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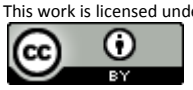

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INTEGER LINEAR PROGRAMMING ON PREFERENCE MAXIMIZED OF WORKFORCE SCHEDULING

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Abstract: This study investigated the application of integer linear programming with the purpose of solving workforce scheduling problems in real life and satisfying the constraints at the same time, which includes the staff preferences towards shift and company policies. Integer linear programming is a well-known mathematical approach which is able to obtain the optimal solution faster than manually schedule construction in a less-complex way. In this study, a weekly schedule which involved thirteen staff is obtained successfully by using integer linear programming approach through the help of LP Solve IDE software. The result showed that the total staffing cost was successfully minimized due to reduced number of full shift assigned to staff. In addition, the staff satisfaction is maximized by satisfying all their preferences.

Keywords: Workforce scheduling problem, integer linear programming, optimization problem.

I. INTRODUCTION

In general, scheduling is the process of limited resources allocation over time to meet the balance between requirements of staff and the tasks given [7]. In the recent study of Burke and Soubeiga[5], they stated that staff scheduling is about assigning the right staff to the right position at the right time in order to fulfill both the internal and external demands of the organization. According to Bakir and Aksop[3], scheduling can also be referred to a process of planning to perform some activities using the limited resources available while optimizing at least one objective and considering several constraints. Scheduling is commonly known as a time consuming and challenging task due to its complexity in meeting the staff preferences, organization rules and regulations. All of these criteria can be referred as constraint. The constraint need to be obeyed in order to obtain an effective schedule. Hakansson [9]stated that the staff, demands, rules and laws and quality aspects are the four elements that should be considered in the process of arranging an effective and efficient schedule. Scheduling staff is an important task as an optimal schedule can boost the performance of both the staff and organization by creating a smooth flow of work order in the workplace, which allows the staff to be fully focus on the tasks given. On top of that, there are several reasons why staff scheduling should be concerned [18]. First of all, the staff may perform better when their preferences are considered in the scheduling process as they feel that they are being highly respected. Scheduling is about assigning the right people at the right job position at the right time. Thus, the performance of the staff is better when they are being assigned with the job that they are expert in.

Hence, an effective schedule leads to better performance among staff. Moreover, through the process of scheduling, the manager can be trained to be more considerate and thoughtful when he or she takes into consideration of the staff preferences.

A good and properly schedule has great impact on the optimization of the company performance by using the minimum operation cost in order to gain the maximum profit [12]. Scheduling is extensively used in various fields. According to Al-Najjar and Ali [2], scheduling can be categorized into three types which are operations scheduling, demand scheduling and personnel scheduling. When the staff is temporarily allocated to jobs for some purpose, it is known as an operations scheduling process. Meanwhile, a demand scheduling is a process of assigning customers to a period of order fulfillment time. On the other hand, a personnel scheduling involves the process of planning the time on when the staff will be work on their job. Personnel scheduling concern with some interrelated areas which includes short-term scheduling, budgeting and staffing employees [2]. Personnel scheduling is important for a retail store to have enough staff to run the business while maintaining a balance between staff requirements and the task assigned in order to prevent under staff or overstaff. Apparently, it is impossible for the manager to assign the staff to their job manually since staff scheduling is a complex process that consume a large amount of time. Hence, most of the organizations implement mathematical model for staff scheduling to overcome the problem.

In general, there are two types of algorithms that can be used by managers in order to solve staff scheduling problems, either optimization or heuristics approach. Linear programming and integer linear programming had been widely applied in various fields to solve scheduling problem such as nurse scheduling [11, 16, 19], timetable scheduling [3] and workforce scheduling [13]. According to the recent study of Khumaraguru *et al.* [10], an optimization method concerned with optimizing the objective function formulated either by maximizing or minimizing the objective function is extensively used in the hospitals to arrange the schedule due to its effectiveness in solving nurse scheduling problem. By implementing linear programming method, an optimal schedule is produced and solved by using Excel solver [11]. Meanwhile, Mohamad and Said [13] mentioned that integer linear programming approach is recognized as a powerful tool to solve the daily staff scheduling problem by considering hourly requirements patterns. The objective function is formulated to maximize the staff satisfaction by taking into consideration their preferences with the given set of constraints in which all the variables are in integer value. Integer linear programming method which the decision variables can only take discrete value but cannot be in continuous form is also popular in solving workforce scheduling [17].

