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Bus Drivers Scheduling by using Linear Programming

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Abstract
Scheduling is essential to the proper running of the process industries, especially in today's competitive global market. Scheduling can be done in staff management to improve profit margins. This study considers the scheduling of bus drivers for a private travel agency in India. The purpose of this study is to optimize the driver's schedule based on five days' work and three shifts in succession. A linear programming model is established where each driver will be given two days off on the condition that they drive three shifts in a row. Two models have been solved and the results obtained show the minimal number of drivers required for each shift in a day. This problem was solved using an Excel solver. Model 1 was constructed to reduce the total number of bus drivers in a day for a week where bus drivers work for five days in a row while guaranteeing that the required workforce is sufficient. Model 2 was created from the optimal solution Model 1 to reduce the total number of bus drivers in each shift in a day where the bus drivers work three shifts in a day. The constraints are determined by calculating the maximum number of drivers required for each shift, with the goal of reducing the number of drivers per day. As a result, the number of drivers working each shift changes every day. For each shift in a day there shows a huge variation in the number of drivers starting the first shift and third shift.
Keywords: Mathematical model, Linear Programming, Scheduling

1. Introduction

Scheduling is a commonly used technique that involves handling multiple tasks and constraints at once. Staff scheduling is a typical issue for most businesses, whether they are in the service sector or operate industrial operations. Workforce scheduling problems occur in a variety of service industries, including nurses in hospitals, police officers, restaurants, vehicles, airlines, telephone operators, and others. A typical problem of this type is that the scheduler must assign an appropriate day off to each of the employees who work standard shifts with different starting times while ensuring that the required number of employees are on duty throughout the day and week. The aim is to assign employees to tasks, work shifts, or rest times while taking into consideration organizational and legal rules, employee talents and preferences, demand needs, and other relevant criteria.

Employees will leave their jobs for a variety of reasons, but the primary ones are usually because of inadequate work-life balance, free time, and flexibility [1]. Scheduling employees can be a difficult task. A few challenges we may face are finding the perfect shift to accommodate all of your employee's availability. Ensuring that employees get the hours they deserve for seniority is one of challenges for scheduler [2]. Other than that, unexpected absences from employees will provide difficulties for the scheduling [3].

Managers who still use pen and paper to compile and disseminate personnel rosters are not only making their lives a million times more difficult, but they are also prone to errors and misunderstandings. Worse, a lot of back and forth calling and messaging on managers' and employees' personal phones is time-consuming, unproductive, and can lead to additional concerns such as improper messaging or a lack of work-life separation [4].

Workforce scheduling, also known as labour or staff scheduling, is a tough and time-consuming issue that must be solved by any corporation or company that employs people who work in shifts or on irregular working days. Without the use of a technique such as linear programming, creating a schedule with the optimal number of shifts (optimal schedule) requires great accuracy and significant processing time. The time required to create an optimal work schedule ranges from 2 to 7 days, depending on the availability of data, tools, accuracy, and experience of the schedule creator. Therefore, this paper presents a mathematical model to minimize the number of bus drivers for each shift in a day.

The objectives of this research are (1) to apply a linear programming model to minimize the number of bus drivers for each shift and (2) develop a schedule for the bus drivers.

In this research, the attention is focused on minimizing the number of bus drivers for each shift for a day. The scheduling data of private travel agencies in India from previous paper have been considered. Based on the data, a linear programming model was used to minimize the number of bus drivers for each shift and will be solved by using excel solver.

The significance of this research is to help employers organize the scheduling shift for the bus driver. Optimal scheduling of bus drivers can result in significant savings on operating costs. Many companies offer jobs that are done in shifts. It is very important to schedule employers on the right shifts so that both the employer and the employee benefit, and so that employers can perform optimally to improve the company's performance.

2. Literature Review

In any organisation, the staff scheduling problem entails identifying demand requirements, designing the most appropriate work fundamental blocks (shifts, duties, pairings, etc.), organising those blocks into lines of work or schedules, and allocating the staff elements to the schedules. As with many other planning problems, these involve decisions that are not independent of one another and can be seen in a timeline perspective, ranging from long to short-term planning, strategic to tactical and operational decision-making, and thus temporal dependencies between them must be considered [5].

Diverse work environments have different requirements, and as a result, staff scheduling problems with distinct characteristics occur. Constraints and objectives vary depending on the problem's characteristics while modelling it. There are several approaches to resolving the scheduling issue. Scheduling is an essential component of the successful operation of process industries. Profit margins are so small in today's competitive globalised market, scheduling is critical for most businesses. There are a few techniques that can be utilised to solve scheduling issues.

