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Using the Excel Solver to Solve Linear Programming Problem of Work Shift Schedule

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Abstract: Scheduling is important in every organization since it establishes order and flow, ensuring that all activities are completed on time. To deal with uncertainties arising from overstaffing and understaffing cases, an optimization approach based on linear programming is proposed and is evaluated using the Microsoft Excel Solver. This study concentrates on a productive method for solving a labour scheduling problem found in a small-scale company, proposing the requirement of part-time labours in each shift, thus offering a logical way of managing these tasks and producing a new schedule each week, by virtue of changing demand for service while maximizing labour preferences. The findings show the total part-time employees that need to be employed has been reduced and the number of employees available for each shift is also shown. The results point to an optimum schedule that uses the solution to reduce the number of part-time employees on the payroll while simultaneously maximizing employee preferences, preventing the company from being understaffed on weekends but overstaffed on weekdays.

Keywords: Excel Solver, Scheduling, Linear Programming

1. Introduction

Scheduling is the process of arranging, controlling and optimizing work and workloads in a production process or manufacturing process. Scheduling may broadly be defined as the allocation of resources to tasks over time in such a way that a predefined performance measure is optimized [1]. The planning process in a building company helps the entrepreneur provide an overview of how the project was planned. Apart from that, it has been discovered that staff scheduling is usually done using spreadsheets to assign schedules to the staff on preferred days and times. The other method of scheduling is to send emails with the schedule information to the appropriate staff members. It has been observed that the method of assigning schedules such as key in staffs shift on spreadsheet manually is time consuming and prone to errors. The Excel Solver enables the development and testing of the created model to minimize excess hours spent by students and maximize their preferences at as

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librarians [2]. Hence, the variable number limitation of Microsoft Excel was overcome. Furthermore, manually integrating all these criteria and constraints into a schedule is a massive task. A manual schedule system may also be susceptible to human errors, resulting in overstaffing or understaffing and the high expenses on the workers will be detected. Workers' scheduling is essential in any organization since an excess or lack of workers results in a loss of time and money for the company. The company's outcome will be improved by proper worker scheduling. Many organizations offer jobs that must be completed in shifts. Hence, it is essential to schedule employer's inappropriate shifts so that both the employer and the employee benefit and the company's productivity is improved [3].

The scheduling problem of employees encompasses several issues, including the organization, personnel, demand requirements, regulations, and the schedule, all of which must be considered and balanced [4]. Personnel scheduling issues are common in the service business including the scheduling of hospital nurses, hotel staff, bank checking encoder, hotel and airline reservation staff, telephone operators, patrol staff, restaurant waiters or waitresses, construction company labour scheduling and others [5]. A detailed schedule was drawn up before the work in each area began. The critical task of cost-effective scheduling must be undertaken by front line managers or contractors in a service or building company. Therefore, this study aims to model the work shift problem using the linear programming method while minimizing the number of part-time employees on its payroll as well as maximizing employees' preferences. All linear programming problems (LPP) share similar characteristics which are objective function, constraints and decision variables [6]. As a result, linear programming denotes maximizing or minimizing a quantity (the objective function) when working with restricted resources (the constraints). In LPP, it is preferable to express the objective and constraints as linear equations or inequalities.

2. Methodology

Date	Day	Staff1 (M1)	Staff2 (M2)	Staff3 (M3)	Staff4	Staff5	Staff6	Staff7	St
01-Jul-19	Monday	free	09-15	15-22	15-22	free	bo	10-15	
02-Jul-19	Tuesday	09-17	16-21	18-22	10-15	free	-	15-22	
03-Jul-19	Wednesday	09-17	16-22	free	15-21	09-15	bo	free	
04-Jul-19	Thursday	free	15-22	09-14	free	16-22	bo	10-15	
05-Jul-19	Friday	09-17	15-22	07-15	09-15	10-16	bo	16-22	
06-Jul-19	Saturday	14-22	15-22	10-15	free	free	bo	10-15	
07-Jul-19	Sunday	09-17	free	15-22	15-22	09-15	bo	15-22	
08-Jul-19	Monday	09-17	free	15-22	16-22	free	bo	15-22	
09-Jul-19	Tuesday	free	09-14	free	10-15	16-22	-	free	
10-Jul-19	Wednesday	free	free	free	go	09-15	bo	16-22	1
11-Jul-19	Thursday	09-17	16-22	15-22	go	09-15	bo	15-21	0
12-Jul-19	Friday	14-22	10-15	16-22	go	free	bo	09-14	1
13-Jul-19	Saturday	09-17	07-15	10-15	go	09-15	bo	16-22	f
14-Jul-19	Sunday	free	09-14	09-17	go	15-22	bo	free	1
15-Jul-19	Monday	09-17	16-22	free	go	free	bo	free	1
16-Jul-19	Tuesday	09-17	free	10-15	-	10-16	bo	15-22	f
17-Jul-19	Wednesday	09-17	16-22	09-15	go	15-22	bo	free	1

