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STAFF SCHEDULING AT A COFFEE SHOP USING LINEAR PROGRAMMING MODEL

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ABSTRACT

This study modified a linear programming model to represent a working schedule with the optimum number of staff in every shift to fulfil the current workload at a local coffee shop. This coffee shop deals with number of shifts that is not usual which is seven shifts compared to any other companies which is usually three or four shifts. This problem can lead to overstaffing as the working shifts are too packed. The staff working schedule must be the best possible scenario that could optimize all the resources owned, at the same time satisfies all the operational constraints. The challenge is to adjust the working schedule that could allow least number of staff working in a week. A Binary Linear Programming model is utilized to determine the shifts duties for each workers considering the rest day between working shifts, the required number of staff for each shift and other constraints. Model is solved using Open Solver. New schedule needs a total of 100 working shifts in seven days, as compared to the current schedule of 378 working shifts for the same duration. A new schedule was developed with the aim of maximizing the number of employees at a coffee shop during regular business hours to avoid understaffing during peak hours. In conclusion, the proposed mathematical model can provide a quick solution in maximizing the number of workers during seven days schedule of working.

Keywords*: Staff scheduling, Binary Integer Programming, Mathematical model, Maximizing*

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Introduction

Staff scheduling research has been widely studied over the last few decades since it is one of the most difficult organizational problems (Soriano et al., 2020). Employee or scheduling, as defined by Nobil et al., (2022), includes the cost-effective construction of employees' work activities while following to union rules. Every workplace, such as banks, factories, hospitals, and restaurants, requires a timetable to ensure that all employees are satisfied and that a healthy work-life balance is achieved. The most difficult aspect of staff scheduling is finding an appropriate day off for each number of employees who work standard shifts with various times while ensuring there are always enough people on duty.

Covid 19 pandemic has been conquering the world over the past two years. Corona Virus not only causes many deaths, but it also has an economic impact because the government has ordered that all non-essential services being shut down. Economy is progressively returning to normal once the vaccine was implemented in every country. As a result, many businesses are open as usual, and people are starting to go out to destinations like retail malls and vacations. Shopping mall is where most people spend their weekends. Restaurants, as well as coffee shops, are always packed. On weekdays, a coffee shop is one of the places where individuals meet up with friends or colleagues, work alone, or simply relax. On weekends, the coffee shop is busier, and ordering can take a long time due to the lack of employees. With fewer employees, productivity will drop, resulting in negative customer feedback. As a result, it is important to maintain a positive reputation in order to remain competitive.

Staff scheduling establishes a timetable for employees during their working hours to meet the current demands in the workplace, allowing work to continue uninterrupted as shifts change. The goal of linear programming (LP) models, which will be used in this research to explore staff scheduling, is to get the best feasible result in a mathematical model based on specific constraints that have been established. All linear programming (LP) optimization problems provide an objective function that aims to characterize the constraints and optimality of a problem in order to show particular conditions for the problem (Hasan & Rajib Arefin, 2017). This approach was used by Akkermans et al. (2021) to solve the shift and break design challenge. This study proposes a two-phase strategy to coming up with a solution in each phase using integer linear programming (ILP), with the first phase determining how many shifts and which template shifts would be utilized, and the second step allocating breaks to the shifts. The purpose is to minimize the weighted sum of overstaffing, understaffing, and template shifts to the lowest possible value. However, the strategy adopted was ineffective. Due to the increased number of possible templates shifts for real-life occurrences, the strategy used did not produce effective result when solving the ILP. To solve the difficulty, this research looked at template shifts at a 15-minute temporal granularity for real-life scenarios.

