION

After utilizing Excel Solver, an optimized schedule that meets specified constraints and objectives is obtained. The obtained schedule reflects the optimal allocation of staff members to shifts and days, taking into account the objective function and constraints. Each staff member is assigned to only one shift per day, ensuring a clear and well-defined schedule without any overlaps or conflicts. This avoids confusion and allows staff members to focus on their designated tasks.

The schedule ensures that the number of staff members working at the counter for each shift is precisely 2, as specified by the constraints. This guarantees effective customer service, as there are always sufficient staff members available to assist library patrons and handle their inquiries. Additionally, the optimized schedule guarantees that the total number of working staff scheduled for the three shifts on weekdays meets the requirement of at least 30 staff members. This prevents understaffing issues and ensures that the library operates smoothly, even during busy periods or in the face of unexpected absences.

Table 3 provides a comprehensive overview of how the staff scheduling model successfully meets the library's requirements. It demonstrates the careful allocation of staff members to ensure optimal coverage, adherence to shift limits, and consideration of weekend staffing constraints. By effectively managing and fulfilling these requirements, the library can maintain a well-balanced and efficient workforce. The table showcases that each staff member adheres to the stipulated guideline of working only one shift per day. This ensures fairness and prevents staff members from being overburdened. Additionally, the maximum allocation of two staff members at the counter for each shift helps maintain a manageable and productive environment. The scheduling model takes into account the demands of weekday operations by scheduling a minimum of 30 staff members across the three shifts. This ensures sufficient coverage and allows for smooth library operations during the weekdays when patron traffic is typically higher.

Acknowledging the dedication and commitment of staff members, the model rewards those who undertake night shifts on Fridays by granting them the entire weekend off duty. This recognition incentivizes staff members to take on challenging shifts and promotes a positive work environment. During weekends, the model restricts the number of staff members assigned to the counter to a maximum of two individuals. This limitation aims to maintain a balanced workforce while considering the specific demands of weekend operations. By optimizing staff allocation during weekends, the library can effectively serve patrons while ensuring efficient resource utilization.

The visual representation of these requirements in Table 3 provides a clear understanding of how the scheduling model effectively manages and fulfills the library's staffing needs. It highlights the model's ability to create a well-structured and balanced schedule that maximizes staff productivity and ensures high-quality service delivery. Ultimately, the staff scheduling model showcased in Table 3 successfully meets the library's requirements by adhering to guidelines such as single-shift per day, limited counter allocation, sufficient weekday coverage, and weekend limitations. This model optimizes staff allocation, recognizes staff members' dedication, and promotes an efficient and productive work environment. By implementing this scheduling model, the library can effectively manage its staffing resources and provide exceptional service to its patrons.

Table 3 Optimized Library Staff Schedule

STAFF NUMBER	**WEEK**																
	MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY	SUNDAY
	M	A	E	M	A	E	M	A	E	M	A	E	M	A	E	M	M
1			✓			✓			✓			✓		✓		✓	
2		✓			✓			✓				✓			✓		
3		✓			✓			✓			✓			✓			✓
4	✓			✓			✓				✓		✓				✓
5	✓			✓			✓			✓			✓			✓	
6			✓			✓			✓	✓					✓		

M: Morning shift, A: Afternoon shift, E: Evening shift

The detailed schedule provided in Table 3 offers a comprehensive overview of the assigned shifts for each staff member throughout the week. Taking Staff 1 as an example, staff 1 is responsible for the evening shift from Monday to Thursday, providing support during the crucial hours of the library's operation. On Fridays, they are assigned to the afternoon shift, accommodating the shifting demands of patrons during the day. Additionally, Staff 1 plays an essential role in weekend operations by diligently fulfilling their duties on Saturdays, specifically during the weekend shifts.

The allocation of shifts for Staff 1 exemplifies the careful consideration given to meeting the library's requirements. By strategically assigning staff members to different shifts, the library ensures adequate coverage during various time slots, effectively managing its operations. This approach allows the library to cater to the diverse needs of its patrons throughout the week, including weekends when visitor patterns may differ. By distributing staff members strategically, the library can optimize its resources and provide excellent service to its users.