Linear Programming (LP) approach to determine how the police department can minimize the total number of officers needed to meet all shift requirements. The LP model is also used to present how many duty officers should report to work at the beginning of each period to minimize the staffing requirements for a duty day [6].

Next, the LP techniques used to resolve the labour scheduling problem in a construction company by recommending an expected labour costs for a week and the part-time labour requirements for each shift [7]. The most common constraints that apply to labour scheduling are requirement of skilled labourers in each shift, same working shift for several days in a row, assignments for shift type(s), maximum number of consecutive working days, minimum amount of leisure time between two shifts, day off, for specific labour, there is a maximum number of hours that can be worked, and no consecutive shifts are permitted. LP technique provides a logical way to organize these tasks and create a new schedule each week that takes into account the changing demand for services while minimizing labour costs and maximizing employee preferences.

Furthermore, a mathematical model was constructed by using LP. The minimum number of drivers required for each shift in a day has been computed using this methodology, which reduces the amount spent on reserved drivers [8]. The goal of this study is to reduce the number of drivers assigned to each shift, thereby reducing the amount of money spent on reserved drivers. In regions where driver allocation is done on a rotating basis, the same mathematical methodology has been employed. The functions studied in the mathematical model are assumed to be linear in nature in this study. If the results produced after solving the problem are non-integer, the problem is extended as an Integer Linear Programming Problem by adding one more integer constraint on the variables. The information was gathered from one of the transport corporations in a metropolitan city. The real-world problem was represented as a mathematical model using the data provided, and the optimal solution was found using the LP technique. The same approach was used to determine the best allocation of the resources. For a private travel agency, the same model was used to determine the best driver distribution from Monday to Friday. All of the subproblems are solved, and optimal solutions are tabulated using a computation technique with Excel solver.

In addition, during the Covid-19 pandemic, optimization models were employed to handle flexible staff scheduling challenges as well as some of the key issues that arose from efficient labour management [9]. The focus is on new optimization models that simultaneously consider demand requirements, employees' personal and family duties, and anti-Covid-19 measures. The models allow determining the working mode to be assigned to the employees: working remotely or on-site, based on the anti-Covid-19 measures. An alternative partition of a workday into shifts to the typical two shifts, morning and afternoon, is offered in order to boost employee happiness and maintain the best possible work-life balance. The model was tested on real data provided by the University of Calabria's Department of Mechanical, Energy, and Management Engineering.

LP used to study and analyses the scheduling process in practice and the job shop scheduling problem is a well-known combinatorial optimization problem [10]. The goal of this study is to minimize the schedule's fairness using a variety of different constraints and evaluation functions. This paper demonstrates how the job scheduling problem can be solved using linear programming and how BISMI Trades has successfully implemented it. For the purpose of optimizing task scheduling, a linear programming model is designed for the business. The optimal solution is found using Excel's solver in a numerical illustrative example of personnel scheduling for a four-hour shift. Finally, some conclusive findings have led to suggested recommendations.

Binary and integers variables are used in order to model restaurant staffing timetabling problem [11]. The main purpose of this research is to create a model that can generate a timetable that is suitable for Matur og Drykkur's Restaurant needs as well as those of other restaurants in similar situations. Binary and integers variable method provide an answer to the question of how many staff members Matur og Drykkur Restaurant requires to remain open for lunch and supper successfully and cost-effectively, as well as what strategy may be used to reduce personnel costs and overtime while meeting the restaurant's demands.

Moreover, Thompson's framework was used for a restaurant with a staff of 30 full-time and 19 part-time employees [12]. A weekly planning horizon addresses both staffing and scheduling issues. Based on previous experience, the management determined a full-time to part-time ratio of 6:4, which they felt would ensure acceptable service standards. The established Integer Programming (IP) model assumes that full-time employees are more productive than part-timers, but that this comes at a cost. As a result, the problem's answer is to reduce overall labour expenses while maintaining adequate service levels. The results showed an increase in the scheduling system's overall efficiency, as well as a reduction in the labour costs of overstaffing and the opportunity costs of understaffing. The topic of high turnover costs in hospitality firms is highlighted in this work. A well-organized schedule can help employees feel more engaged and motivated, resulting in a higher rate of workforce retention. However, the model has certain flaws, such as not taking into account employees' preferences or availability, which can be crucial to their job retention.