Furthermore, when trying to solve optimization problems in programming, we must choose the solution for the job related to problem categories and design for specific types. A hybrid power system combining thermal, hydro, and wind power was studied using mixed-integer linear programming (MILP). MILP technique has been proposed by Fu et al., 2019 to improve its efficiency while handling the symmetric problem in MILP formulas by reforming hierarchical constraints. As a result, various scales of experiments have been carried out to prove the effectiveness of the proposed method approach. Nobil et al. (2022) applied MILP in their study to establish homogeneous personnel shift scheduling to meet the constraints of the number of workers each shift. The goal of the research is to reduce hospital expenses by optimizing the scheduling of individuals with consistent competencies. Experienced nurses who can work in service staff departments or in the same hospital department are examples of homogeneous people. In addition, Lunardi et al. (2020) studied the online printing shop scheduling problem by applying MILP and constraints programming models to reduce the time required for the last task to leave the system to complete. This is due to the increased complexity of printing jobs, such as the increased use of online advertising and the decrease in printed substance, which results in a decrease in demand. Taking advantage of the Internet and moving toward mass customization, online printing firms attract more consumers and reduce prices.

Mathematical programming methods are used to find the solutions of staff scheduling problems such as linear programming, integer programming, column generation and heuristic methods such as tabu search. Akkermans et al. (2021) studied how to avoid overstaffing and understaffing during working hours by selecting a restricted number of template shifts (which specify a start time and duration). Binary programming was used to model the proposed approach (BIP). Bürgy et al. (2019) and Soriano et al. (2020) discussed real-world issues such as shifting labor demand, working conditions, and employee preference-related costs. When the number of employees and the size of the firm grows, it becomes more difficult to schedule all the employees while still following to certain rules, regulations, and employee preferences. The goals are to minimize demand fulfilment, employee preference-related costs, and working conditions as low as possible. Pan et al. (2016) studied museum multi-activity shift scheduling and proposed a tabu search strategy for dealing with the specific multi-activity shift scheduling problem by using heuristic optimization approaches to ensure workload requirements are met in all slots and activities. Heuristic solutions were also used by Pandey et al. (2021), Akkermans et al. (2021), Álvarez et al. (2020), and Dahmen et al. (2020) to solve their difficulties.

Alwadood et al. (2021) and Popović et al. (2021) established an exact solution optimization model for staff scheduling and warehouse management. Alwadood et al. (2021) solve the problem of minimizing the number of workers who must be on duty during the weeks of the Covid-19 pandemic outbreak, whereas Popović et al. (2021) handle the problem of minimizing the total cost of the workforce. As a result, the mathematical model has successfully optimized the workforce while considering all new constraints imposed during the MCO, while the other has successfully provided a solution that allows for cost savings in the warehouse while also increasing its efficiency and sustainability. Fujita et al., (2016) and Popović et al. (2021) discussed ways to decrease personnel numbers. As a result, Fujita et al. (2016) proposed new shift scheduling models that consider monthly staff as well as one-time employees.

In studies on retail scheduling, Pandey et al., 2021 and Álvarez et al. (2020) focused on reducing the total amount of overstaffing and understaffing. The BIP model was used to model both methods. There are a few common positions in retail stores, including cashier, departmental clerk, and customer service counter clerk. To improve the service level and optimize resources, it might be challenging to schedule and identify the best staff for retailers. Because of this, retailers must concentrate on staffing and scheduling to achieve operational efficiency. According to Bürgy et al. (2019), each employee is qualified to perform specific jobs and not only has a specification of preferred work hours, but also overall work time limits each day and each week. In order to achieve shift flexibility, assigning several shift breaks enhances demand over the course of an operating day. Additionally, including a break in an employee's shift may reduce overstaffing at certain times of the day (Álvarez et al., 2020).

Leung et al. (2021) and Guerriero & Guido (2021) developed models for optimizing nursing staff demand and a flexible staff scheduling problem. The BIP model was used to model the method. This study was conducted by Guerriero & Guido (2021) to maximize employee on-site and remote work while also maximizing staffing levels. The study effectively demonstrated the use of digital technology in nursing homes while modeling a flexible staff scheduling problem and proposing a creative workday organization based on more than the typical two shifts.