Figure 2.1: Work schedule for employees in July 2019

Figure 2.1 shows the data for the shift schedule of 30 part-time employees in July 2019 by a retail company [7]. Their attention was centred on full-time staff. They did not take part-time employees and trainees into account. Among the personnel, there were one manager and two assistant managers. All employees were required to have a weekly day off, and two consecutive days off were occasionally available. After describing the unequal workload, something might be done: a revised work schedule. Unreasonable overwork, a lack of breaks between shifts, and a lack of days off: the new and improved timetable should avoid all of this. Given all of these considerations, it is evident that personnel scheduling may be a complicated and time-consuming operation [8].

2.1 Model formulation

The objective is to minimize the number of part-time employees on its payroll by applying linear programming using the Solver. Therefore, the minimization of Z is shown.

Objective function:

$$\text{Minimize } Z = \sum_{i=1}^{7} x_i$$

Subject to:

$$x_1 + x_4 + x_5 + x_6 + x_7 \geq 17$$
$$x_1 + x_2 + x_5 + x_6 + x_7 \geq 13$$
$$x_1 + x_2 + x_3 + x_6 + x_7 \geq 15$$
$$x_1 + x_2 + x_3 + x_4 + x_7 \geq 19$$
$$x_1 + x_2 + x_3 + x_4 + x_5 \geq 14$$
$$x_2 + x_3 + x_4 + x_5 + x_6 \geq 16$$
$$x_3 + x_4 + x_5 + x_6 + x_7 \geq 11$$

Restriction condition $\sum_i x_i \geq 0$

where
i = day of the employees will work on
x_i = the shift taken from day 1 to day 7
Z = number of part-time employees

2.2 Notation

In this approach, from the constraints and objective function shown in model formulation, the focus is on demand for 5 working days per week with 2 days off in a row to decide if there are enough workers to cover all shifts. Table 2.1 shows the decision variables x_i where $i = 1,2,3,\ldots,7$ represent the number of workers who will work on five consecutive days beginning on Monday ($i = 1$), Tuesday ($i = 2$), Wednesday ($i = 3$), Thursday ($i = 4$), Friday ($i = 5$), Saturday ($i = 6$), and Sunday ($i = 7$).

Table 2.1: Explanation of decision variables

Variables	Mon	Tue	Wed	Thu	Fri	Sat	Sun
x_1	Working day	**Day off**	**Day off**	Working day	Working day	Working day	Working day
x_2	Working day	Working day	**Day off**	**Day off**	Working day	Working day	Working day
x_3	Working day	Working day	Working day	**Day off**	**Day off**	Working day	Working day
x_4	Working day	Working day	Working day	Working day	**Day off**	**Day off**	Working day
x_5	Working day	Working day	Working day	Working day	Working day	**Day off**	**Day off**
x_6	**Day off**	Working day	Working day	Working day	Working day	Working day	**Day off**
x_7	**Day off**	**Day off**	Working day	Working day	Working day	Working day	Working day

2.3 Implementation of the Excel Solver on the work schedule model

Employee Schedulling Model										
Decision Variables: Number of Employees Starting Their Five-day Shift on Various Days										
MON	TUE	WED	THU	FRI	SAT	SUN	Objective is to Minimize Total Employees			
0	0	0	0	0	0	0	0			
Constraint on Employee Avalabilities										
Days	Shift							Number of Employees Available		Number of Employees Needed
MON	1	0	0	1	1	1	1	0	>=	17
TUE	1	1	0	0	1	1	1	0	>=	13
WED	1	1	1	0	0	1	1	0	>=	15
THU	1	1	1	1	0	0	1	0	>=	19
FRI	1	1	1	1	1	0	0	0	>=	14
SAT	0	1	1	1	1	1	0	0	>=	16
SUN	0	0	1	1	1	1	1	0	>=	11

Figure 2.2: Number of total employees before maximize

A variety of part-time staff on various days of the week is used to minimize the number of part-time employees as well as to maximize employees' preferences. From Monday to Sunday, several employees are required for each day. The Excel sheet in Figure 2.2 shows the employee scheduling model where the number of employees starting their five-day work shift in five consecutive days as the decision variables.