It is important to emphasize that the example of Staff 1 is indicative of the overall scheduling approach for all staff members. Each staff member's schedule is designed to align with the library's requirements, ensuring that there is sufficient coverage and efficient utilization of staff resources. Through this well-coordinated scheduling process, the library can effectively manage its operations and deliver quality services to its patrons.

5. CONCLUSION AND RECOMMENDATION

This research project aimed to develop and implement an automated scheduling system for library staff at a local university. The objectives of the study were successfully addressed, resulting in the identification of important components for staff scheduling, modification of a binary integer programming model to generate the optimal schedule. The findings and implementation of the automated scheduling system have significant implications for increasing efficiency, accuracy, and effectiveness in library staff scheduling. The results of the research highlight the key components that contribute to an optimized staff schedule, including the number of staff members, the number of shifts, and the number of working days. By considering these factors, the automated scheduling system can generate schedules that meet the specific demands of library operations, ensure sufficient coverage, and prevent understaffing issues. This leads to improved customer service and smoother library operations. Furthermore, the automated system enhances staff satisfaction by taking into account individual preferences and skills when assigning shifts. By considering staff preferences, the system creates a fair and balanced schedule, preventing overburdening of staff members and promoting a positive work environment. Additionally, the system rewards staff members who undertake challenging shifts by granting them time off, which incentivizes their commitment and dedication.

Based on the results and discussions of this research project, a schedule that avoids assigning staff members to back-to-back shifts was implemented specifically for weekends. However, it is recommended to further enhance the scheduling system by implementing a similar approach for weekdays as well. By implementing a schedule that ensures an adequate break between shifts, the library can prioritize the health and work-life balance of its employees, leading to improved productivity and overall satisfaction. To address this issue, the scheduling system should be modified to include specific constraints that prevent the assignment of back-to-back shifts, particularly when a night shift is followed by a morning shift. The system can be programmed to calculate the minimum interval required between the end of one shift and the start of the next, taking into consideration the necessary time for rest, recovery, and commute. By enforcing these constraints, the system can generate schedules that distribute shifts in a manner that allows staff members to have sufficient time to recuperate and prepare for their next shift.

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APPENDIX A

i = number of staff where *i* =1…*i* = 6

j = number of shift where *j* = 1,2,3

k = number of day (weekday where *k* = 1,2,3,4,5 and weekend where *k* = 6,7)

Binary

$$x_{ijk} = \begin{cases} 1, \text{staff } i \text{ works on shift } j \text{ on day } k \\ 0, \text{otherwise} \end{cases}$$

$\sum \sum x_{ijk}$ $\forall i, j, k$

i = 1

x_{111} , x_{112} , x_{113} , x_{114} , x_{115} , x_{116} , x_{117} , x_{121} , x_{122} , x_{123} , x_{124} , x_{125} , x_{131} , x_{132} , x_{133} , x_{134} , x_{135}

i = 2

x_{211} , x_{212} , x_{213} , x_{214} , x_{215} , x_{216} , x_{217} , x_{221} , x_{222} , x_{223} , x_{224} , x_{225} , x_{231} , x_{232} , x_{233} , x_{234} , x_{235}

i = 3

x_{311} , x_{312} , x_{313} , x_{314} , x_{315} , x_{316} , x_{317} , x_{321} , x_{322} , x_{323} , x_{324} , x_{325} , x_{331} , x_{332} , x_{333} , x_{334} , x_{335}

i = 4

x_{411} , x_{412} , x_{413} , x_{414} , x_{415} , x_{416} , x_{417} , x_{421} , x_{422} , x_{423} , x_{424} , x_{425} , x_{431} , x_{432} , x_{433} , x_{434} , x_{435}

i = 5

x_{511} , x_{512} , x_{513} , x_{514} , x_{515} , x_{516} , x_{517} , x_{521} , x_{522} , x_{523} , x_{524} , x_{525} , x_{531} , x_{532} , x_{533} , x_{534} , x_{535}

i = 6

x_{611} , x_{612} , x_{613} , x_{614} , x_{615} , x_{616} , x_{617} , x_{621} , x_{622} , x_{623} , x_{624} , x_{625} , x_{631} , x_{632} , x_{633} , x_{634} , x_{635}