A mathematical model for the nurse scheduling problem based on the concept of a multi-commodity network flow model [13]. The suggested approach was tested using both hypothetical and benchmark scenarios before being used for a real-world case study in an Egyptian hospital. The results show that utilising the proposed approach to generate the schedule required to solve the problem is advantageous. Furthermore, it demonstrates the superiority of the acquired schedule over those generated manually by the supervisor head nurse since it increases nurse satisfaction by developing a fair scheduling system that considers nurses' preferences while also lowering overall overtime costs by 36%.

An employee shift scheduling issue in the service industry is dealt with using a multi-objective decision model [14]. The goal of the problem is to accommodate employee preferences while reducing the overall workload of the workforce. A multi-objective decision model has been created within this multi-objective structure by taking into account the needs of the workforce. The weights/priorities of the goal functions were then determined using a multi-criteria decision-making model. The issue is scalarized using the Weighted Sum Scalarization (WSS) and Conic Scalarization (CS) methods with the aid of these derived weights. When Pareto solutions are compared, it is seen that more Pareto solutions are obtained with CS method. Additionally, in comparison to the manually created schedule, superior schedules have been obtained in a very short period of time.

3. Methodology

3.1 Data Collection

Data has been collected from a private travel agency in India [8]. The scheduling of drivers for a private travel agency operating on all days of the week is considered and the data are presented in Table 1. Each driver is assumed to work for six days in a row, with four shifts per day. A model was developed in which each driver worked for six days and two shifts in a row [8]. However, this study will investigate the case when the driver works five days and three shifts in a row.

Table 1: Data from a private travel agency

Days	**Number of Drivers**				
		Shifts			
	Total	1	2	3	4
Monday	100	30	20	30	20
Tuesday	80	25	15	25	15
Wednesday	90	25	20	25	20
Thursday	85	30	15	30	10
Friday	95	30	15	35	15
Saturday	110	25	25	40	20
Sunday	70	10	25	25	10
Total		175	135	210	110

3.2 Mathematical Model

This section will discuss two models for determining the minimum number of drivers needed for each shift in a day for a week.

3.2.1 Model 1

The first model, Model 1 will investigate mathematical model to minimize the number of bus drivers when driver works 5 days consecutively in a week.

Let x_i be the number of drivers who will be on duty on i^{th} $(i = \text{Monday to Sunday})$. Consider the allocation of drivers as in Table 2. For instance, x_2 represent number of bus drivers who will be on duty on Tuesday.

Table 2: Allocating a driver for five consecutive days of work

	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Monday							
Tuesday							
Wednesday							
Thursday							
Friday							
Saturday							
Sunday							

Drivers will work

The LP formulation is given as follows:

$$\textbf{Minimize Z} = \mathbf{x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7} \quad (1)$$

Subject to

$\mathbf{x_1 + x_4 + x_5 + x_6 + x_7 \geq 100}$ (Monday constraint) (2)
$\mathbf{x_1 + x_2 + x_5 + x_6 + x_7 \geq 80}$ (Tuesday constraint) (3)
$\mathbf{x_1 + x_2 + x_3 + x_6 + x_7 \geq 90}$ (Wednesday constraint) (4)
$\mathbf{x_1 + x_2 + x_3 + x_4 + x_7 \geq 85}$ (Thursday constraint) (5)
$\mathbf{x_1 + x_2 + x_3 + x_4 + x_5 \geq 95}$ (Friday constraint) (6)
$\mathbf{x_2 + x_3 + x_4 + x_5 + x_6 \geq 110}$ (Saturday constraint) (7)
$\mathbf{x_3 + x_4 + x_5 + x_6 + x_7 \geq 70}$ (Sunday constraint) (8)

The non-negativity constraint on the variables

$$x_1, x_2, x_3, x_4, x_5, x_6, x_7 \geq 0 \quad (9)$$

The main objective of the problem is to minimize the total number of drivers in a week. The constraints are formulated using the data from Table 2. The agency must ensure that enough bus drivers are working on each day of the week. For example, at least 100 bus drivers must be working on Monday. This means that the number of bus drivers working on Monday is given in constraint (2). Adding similar constraints for the other six days of the week and the sign restrictions $x_i \geq 0\ (i = 1, 2, \dots, 7)$ yields the others constraint (3) until (8). Same goes to another six days in a week.

3.2.2 Model 2

The second model, Model 2 will investigate mathematical model to minimize the number of bus drivers when driver works 3 shifts consecutively in a day.

Let y_i be the number of drivers who will be on duty on i^{th} shifts where *i*= 1,2,3 and 4. Consider the allocation of drivers as in Table 3.