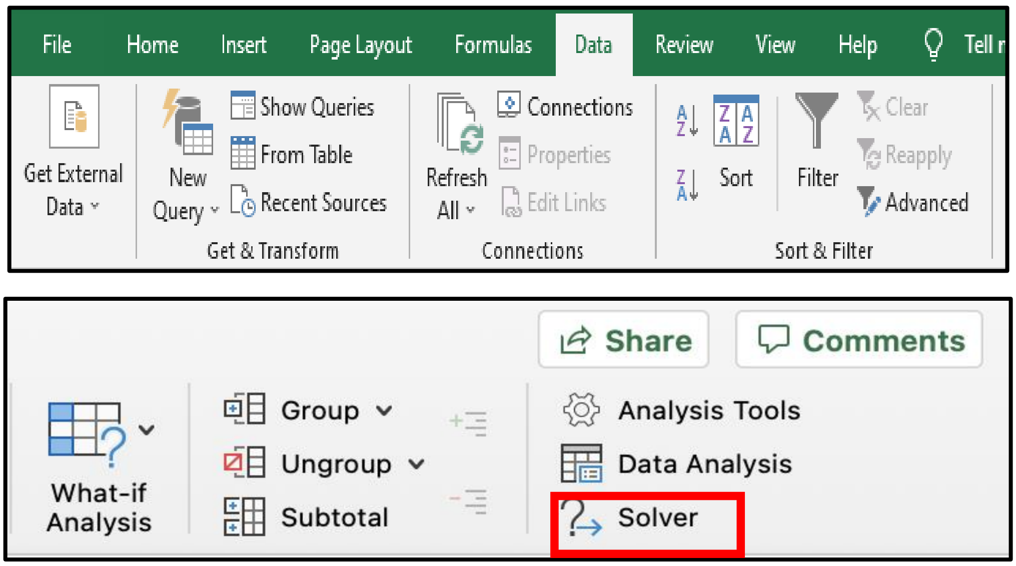

Figure 2.3 Excel Solver tool option

Figure 2.3 shows the Excel solver tool option which can be seen under the Data tab. It is a feature in Excel that allows to determine an optimal value for a formula in one cell called the objective cell, subject to particular constraints or limits on the values of other formula cells on the worksheet. In other words, the Excel Solver uses a set of cells known as decision variables to compute the formulas in the objective and constraint cells. Hence, the result can be seen in the next section.

3. Results and Discussion

Rebuilding the timetable with available workers is typically easy, but modifying the schedule may need changes to other job schedules as well. The daily report on the certain shift in a day (1, 0) shows the availability of employees. A value of 1 for a certain cell indicates that the employee is required for work, whereas a value of 0 indicates that the employee is not required on that day [9]. A model that includes the majority of aspects of linear programming is presented in this section. The majority of businesses consider their horizon of planning as a week. Each day of the week necessitates a certain number of part-time employees. Each employee must be present at work for five days in a row. The company intends to meet its daily needs with only part-time employees. Hence, a solution to this model is built in order to achieve its optimality and efficiency.

3.1 Results analysis

Employee Schedulling Model							
Decision Variables: Number of Employees Starting Their Five-day Shift on Various Days							
MON	TUE	WED	THU	FRI	SAT	SUN	Objective is to Minimize Total Employees
6	3	3	7	0	3	1	23

Constraint on Employee Avalabilities										
Days	Shift							Number of Employees Available		Number of Employees Needed
MON	1	0	0	1	1	1	1	17	>=	17
TUE	1	1	0	0	1	1	1	13	>=	13
WED	1	1	1	0	0	1	1	16	>=	15
THU	1	1	1	1	0	0	1	20	>=	19
FRI	1	1	1	1	1	0	0	19	>=	14
SAT	0	1	1	1	1	1	0	16	>=	16
SUN	0	0	1	1	1	1	1	14	>=	11

Figure 3.1: The solution obtained after running test

The solution in Figure 3.1 represents those 6 employees who begin their shift on Monday, 3 employees who begin their shift on Tuesday, 3 employees who begin their shift on Wednesday, 7 employees who begin their shift on Thursday, no one who begins their shift on Friday, 3 employees who begin their shift on Saturday, and 1 employee who begins their shift on Sunday. By applying the Excel Solver, 23 employees are sufficient to cover all working days. Furthermore, all constraint conditions are satisfied. On day one, 17 people are required, and there are already 17 available. This optimal solution calls for employees to begin work each day of the week for five consecutive days. Similarly, availability and requirements are balanced at the end of day 2. On days 3 and 4, employee availability is one higher than required, however, on day 5, employee availability is five more than required. On day 6, availability and requirements are balanced. However, on day 7, employee availability is three more than required.