Staff scheduling is essential to preserving a fair schedule for all employees and ensuring employees satisfaction. However, the company must create a balance between the number of employees and the unexpected number of customers during working hours, depending on peak and non-peak hours to avoid having too many employees during non-peak hours and being understaffed during peak hours. This coffee shop works an unusual number of shifts: seven, as opposed to the usual three or four shifts at other businesses. Because the working shifts are excessively full, this situation may result in overstaffing. Because there is no fixed break time in the coffee shop, difficulties can have a detrimental influence on the customer experience and employee satisfaction. Moreover, part-time employees who work on their own schedules make it harder for managers to create a schedule.

This study focuses on the personnel scheduling of a local coffee shop during seven days of working hours. The staff of the coffee shop is considered in this case study because of their important tasks in making sure that the business runs smoothly to serve the order from customers. The coffee shop in this study is operating for a week. Therefore, the working shift in the coffee shop has been changed to three shifts per day to ensure there is no overstaffing during working days. Table 1 shows the summary of past research on staff scheduling.

Table 1: Summary of Past Research on Scheduling.

Author	Objective	Area Applied	Algorithm
Akkermans et al. (2021)	To select a small number of templates shifts to avoid overstaffing and understaffing.	Shift scheduling	Integer linear programming
Álvarez et al. (2020)	To minimize the sum of overstaffing and understaffing.	Shift scheduling	Binary integer programming
Popović et al. (2021)	To minimize the total cost of the workforce.	Scheduling	Linear programming
Nobil et al. (2022)	Minimize the total variable cost of payrolls, including of base pay, benefits, overtime, and overnight pay.	Shift scheduling	Mixed integer linear programming
Dahmen et al. (2020)	To minimizing the sum of overstaffing and understaffing.	Scheduling	Integer programming
Bürgy et al. (2019)	To minimize the sum of demand fulfilment and employee preference-related cost.	Employee scheduling	Integer programming
Pandey et al. (2021)	Minimize the total weighted cost of overstaffing and understaffing.	Shift scheduling	Mixed integer linear programming
Fujita et al. (2016)	To reduce the number of excess regular employees.	Shift scheduling	Binary integer programming
Soriano et al. (2020)	Minimize the total penalty function of over/under coverage from employee demand, overtime, and unsatisfied employee demand and working condition.	Employee scheduling	Analytic hierarchy process and Mixed integer linear programming
Guerriero & Guido (2021)	To maximize employee work on site and remote work.	Shift scheduling	Integer programming
Alwadood et al. (2020)	Minimize the number of personnel who must be on duty during the weeks.	Staff shift scheduling	Binary integer programming
Leung et al. (2020)	To optimize nursing staff demand	Shift scheduling	Binary integer programming
Pan et al. (2016)	To ensure workload requirements are satisfied in all slots and activities by using optimization methods.	Shift scheduling	Integer linear programming

Methodology

In this study, a mathematical model is modified to best represent the scheduling problem in a coffee shop. Currently, it operates in 7 shifts, as compared to 3 or 4 shifts maximum in other establishments. Planning schedules in this situation are not easy as many issues must be factored in. Hence, a 3 shifts schedule is proposed in the hope to optimize the planning process. The proposed opening time for each shift with the number of required staff either full-time or part-time including the manager or supervisor is shown in Table 2.

Table 2: The proposed number of staff required for each shift.

Day/Shifts	Total number of employees needed in 1 shift	Number of managers/supervisors proposed
930 am – 530 pm	2 staff	1 manager/supervisor
12 pm – 8 pm	5 staff	1 manager/supervisor
4 pm –12 am	4 staff	1 manager/supervisor

The modified mathematical programming model is based on Alwadood et al. (2020). The model formulation including the symbol of parameter, indices, and decision variables of the binary is listed below:

Notation:

i : position of all staff

j : shift available

k : day working

I : set of staff

J : set of shifts

K : set of days

A_k : total number of full-time and part-time workers required each shift.

B_k : the number of part-time workers required to work per week.

C_k : the number of managers required to work per week.