Table 3: Allocating a driver for three consecutive shifts in a day

	y_1	y_2	y_3	y_4
Shift 1				
Shift 2				
Shift 3				
Shift 4				

Drivers will work

The LP formulation is given as follows:

$$\textbf{Minimize Z} = y_1 + y_2 + y_3 + y_4 \quad (10)$$

Subject to

Subproblem: 1 (Monday)

$y_1 + y_3 + y_4 \geq 30$ (Shift 1 constraint) (11)
$y_1 + y_2 + y_4 \geq 20$ (Shift 2 constraint) (12)
$y_1 + y_2 + y_3 \geq 30$ (Shift 3 constraint) (13)
$y_2 + y_3 + y_4 \geq 20$ (Shift 4 constraint) (14)
$y_1 + y_2 + y_3 + y_4 \leq 101$ (Monday constraint) (15)

Subproblem: 2 (Tuesday)

$y_1 + y_3 + y_4 \geq 25$ (Shift 1 constraint) (16)
$y_1 + y_2 + y_4 \geq 15$ (Shift 2 constraint) (17)
$y_1 + y_2 + y_3 \geq 25$ (Shift 3 constraint) (18)
$y_2 + y_3 + y_4 \geq 15$ (Shift 4 constraint) (19)
$y_1 + y_2 + y_3 + y_4 \leq 81$ (Tuesday constraint) (20)

Subproblem: 3 (Wednesday)

$y_1 + y_3 + y_4 \geq 25$ (Shift 1 constraint) (21)
$y_1 + y_2 + y_4 \geq 20$ (Shift 2 constraint) (22)
$y_1 + y_2 + y_3 \geq 25$ (Shift 3 constraint) (23)
$y_2 + y_3 + y_4 \geq 20$ (Shift 4 constraint) (24)
$y_1 + y_2 + y_3 + y_4 \leq 91$ (Wednesday constraint) (25)

Subproblem: 4 (Thursday)

$y_1 + y_3 + y_4 \geq 30$ (Shift 1 constraint) (26)
$y_1 + y_2 + y_4 \geq 15$ (Shift 2 constraint) (27)
$y_1 + y_2 + y_3 \geq 30$ (Shift 3 constraint) (28)
$y_2 + y_3 + y_4 \geq 10$ (Shift 4 constraint) (29)
$y_1 + y_2 + y_3 + y_4 \leq 96$ (Thursday constraint) (30)

Subproblem: 5 (Friday)

$y_1 + y_3 + y_4 \geq 30$ (Shift 1 constraint) (31)
$y_1 + y_2 + y_4 \geq 15$ (Shift 2 constraint) (32)
$y_1 + y_2 + y_3 \geq 35$ (Shift 3 constraint) (33)
$y_1 + y_3 + y_4 \geq 15$ (Shift 4 constraint) (34)
$y_1 + y_2 + y_3 + y_4 \leq 96$ (Friday constraint) (35)

Subproblem: 6 (Saturday)

$\mathbf{y_1 + y_3 + y_4 \geq 25}$	(Shift 1 constraint)	(36)
$\mathbf{y_1 + y_2 + y_4 \geq 25}$	(Shift 2 constraint)	(37)
$\mathbf{y_1 + y_2 + y_3 \geq 40}$	(Shift 3 constraint)	(38)
$\mathbf{y_2 + y_3 + y_4 \geq 20}$	(Shift 4 constraint)	(39)
$\mathbf{y_1 + y_2 + y_3 + y_4 \leq 111}$	(Saturday constraint)	(40)

Subproblem: 7 (Sunday)

$\mathbf{y_1 + y_3 + y_4 \geq 10}$	(Shift 1 constraint)	(41)
$\mathbf{y_1 + y_2 + y_4 \geq 25}$	(Shift 2 constraint)	(42)
$\mathbf{y_1 + y_2 + y_3 \geq 25}$	(Shift 3 constraint)	(43)
$\mathbf{y_2 + y_3 + y_4 \geq 10}$	(Shift 4 constraint)	(44)
$\mathbf{y_1 + y_2 + y_3 + y_4 \leq 89}$	(Sunday constraint)	(45)

The non-negativity constraint as

$$\mathbf{y_1, y_2, y_3, y_4 \geq 0} \quad (46)$$

Since each day has four shifts, with $i = 4$ and each driver would drive three shifts consecutively, the seven subproblems are formulated with the common objective function. The constraints are formulated using the data from Table 3. The agency must ensure that enough bus drivers are working on each shift in a day. For example, at least 30 bus drivers must be working on shift 1 on Monday. This means that the number of bus drivers working on Monday is given in the constraint (11). Adding similar constraints for the other three shift of the days and the sign restrictions $y_i \geq 0\ (i = 1,2,3,4)$ yields the others constraint (12) until (14).