Instead of optimization methods, meta-heuristic techniques such as genetic algorithm and tabu search are also used by previous researchers to solve scheduling problem. Genetic algorithm is a powerful stochastic meta-heuristics method that commonly used to solve workforce scheduling problems for its ability in solving complex problems and parallelism [6, 8, 15]. Genetic algorithm is implied to solve the problem based on natural selection process. Algethami *et al.* [1] applied genetic algorithm in their recent study to solve workforce scheduling and routing problem. Meanwhile, Greenspan [8] used genetic algorithm to solve the employee scheduling problem. Tabu search is a meta-heuristic method that proposed by Glover in 1986 and was formalized 3 years later [14]. Tabu search is commonly applied to solve combinatorial optimization problems by obtaining an optimal or near- optimal solution. The recent study of Burke and Soubeiga[5] aims to construct an optimal weekly timetable for 30 nurses at a hospital in UK in order to minimize the cost of penalty corresponding to the assigned shift patterns that preferred by the nurses. Another study by Brueckeret *al* [4] also applied tabu search to solve aircraft maintenance and staffing problem.

In general, integer linear programming is a mathematical optimization approach that widely used in solving workforce scheduling problem in real economics and business world. Among all the optimization and heuristics approaches, integer linear programming approach is chosen to be implemented to solve the scheduling problem in this study due to its effectiveness and simplicity to be implemented [13]. Integer linear programming deals with constrained optimization situations which utilize the available resources in the best way under certain constraints. Since the constraints in this study are in moderate amount hence integer linear programming is the best option of approach for solving the retail staff scheduling problem.

II. METHODOLOGY

This research is mainly about solving a workforce scheduling problem in a retail store by using integer linear programming approach. There are a total of thirteen staffs in the retail store. There are two supervisors, nine of them are staffs who is in charge in serving walk-in customers while the other two staff are cashier who in charge for facilitating money transaction for the retail store. In order to make the scheduling system more systematic, there are three shifts available, which are morning shift, afternoon shift and full shift respectively. Morning shift starts from 10:00a.m. to 6:00p.m. Afternoon shift starts from 2:00p.m. and ends at 10:00p.m. for Sunday to Thursday while from 2:30p.m. to 10:30p.m. for Friday, Saturday and public holidays. Meanwhile, full shift starts from 10:00a.m. to 10:00p.m. on Sunday to Thursday and 10:00a.m. to 10:30p.m. on Friday, Saturday and public holidays.

The weekly working schedule is obtained through an informal interview with one of the staff. Moreover, informal interview also has been conducted with every staff in order to determine their preferences of shift. This study is focusing on obtaining three optimal schedules which includes staff schedule, supervisor schedule and cashier schedule with the optimal number of staff in order to

prevent overstaff and to minimize the total staffing cost. The salary per hour for every staff category on different type of shift is calculated and the calculation is shown as below.

$$\text{Salary per hour} = \frac{\text{Monthly basic salary}}{\text{Number of week per month} \times \text{Total working hour per week}}$$

TABLE I. DAILY SALARY OF DIFFERENT STAFF CATEGORY

Shift assigned	*Daily salary (RM)*		
	Supervisor	*Staff*	*Cashier*
M, Morning shift (8hours)	75	54.17	54.17
N, Afternoon shift (8hours)	75	54.17	54.17
F, Full shift (Sunday to Thursday - 12hours)	131.25	94.80	94.80
F, Full shift (Friday, Saturday – 12.5hours)	138.28	99.87	99.87

Table 1 shows the daily salary based on the shift assigned for different staff category which included supervisor, staff and cashier. The daily salary for full shift is higher compared to morning shift or afternoon shift as the worker needs to work longer time period on full shift. For instance, the daily salary of a cashier who works on morning shift is RM54.17 while who works on full shift on Friday will be paid of RM99.87. Meanwhile, a supervisor is getting higher salary than staff and cashier.