D_k : the number of supervisors and full-time staff required to work per week.

E_k : number of full-time required in each shift.

Decision variables:

X_{ijk} = {1, if staff i is working on shift j on day k , 0 otherwise.

The fully modified BIP model for staff scheduling is as follows:

Maximize staff, $Z = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} X_{ijk}$ (1)

Subject to

$$\sum_{j=1}^{J} X_{ijk} \leq 1 \ \forall i,k \tag{2}$$

$$\sum_{i=5}^{18} X_{ijk} \leq A_k \ \forall j,k \tag{3}$$

$$\sum_{i=9}^{18} X_{ijk} \leq B_k \ \forall j,k \tag{4}$$

$$\sum_{i=1}^{1} X_{ijk} = C_k \ \forall j,k \tag{5}$$

$$\sum_{i=2}^{8} X_{ijk} = D_k \ \forall j,k \tag{6}$$

$$\sum_{i=1}^{4} X_{ijk} \geq E_k \ \forall j,k \tag{7}$$

$$X_{ijk} = \{0,1\} \ \forall i,j,k \tag{8}$$

The objective function (1) intends to maximize the number of staff of each position in all shifts for each day. Constraint (2) ensures that all staff i working 1 shift per day. Constraint (3) considers the number of part-time and full-time staff required to work on each shift per day. Constraint (4) considers the number of part-time staff required to work per week. Constraint (5) ensures the number of working days for the manager per week and (6) considers the required number of working days for the supervisor and full-time per week. Constraint (7) ensures there is a minimum number of managers and supervisors working each shift. Constraint (8) restricts the value of the decision variable to be either '1' or '0'.

Implementation

All data is gathered and structured in Microsoft Excel. From the data gathered, there are 378 working shifts in a week. The objective function of this model is to maximize the staff working in a day subject to the constraint proposed. To solve the mathematical model in linear programming, decision variables are the sets of values that will be determined. X_{ijk} is the decision variable which refers to all 378 working shifts, where i is staff, j is working shift available and k is day working.

X_{ijk} : decision variable for staff i working on shift j during day.

X_{ijk} = {1, if staff i is working on shift j on day k , 0 otherwise.

$$\text{Maximize staff, } Z = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} X_{ijk}$$

6 constraints were considered which are the sum shift of staff working in a day is less than or equal to 1. The equation of inequalities of constraint (2) is shown below:

$$\sum_{j=1}^{J} X_{ijk} \leq 1$$

Constraint (3) is the required number of full-time and part-time in each shift. There are 3 proposed shifts, and the equation will be presented as follows:

$$\sum_{i=5}^{18} X_{ijk} \leq A_k$$

Morning shifts, $j = 1$

$$\sum_{i=5}^{18} X_{ijk} \leq 2$$

Afternoon shifts, $j = 2$

$$\sum_{i=5}^{18} X_{ijk} \leq 5$$

Closing shifts, $j = 3$

$$\sum_{i=5}^{18} X_{ijk} \leq 4$$

Next, constraint (4) is related to the number of part-time required to work per week. The maximum day working part-time per week is 6 days to make sure that they at least get 1 day off per week. Constraint (5) and (6) is the requirement numbers of manager, supervisor and full-time respectively. Based on data collected, managers in the coffee shops 2 days off per week while supervisor and full-time staff will get 1 day off per week. Thus, the constraint equalities and inequalities are written below:

$$\sum_{i=9}^{18} X_{ijk} \leq 6$$

$$\sum_{i=1}^{1} X_{ijk} = 5$$

$$\sum_{i=2}^{8} X_{ijk} = 6$$

The last constraint (7) is related to the minimum number of managers or supervisors working in each shift available. Each shift requires at least 1 manager or supervisor. This is to prevent more than 2 people working in the same shift. Thus, the equation will be presented based on the inequalities below:

$$\sum_{i=1}^{4} X_{ijk} \geq E_k$$

Morning shifts, $j = 1$

$$\sum_{i=1}^{4} X_{ijk} \geq 1$$

Afternoon shifts, $j = 2$

$$\sum_{i=1}^{4} X_{ijk} \geq 1$$

Closing shifts, $j = 3$

$$\sum_{i=1}^{4} X_{ijk} \geq 1$$

Result and Discussion

Results were obtained using Microsoft Excel Solver. Table 3 shows the staff position in the column on the left, and the row shift denotes the morning (M), afternoon (A), and closing (C) shifts for each day. Each row of the table contains the work schedule for every employee. The binary output '1' indicates that the employees are working their allocated shift, whereas the binary output '0' shows that they are not. The total number of staff working during each shift and day is shown in the last two rows. Based on the schedule extracted from the results shows that the criteria for a manager are successfully fulfilled. Managers can get 2 days off per week based on the restrictions proposed. On top of that, in constraint (6), making sure that supervisors and full-time get 1 day off per week is also achieved.

This study was intended to optimize the number of staff working during the day to prevent overstaffing. The mathematical model was modified based on the requirements that must be satisfied to the new working schedule. Based on the new schedule generated by the modified mathematical model, the staff only recorded a total of 100 working shifts per week. The coffee shop has successfully reduced the number of staff working to a maximum of 15 staff per day by solving the modified model. From the maximum number of staff working per day on day 1 and day 2, both day 1 and day 2 could be indicated as weekends because more staff are required to work during busy days. For example, day 1 is denoted as Saturday, and day 2 as Sunday.

Considering all newly imposed restrictions, the mathematical model has successfully developed the new schedule compared to the total of 378 working shifts per week in the current working schedule of the coffee shop.

Conclusion and Recommendation

This study was intended to maximize the number of staff at a coffee shop who must be on duty during seven days of working hours. The mathematical model was modified subject to the requirements and restrictions of the management. The linear programming (LP) model formulation accommodated the differences in a staff position to obtain the optimal number of staff for each position and working shift in a week. The current schedule requires staff to work one shift per day for seven days, and this resulted in a total of 378 working shifts. However, the new schedule generated by the modified mathematical model proposed that there should only be 100 working shifts needed during working days when the work schedule follows the new requirements imposed. Therefore, the mathematical model has successfully optimized the number of staff, considering all new restrictions imposed during seven days of working.

Despite the achievements recorded in this study, there is also room for improvement in future research. Instead of constructing a weekly schedule, future research may focus on a monthly schedule which includes break time and a capacity to reschedule if any emergencies occur.

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Table 3: The proposed staff scheduling for 7 days

		Day 1			Day 2			Day 3			Day 4			Day 5			Day 6			Day 7			Total day
		Shift			Shift			Shift			Shift			Shift			Shift			Shift			
		M	A	C	M	A	C	M	A	C	M	A	C	M	A	C	M	A	C	M	A	C	
Manager/ Supervisor	1	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	5
	2	0	1	0	0	0	1	0	0	1	0	1	0	1	0	0	0	1	0	0	0	0	6
	3	0	0	1	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	0	0	6
	4	1	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	1	6
Fulltime	5	0	1	0	0	0	1	0	0	1	1	0	0	0	0	0	1	0	0	1	0	0	6
	6	0	0	1	0	1	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	6
	7	1	0	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	1	0	6
	8	1	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	1	6
Part time	9	0	1	0	0	1	0	0	0	1	0	0	1	1	0	0	0	1	0	0	0	0	6
	10	0	1	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	1	6
	11	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	1	0	1	0	5
	12	0	1	0	0	0	1	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	6
	13	0	0	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	0	0	1	0	6
	14	0	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	4
	15	0	0	1	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	1	0	0	6
	16	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	4
	17	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	1	0	1	0	5
	18	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	1	5
Total staff per shift		4	6	5	4	6	5	3	6	5	3	6	5	3	6	5	3	6	5	3	6	5	
Total staff per day		15			15			14			14			14			14			14			

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