Constraint (2): $\sum_{j=1}^{3} x_{ijk} \leq 1$ $\forall i, k$

i = 1, *k* = 1

$$x_{111} , x_{121} , x_{131} \leq 1$$

i = 1, *k* = 2

$$x_{112} , x_{122} , x_{132} \leq 1$$

i = 1, *k* = 3

$$x_{113} , x_{123} , x_{133} \leq 1$$

$i = 1, k = 4$

$$x_{114}, x_{124}, x_{134} \leq 1$$

$i = 1, k = 5$

$$x_{115}, x_{125}, x_{135} \leq 1$$

$i = 2, k = 1$

$$x_{211}, x_{221}, x_{231} \leq 1$$

$i = 2, k = 2$

$$x_{212}, x_{222}, x_{232} \leq 1$$

$i = 2, k = 3$

$$x_{213}, x_{223}, x_{233} \leq 1$$

$i = 2, k = 4$

$$x_{214}, x_{224}, x_{234} \leq 1$$

$i = 2, k = 5$

$$x_{215}, x_{225}, x_{235} \leq 1$$

$i = 3, k = 1$

$$x_{311}, x_{321}, x_{331} \leq 1$$

$i = 3, k = 2$

$$x_{312}, x_{322}, x_{332} \leq 1$$

$i = 3, k = 3$

$$x_{313}, x_{323}, x_{333} \leq 1$$

$i = 3, k = 4$

$$x_{314}, x_{324}, x_{334} \leq 1$$

$i = 3, k = 5$

$$x_{315}, x_{325}, x_{335} \leq 1$$

$i = 4, k = 1$

$$x_{411}, x_{421}, x_{431} \leq 1$$

$i = 4, k = 2$

$$x_{412}, x_{422}, x_{432} \leq 1$$

$i = 4, k = 3$

$$x_{413}, x_{423}, x_{433} \leq 1$$

$i = 4, k = 4$

$$x_{414}, x_{424}, x_{434} \leq 1$$

$i = 4, k = 5$

$$x_{415}, x_{425}, x_{435} \leq 1$$

$i = 5, k = 1$

$$x_{511}, x_{521}, x_{531} \leq 1$$

$i = 5, k = 2$

$$x_{512}, x_{522}, x_{532} \leq 1$$

$i = 5, k = 3$

$$x_{513}, x_{523}, x_{533} \leq 1$$

$i = 5, k = 4$

$$x_{514}, x_{524}, x_{534} \leq 1$$

$i = 5, k = 5$

$x_{515}, x_{525}, x_{535} \leq 1$

i = 6, *k* = 1

$x_{611}, x_{621}, x_{631} \leq 1$

i = 6, *k* = 2

$x_{612}, x_{622}, x_{632} \leq 1$

i = 6, *k* = 3

$x_{613}, x_{623}, x_{633} \leq 1$

i = 6, *k* = 4

$x_{614}, x_{624}, x_{634} \leq 1$

i = 6, *k* = 5

$x_{615}, x_{625}, x_{635} \leq 1$

Constraint (3): $\sum_{i=1}^{6} x_{ijk} \leq 2 \qquad \forall j, k$

j = 1, *k* = 1

$x_{111}, x_{211}, x_{311}, x_{411}, x_{511}, x_{611} \leq 2$

j = 1, *k* = 2

$x_{112}, x_{212}, x_{312}, x_{412}, x_{512}, x_{612} \leq 2$

j = 1, *k* = 3

$x_{113}, x_{213}, x_{313}, x_{413}, x_{513}, x_{613} \leq 2$

j = 1, *k* = 4

$x_{114}, x_{214}, x_{314}, x_{414}, x_{514}, x_{614} \leq 2$

j = 1, *k* = 5

$x_{115}, x_{215}, x_{315}, x_{415}, x_{515}, x_{615} \leq 2$

j = 2, *k* = 1

$x_{121}, x_{221}, x_{321}, x_{421}, x_{521}, x_{621} \leq 2$

j = 2, *k* = 2

$x_{122}, x_{222}, x_{322}, x_{422}, x_{522}, x_{622} \leq 2$

j = 2, *k* = 3

$x_{123}, x_{223}, x_{323}, x_{423}, x_{523}, x_{623} \leq 2$

j = 2, *k* = 4

$x_{124}, x_{224}, x_{324}, x_{424}, x_{524}, x_{624} \leq 2$

j = 2, *k* = 5

$x_{125}, x_{225}, x_{325}, x_{425}, x_{525}, x_{625} \leq 2$

j = 3, *k* = 1

$x_{131}, x_{231}, x_{331}, x_{431}, x_{531}, x_{631} \leq 2$

j = 3, *k* = 2

$x_{132}, x_{232}, x_{332}, x_{432}, x_{532}, x_{632} \leq 2$

j = 3, *k* = 3

$x_{133}, x_{233}, x_{333}, x_{433}, x_{533}, x_{633} \leq 2$

j = 3, *k* = 4