The mathematical model is formulated to solve the retail scheduling problem with the aim to maximize the staff satisfaction and minimize the staffing cost while satisfying all the hard and soft constraints involved. Decision variables are defined as the first step in formulating the mathematical model to solve the retail scheduling problem.

Indices:

h = staff

i = staff category where 1 = supervisor, 2 = staff and 3 = cashier

j = prefer shift where 1 = morning shift, 2 = afternoon shift and 3 = full shift

k = day of the week where 1 = Monday, 2 = Tuesday, 3 = Wednesday, 4 = Thursday, 5 = Friday, 6 = Saturday and 7 = Sunday

The decision variable is defined and listed as the following:

$$X_{hijk} = \begin{cases} 1, \text{ staff } h \text{ category } i \text{ works for shift } j \text{ on day } k. \\ 0, \text{ otherwise} \end{cases}$$

Where X_{hijk} represents the staff h from category i will work for shift j on day k. There are several constraints that must be fulfilled. The hard constraints consist of the following:

a) Minimum 6 staff work on weekday
b) Minimum 8 staff work on weekend
c) Minimum 1 cashier works
d) Minimum 1 supervisor works

On the other hand, the soft constraints comprise of the requirements and preferences among staff. The soft constraints include the following:

a) Staff 4 and staff 5 prefer to have off day on the same day
b) Staff 11 and staff 13 prefer to have off day on the same day
c) Staff 6 prefer to work for afternoon shift only
d) Staff 6 prefer to have off day on Sunday

In this study, integer linear programming approach is implemented to produce optimal retail staff schedule which consider the staff preferences toward shift. The objective of the integer linear programming model is to minimize the total staffing cost, C_{hijk} and maximize the preference of staff simultaneously as shown below.

Minimize cost = Subject to

$$\sum_{h=1}^{13}\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{7} C_{hijk} X_{hijk}$$

$$\sum_{h=1}^{13}\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{7} X_{hijk} \geq 6$$

$$\sum_{h=1}^{13}\sum_{i=3}^{3}\sum_{j=1}^{3}\sum_{k=1}^{7} X_{hijk} \geq 8$$

$$\sum_{h=10}^{13}\sum_{i=3}^{3}\sum_{j=1}^{3}\sum_{k=1}^{7} X_{hijk} \geq 1$$

$$\sum_{h=12}^{13}\sum_{i=1}^{1}\sum_{j=1}^{3}\sum_{k=1}^{7} X_{hijk} \geq 1$$

$$\sum_{h=6}^{6}\sum_{i=2}^{2}\sum_{j=2}^{2}\sum_{k=1}^{6} X_{hijk} = 1$$

III. RESULTS

This study compared the proposed schedule with the real schedule which produced by the company in order to show the effectiveness of the integer linear programming model. Table 2 shows the current manually-planned weekly schedule of the company.

TABLE II: CURRENT MANUALLY-PLANNED WEEKLY SCHEDULE

Day / Staff	*Mon*	*Tue*	*Wed*	*Thurs*	*Fri*	*Sat*	*Sun*	*Weekly Cost*
Staff 1	F	F	F	off	N	F	F	
Staff 2	F	F	F	F	F	M	off	
Staff 3	M	F	F	F	off	F	F	
Staff 4	F	M	off	F	F	F	M	
Staff 5	F	M	off	F	F	F	M	
Staff 6	N	N	N	N	N	N	off	
Staff 7	M	F	F	F	F	off	F	
Staff 8	N	M	F	off	F	F	F	
Staff 9	off	F	F	F	F	F	F	
Cashier	F	off	F	F	F	F	N	
Cashier	off	F	M	F	F	N	F	