Adding another constraint (15) to make sure the number of bus drivers do not exceed 110 which the maximum required number of bus drivers. The maximum required number of bus driver is obtained from Model 1. Constraint (15) represent the total limit of bus driver on Monday. Same goes to another six days in a week.

4. Results and discussion

This part will go through the results of the mathematical model that was solved using an excel solver to minimize the number of bus drivers needed for each shift in a day.

4.1. Model 1

Table 4 below shows the result for Model 1 using Excel solver. Let x_i be the number of drivers who will be on duty on i^{th} $(i = \text{Monday to Sunday})$. There will be 22 drivers working on Monday and Tuesday while there is no drivers will work on Friday and Sunday. There are the highest number of drivers work on Thursday which is 42 drivers. There are 10 drivers will work on Wednesday.

Let c_i be the constraint on i^{th} $(i = \text{Monday to Sunday})$. From Table 4 below, there is the highest number of drivers will start work on Saturday which is 111 drivers. Next, there is same number of drivers which is 96 drivers will start work on Thursday and Friday. Other than that, there are 101, 81, 91 and 89 drivers will start work on Monday, Tuesday, Wednesday and Saturday.

Table 4: Result for Model 1 using Excel solver

x_i	22	22	10	42	0	37	0
c_i	101	81	91	96	96	111	89

4.2. Model 2

Table 5 below shows the result for Model 2 using Excel solver. Let y_i be the number of drivers who will be on duty on i^{th} shifts where *i*= 1,2,3 and 4. Therefore, Table 5 displays the number of bus drivers who will work on each shift in a day for a week.

Table 5: Result for Model 1 and Model 2 using Excel solver

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
y_1	13	12	10	20	20	20	15
y_2	3	2	5	0	5	15	10
y_3	13	12	10	10	10	5	0
y_4	3	2	5	0	0	0	0

Based on the results from Model 1 and Model 2, the new timetable for a private travel agency in India is shown as in Table 6.

Table 6: New timetable for a private travel agency in India

Days	**Number of Drivers**				
		Shifts			
	Total	**1**	**2**	**3**	**4**
Monday	32	13	3	13	3
Tuesday	24	11	1	11	1
Wednesday	30	10	5	10	5
Thursday	30	20	0	10	0
Friday	35	20	5	10	0
Saturday	40	20	15	5	0
Sunday	25	15	10	0	0

We can observe from Table 6 that the number of drivers working each shift changes every day. For each shift in a day there shows a huge variation in the number of drivers starting the first shift and third shift. This indicates that a large proportion of drivers begin work on Saturdays.

Conclusion

The major purpose of this project was met by developing a mathematical model to reduce the total number of bus drivers in each shift throughout the day, which was solved using an Excel solver. The model was created using all of the requirements, which include bus drivers working 5 days in a row and 3 shifts in a day. As a result, the model produced a staff schedule. Model 1 was constructed to reduce the total number of bus drivers in a day for a week where bus drivers work for five days in a row while guaranteeing that the required workforce is sufficient. Model 2 was created from the optimal solution Model 1 to reduce the total number of bus drivers in each shift in a day where the bus drivers work three shifts in a day.

There may be instances when linear programming is not the best optimization technique to use. For example, where there are multiple objectives, nonlinear objective functions and/or constraints, or soft constraints (that can be violated) rather than hard constraints (that cannot be violated), other more appropriate optimization techniques such as multiple objective linear programming, goal programming, or nonlinear programming should be identified and used instead. Since this research involves day off and shifts problems, it is preferable to utilize a method that can handle multiple objectives.

The optimal solution from LP technique is in the form of a decimal. Notice that the number of bus drivers cannot be in decimal since it is a human. There is no way that the optimal linear programming solution could have been rounded to obtain the optimal all-integer solution. It does not imply false, but it is inaccurate. Therefore, integer programming can be used to show an optimal solution to the bus driver scheduling problem.

In this study, linear programming techniques have been applied to solve bus drivers scheduling problems. In the next research, there may be need of applying multi objectives techniques because this problem required workers to works five days and three shifts in a row. The multi-objective problem (also known as the based multi-objective programming problem) is an area of mathematics that deals with optimization problems involving two or more objective functions that must be optimized simultaneously.

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