$x_{134}, x_{234}, x_{334}, x_{434}, x_{534}, x_{634} \leq 2$

j = 3, *k* = 5

$$x_{135}\,, x_{235}\,, x_{335}\,, x_{435}\,, x_{535}\,, x_{635} \leq 2$$

Constraint (4): $\sum_{i=1}^{i} \sum_{j=1}^{j} \sum_{k=1}^{k} x_{ijk} \geq 30 \quad \forall i, j, k$

Constraint (5): $x_{i35} + x_{i16} + x_{i17} = 1 \qquad \forall i \in i$

i = 1

$$x_{135}\,, x_{116}\,, x_{117} = 1$$

i = 2

$$x_{235}\,, x_{216}\,, x_{217} = 1$$

i = 3

$$x_{335}\,, x_{316}\,, x_{317} = 1$$

i = 4

$$x_{435}\,, x_{416}\,, x_{417} = 1$$

i = 5

$$x_{535}\,, x_{516}\,, x_{517} = 1$$

i = 6

$$x_{635}\,, x_{616}\,, x_{617} = 1$$

Constraint (6): $\sum_{k=6}^{7} x_{i1k} \leq 2 \qquad \forall i$ for *k* = 6, 7

j = 1, *k* = 6

$$x_{116}\,, x_{216}\,, x_{316}\,, x_{416}\,, x_{516}\,, x_{616} \leq 2$$

j = 1, *k* = 7

$$x_{117}\,, x_{217}\,, x_{317}\,, x_{417}\,, x_{517}\,, x_{617} \leq 2$$

APPENDIX B

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UNIVERSITI TEKNOLOGI MARA

Kolej Pengajian Pengkomputeran, Informatik dan Media

Our Reference : 100-KPPIM(PI.9/10/) (MR/429)
Date : 23th May 2023

Madam Norlenda Binti Mohd Noor
Sarrah Sabihah Binti Berhanuddin (2020834208)
Nurul Iwani Binti Aidilakbar (2020834952)
College of Computing, Informatics & Media
Universiti Teknologi MARA
40450 Shah Alam
SELANGOR

Dear Madam.

APPROVAL LETTER - COLLEGE ETHICS REVIEW COMMITTEE

Thank you for submitting your research proposal to College Ethics Review Committee (CERC). After considering your application, the Committee approved your proposal entitled "Staff Scheduling for A Library at A Local University".

Details of the approval are as follows:

Ref. number:	100-KPPIM(PI.9/10/) (MR/429)
Approval Period:	30/03/2023 until 29/09/2023
Authorised personnel:	1. Madam Norlenda Binti Mohd Noor 2. Sarrah Sabihah Binti Berhanuddin (2020834208) 3. Nurul Iwani Binti Aidilakbar (2020834952)

The College Ethics Review Committee operates in accordance to the ICH Good Clinical Practice Guidelines, Malaysian Good Clinical Practice Guidelines and the Declaration of Helsinki. The approval of this project is conditional upon your continuing compliance with these guidelines and declaration.

We draw to your attention the requirement that a report on this research, must be submitted every 12 months from the date of the approval or on the completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of consent for the project to proceed. Amendments, if any, to the study documents are to be submitted to CERC for approval.

If you require further information, please contact CERC Secretariat at 03-7962 2005 / 03-7962 2006 or email at juhaidaabdaziz@uitm.edu.my / afiqahhamid@uitm.edu.my.

Yours sincerely,

DR. JASBER KAUR A/P GIAN SINGH
Chairman
College Ethics Review Committee, KPPIM

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