Supervisor	F	off	F	F	M	F	F	7100.25
Supervisor	off	F	F	F	F	F	F	
Daily Cost	821.93	916.73	1034.44	1075.07	1120.58	1138.16	993.81	

Based on Table 2, the total staffing cost for one week is RM 7100.25, which is considered as high. By excluding all the other operation cost such as shop rental fee and electrical fee, the organization needs to spend approximately RM 28000 on staffing cost for every month. Nonetheless, this amount burdens the organization. From the schedule, it can be seen that the number of full shift that assigned to each of the staff is high which in turn caused the staffing cost to be high. Furthermore, the management of the company did not consider the preference of staff towards the shift and this will cause dissatisfaction among the staff.

Meanwhile, Table 3 shows the most optimal result obtained by integer linear programming technique. Overall, the total staffing cost for the whole week is RM3087.50, approximately RM12000 for one month, which is RM16000 lesser than the current staffing cost in Table 2.

TABLE III: THE PROPOSED WEEKLY SCHEDULE PRODUCED BY LPSOLVE IDE

Day Staff	*Mon*	*Tue*	*Wed*	*Thurs*	*Fri*	*Sat*	*Sun*	*Weekly Cost*
Staff 1	M	off	M	M	F	N	N	3087.50
Staff 2	M	off	F	M	M	off	N	
Staff 3	N	off	off	off	off	off	off	
Staff 4	off	N	off	off	off	off	M	
Staff 5	off	off	off	off	off	M	M	
Staff 6	N	N	N	N	N	N	off	
Staff 7	off	M	off	off	off	M	off	
Staff 8	off	M	off	off	off	off	off	
Staff 9	off	off	off	off	off	off	off	
Cashier	F	off	M	N	M	M	M	
Cashier	off	N	N	M	N	N	N	
Supervisor	F	off	M	N	N	N	N	
Supervisor	off	N	N	M	M	M	M	
Daily Cost	442.73	345.85	461.48	420.85	466.55	475.02	475.02	

In this study, the integer linear programming approach is indeed able to fulfill all the hard constraints and soft constraints. In other words, it can be said that the current staffing cost according in Table 2 is double compared to the staffing cost of the proposed schedule which is generated by LPSolve IDE software. By comparing the result from Table 2 and Table 3, we can see there is a big difference in the total weekly staffing cost. One of the reason which caused the current staffing cost to be high is the number of full shift assigned to staff is too many. Most of the staff are assigned full shift instead of morning shift or afternoon shift. This lead to overstaff and wastage in the form of operation cost. Through optimization approach, not only the organization can save cost, but the competition among staff can also be decreased drastically.

Sensitivity Analysis

To continue evaluating the proposed model, sensitivity analyses is also conducted in solving this scheduling problem. Through these sensitivity analyses, "what if" questions related to the process of arrangement of retail staff to the preferred shift could be answered. Model 1 illustrated the situation where the total number of staff is decreased to twelve persons instead of thirteen persons. Staff 1 is being eliminated in model 1 to see its effect on the mathematical model. In the next Model 2, the number of staff is further reduced to ten persons whereby there are three staff being eliminated, which are Staff 1, Staff 2 and Staff 3. Finally, the number of staff is decreased by five persons in the following Model 3 where there are only left with eight staff, by excluding Staff 1, Staff 2, Staff 3, Staff 4 and Staff 5. According to Table 4, the overall weekly staffing cost is RM3184.38, which is RM96.88 higher than the staffing cost that involved all the staff, RM3087.50 by referring to Table 3.