3.2 Result output

Based on the objectives, the results show that the number of part-time employees on its payroll is being minimized, as well as maximizing employees' preferences by using linear programming. For the first objective, the objective is to model the work shift problem using linear programming method. As in the methodology, the linear programming of the work shift model is created with the help of the Solver tool. For the second objective, it is necessary to obtain a minimum number of part-time employees to work for the company by using the Solver so that the company can reduce any extra cost on the workers. Therefore, from a big number of employees in the company must have reduction towards the number. The result shows that from 30 employees it reduced to 23 employees. Furthermore, the third objective requires us to maximize employees' preferences by using the Solver. The company states that their employees need to be working for 5 days in a row then receive 2 days off either on the weekdays, weekends or both. Each of the employees will obtain the same preferences. The total number of employees available must always be more or equal to the number of employees needed by the company for each day to ensure the company does not face any insufficiency of employees to work on a particular day as well as to maximize each of the employees by receiving the same preferences.

A report from the Excel Solver engine will be useful to prove that all constraints and optimality conditions are satisfied, as shown in Figure 3.2. The information is provided concerning the status of the constraint, in terms of binding or not binding. The summary of the results can be seen in objective cell and variable cells, where it shows the original and final values. The constraints for Wednesday, Thursday, Friday and Sunday show the amount of slack of 1, 1, 5 and 3, respectively indicated for Not Binding restrictions. It reflects the distance of the current solution from the stated limit. The number of slack in a constraint indicates how close it is to becoming a binding constraint. The constraints on Monday, Tuesday & Saturday show Binding restriction and the slack is 0 where constraints are at their limits with no surplus.

A slack variable is a variable that is used to change an inequality constraint into an equality constraint. When slack is zero, the restriction is binding since it limits the adjustments that may be made from that point. When a slack variable is positive, the constraint is non-binding since it does not limit the modifications that may be made from that point. If a slack variable is negative at some point, the point is infeasible. Hence, through this process of creating an efficient work shift for the part-time employees, both objectives to minimize the number of part-time employees on its payroll and to maximize employees' preferences have been achieved.

Objective Cell (Min)

Cell	Name	Original Value	Final Value
$I$6	Objective is to Minimize Total Employees	0	23

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$6:$H$6				
$B$6	MON	6	6	Integer
$C$6	TUE	3	3	Integer
$D$6	WED	3	3	Integer
$E$6	THU	7	7	Integer
$F$6	FRI	0	0	Integer
$G$6	SAT	3	3	Integer
$H$6	SUN	1	1	Integer

Constraints

$I$10:$I$16 >= $K$10:$K$16					
$I$10	MON Number of Employees Available	17	$I$10>=$K$10	Binding	0
$I$11	TUE Number of Employees Available	13	$I$11>=$K$11	Binding	0
$I$12	WED Number of Employees Available	16	$I$12>=$K$12	Not Binding	1
$I$13	THU Number of Employees Available	20	$I$13>=$K$13	Not Binding	1
$I$14	FRI Number of Employees Available	19	$I$14>=$K$14	Not Binding	5
$I$15	SAT Number of Employees Available	16	$I$15>=$K$15	Binding	0
$I$16	SUN Number of Employees Available	14	$I$16>=$K$16	Not Binding	3
$B$6:$H$6=Integer					

Figure 3.2: Report obtained from Excel Solver

4. Conclusion

As conclusion, staff scheduling is the process of assigning a suitable number of the personnel to jobs on each workday. It is necessary to determine when staff members are available to have their shift starts and when they will be required to work. Staff scheduling is a difficult scheduling problem that frequently influences the execution of a project in a small-scale industry. An overview of the planning and staff scheduling problem in a small-scale company is shown in this study, which shows the minimum requirement of manpower for the proper execution of a job in each shift, the temporary employees that must be hired from outside to meet the shift demands and the employee that must be hired. It should be highlighted that the constraints indicated in this system are in terms of the need for a part-time employee.

The results were obtained to maximize the fairness of the schedule while considering all of the restrictions, with the goal to utilize time and effort efficiently and balance the workload to produce more satisfied and effective results. Using Excel Solver, the amount of personnel employed by this company has been demonstrated which is 23 employees are sufficient to cover all working days and it is more than sufficient to conduct day-to-day operations. The number of employees available to work every day is between 14 to 20 persons from Monday to Sunday. As a result, it has been proven that an unfair timetable result from lack of management abilities in this area. As staff availability varies and changes from week to week, scheduling becomes even more important for the effective operation of a shift.

For future work suggestions, the only condition that has not yet been addressed is the morning/afternoon shift equality. A suggested solution for that need is to have alternate shifts: a person works one week in the morning and the next the afternoon and so on. Another futuristic development in the field of the area is evaluating the mean behaviour of approximation, which consists of experimental investigations employing task scheduling, which will be valuable and significant for future researchers since it is employed real-world challenges. Lastly, a plausible alternative to these problems is to finding a more efficient and easy way of organizing jobs and resources.

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