TABLE IV:MODEL 1:WEEKLY SCHEDULE (NUMBER OF STAFF DECREASED BY ONE PERSON)

Day Staff	*Mon*	*Tue*	*Wed*	*Thurs*	*Fri*	*Sat*	*Sun*	*Weekly Cost*
Staff 2	M	off	M	M	F	N	N	3184.38
Staff 3	M	off	F	M	M	off	N	
Staff 4	N	N	off	off	off	off	off	
Staff 5	off	off	off	off	off	off	M	
Staff 6	N	N	N	N	N	N	off	
Staff 7	off	M	off	off	off	M	M	
Staff 8	off	M	off	off	off	M	off	
Staff 9	off	off	off	off	off	off	off	
Cashier	F	off	M	N	M	M	M	
Cashier	off	F	N	M	N	N	N	
Supervisor	F	off	M	N	N	N	N	
Supervisor	off	F	N	M	M	M	M	
Total Cost	442.73	442.73	461.48	420.85	466.55	475.02	475.02	

The total weekly staffing cost of Model 2 in Table 5 which only involving ten staff through eliminating three staff is RM3225.01, which is increased by RM137.51 compared to the staffing cost in Table 3.

TABLE V: MODEL 2: WEEKLY SCHEDULE (NUMBER OF STAFF DECREASED BY THREE PERSONS)

Day Staff	*Mon*	*Tue*	*Wed*	*Thurs*	*Fri*	*Sat*	*Sun*	*Weekly Cost*
Staff 4	M	N	M	F	off	N	N	
Staff 5	M	off	F	M	F	off	N	
Staff 6	N	N	N	N	N	N	off	
Staff 7	N	M	off	off	M	off	off	
Staff 8	off	M	off	off	off	M	M	
Staff 9	off	off	off	off	off	M	M	
Cashier	F	off	M	N	M	M	M	

Cashier	off	F	N	M	N	N	N	3225.01
Supervisor	F	off	M	N	N	N	N	
Supervisor	off	F	N	M	M	M	M	
Total Cost	442.73	442.73	461.48	461.48	466.55	475.02	475.02	

Meanwhile Model 3 in Table 6 shows the total weekly staffing cost is RM3265.64, increased by RM178.14 as compared to the total staffing cost which involved every staff as shown in Table 3.

TABLE VI: MODEL 3: WEEKLY SCHEDULE (NUMBER OF STAFF DECREASED BY FIVE PERSONS)

Day / *Staff*	*Mon*	*Tue*	*Wed*	*Thurs*	*Fri*	*Sat*	*Sun*	*Weekly Cost*
Staff 6	N	N	N	N	off	N	N	3265.64
Staff 7	M	M	M	off	F	N	M	
Staff 8	M	M	off	F	F	M	F	
Staff 9	N	N	F	M	off	M	M	
Cashier	F	off	M	N	M	M	M	
Cashier	off	F	N	M	N	N	N	
Supervisor	F	off	M	N	N	N	N	
Supervisor	off	F	N	M	M	M	M	
Total Cost	442.73	442.73	461.48	461.48	466.55	475.02	515.65	

IV. CONCLUSION

In conclusion, an optimal and feasible weekly retail staff schedule is obtained through the implementation of optimization approach which is integer linear programming approach with the assist of software named LPSolve IDE. In addition, all constraints included hard and soft constraints were totally fulfilled. Through this study, the problem of complexity and large time consuming in workforce scheduling process were solved at the same time. Furthermore, the total staffing cost of the company is successfully minimized compared to the current schedule. This is due to the number of full shift assigned to staff is reduced. Aside from that, the number of staff that works on each day is also reduced to the sufficient amount. Hence, the retail company can save more on staffing cost by solving the overstaff problem. Besides that, the satisfaction among the staff is successfully maximized by maximizing their preferences of shift through fulfilling the soft constraints requirement. Staff's preferences are important to be taken into consideration in workforce scheduling as a satisfied staff always perform better in their work than unsatisfied staff. Consequently, the productivity of the retail company can be increased. However, there is a limitation which can be improved in future investigation where the sample size of this study is small. Therefore, future study is suggested to include a large number of staff and more number of constraints which able to be solved by other metaheuristic methods and comparison can be done with optimization methods.

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