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Optimizing Toll Collector Scheduling using Goal Programming

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ABSTRACT

The importance of providing an effective shift work schedule cannot be overstated, particularly when considering the continuous 24-hour service requirement. Each employee has their own schedule preferences, and while some positions offer just one or two shifts, others encompass three separate scheduling periods within a day. The issue arises when these varying schedules lead to disparities among workers of toll collectors in terms of overall time spent, creating an inequitable situation. Unfortunately, the objectives of the Bentong Toll Plaza and the preferences of the toll collectors have not been in harmony, which could potentially impact the performance and work-life balance of the toll collectors. The ongoing challenge faced by managers is the selection of the most suitable shift schedule. Thus, this study aims to introduce a new cyclic scheduling approach to streamline the task of creating schedules at Bentong Toll Plaza. Goad programming is applied to meet the requirements of four rigid constraints and three flexible constraints. The initial schedule is used for the first 15 days and then systematically rotated for another 15 days until all toll collectors have experienced all 15 schedule sets. This scheduling process was facilitated through the utilization of Lingo software, resulting in an optimized 15-day shift schedule for toll collectors. The third goal was achieved, which was that each toll collector was assigned the same amount of work. However, the first and second goals are not entirely met, but this has a minimal impact on the toll collectors due to the schedule rotation. In conclusion, it has been proven that the generated schedule pattern provides a better schedule in terms of providing each toll collector with the same total number of shifts and off days.

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1. Introduction

Scheduling is a time-consuming task in organizations where work is done around the clock. An employee's work schedule includes the days and times that they are scheduled to work. The nature of the work schedule varies based on the organization and roles involved, ranging from a traditional 40-hour-per-week, Monday-to-Friday arrangement to potentially fluctuating on a daily, weekly, or seasonal cycle [1]. Enhancing a company's worker scheduling techniques is crucial for influencing its overall success. The caliber of scheduling directly reverberates onto the quality and motivation of the workforce [2].

One of the most common issues faced by managers is determining the best schedule for their shift workers. The importance of this issue is highlighted when appropriate scheduling leads to increased satisfaction of the workers and consequently, increased satisfaction of customers[3].This issue arose when workers' schedules differed from one another. For example, some workers worked for 192 hours per 31 days whereas some workers worked for 250 hours per 31 days. Looking at the difference in overall time spent among the workers, we may conclude that this is not equitable. The goals of the Bentong Toll Plaza and the preferences of the toll collector have not been met. This problem may have an impact on toll collector's performance and work-life balance. For instance, scenarios such as working an evening shift followed by a morning or night shift the subsequent day, or a morning shift followed by an evening or night shift the following day, arose due to the dissimilarities in total shifts assigned to each worker.

The primary aim of this study is to propose a novel cyclic scheduling approach utilizing Goal Programming. This innovative approach seeks to aid managers in enhancing operational efficiency while reducing the time spent on the recurrent task of new crafting schedules at the Bentong Toll Plaza in Pahang. Currently, the manager must go through a very tedious process to build the staff schedule manually. This process also needs to be repeated every month. The suggested model will cycle once every 15 days to reduce the manager's burden. Next, the secondary objective of this study is to conduct an analysis of the number of working days and days off for each toll collector.

The existing schedule can be more systematic whilst giving the highest fulfillment and fairness to the toll collector as compared to the existing, manually developed schedule. A fair and equitable workforce shift schedule will result in better workload coordination and ensure an ideal work-life balance. Hence, this study can assist future researchers to compare the findings obtained with other Goal Programming approaches for further evaluation and analysis of the efficiency and reliability of the findings.

2. Literature Review

Goal programming is one of the extensions of linear programming and typically the most effective method used especially in planning and scheduling studies [4]. The goal programming approach allows decision-makers to achieve many goals at once. Structures for constraint programming problems include the definition set, constraints, and function of the decision variables [5]. Instead of only being consistent with decision-making processes in real-world situations, the goal programming method is always capable of offering a good, satisfactory solution that meets the preferred goals set by users [6].

Several researchers have utilized Goal Programming as a suitable problem-solving strategy for addressing scheduling difficulties. Researchers in [7] were the pioneers in researching radiology technicians. Their study aimed to develop a well-balanced and fair personnel schedule for eight radiology technicians, meeting both hospital management requirements and the regulations outlined by the Ministry of Health in the Republic of Turkey. In a separate instance, the goal programming methodology was used to address the challenges of scheduling lecturers in the Department of Mathematics at XYZ University [8]. Moreover, researchers in [9] conducted a study on the security staff scheduling problem to assign the most appropriate security personnel to each designated locations on a university campus by using the goal programming approach and the ILOG CPLEX Studio IDE Optimization tool to solve the problems.

Shift work is defined as work conducted between 1900 and 0600 hours. There is conflict on the definition of shift work in the literature, however it traditionally covers work that occurs outside of standard business hours, such as scheduled evening and night shifts, roster work, and regular three-shift jobs [10]. Shift work can have both short-term and long-term negative effects on individuals' health because shift workers are constantly exposed to circumstances that interfere with the circadian rhythm of the body [11]. Maintaining a fulfilling social life is particularly tough when using work shifts. The ability of healthcare workers to plan social activities is dependent on the quality of their shift schedule in terms of both flexibility and reliability [12].The main goal of job scheduling is to achieve the best system throughput and high-performance computing. A well-organized schedule has a direct impact on customer service, human resource management, and employee satisfaction.

Numerous studies have been conducted by researchers using relevant methodologies to address scheduling issues. For example, a novel importance- and channel-aware scheduling policy had been proposed to optimize the performance of cellular federated edge learning (FEEL)[13]. In a separate study, a fresh approach had been proposed to tackle the air traffic control operator (ATCo) work-shift scheduling problem. Their solution, based on a metaheuristic and regular expression-based technique, optimally transformed the multi-objective challenge into a single optimization problem, incorporating the rank-order centroid function [14].

Concurrently, [15]devised a shift schedule for an underground transit network in Ankara, aiming to minimize the overall cost of hiring machinists and the distribution of machinists across shifts. By analyzing real-world data, they determined the necessary number of machine operators for each shift, along with the total count of required lunch and relief breaks. Remarkably, the findings indicated that the Ankara underground transit network could function effectively with two fewer personnel daily. Moreover, researchers in [16] devoted to finding a solution for the issue of managing activities involving Directed Acyclic Graph (DAG) in a cloud computing environment. The study was conducted by comparing the commonly used the Deep Q-learning (DQL) method in task scheduling with a number of pre-coded common algorithms in WorkflowSi. DQL is essentially the inspiration for fundamental model learning. With this study, a new model of energy consumption was provided which can be effectively used to reduce expenses in the case of the deadline being flexible in the future.

The discussion shows that scheduling problems can be resolved using a variety of techniques, especially when all aspects of scheduling and planning are taken into consideration as well. As a result, the critical task is to identify the most effective and applicable approach to ensure reasonable employee allocation and foster organizational success. Consequently, the objective of this study is to stand for the use of the goal programming method, which is a sound choice among a variety of reasonable strategies for effectively addressing scheduling challenges.

3. Methodology

3.1 Data Collection

The manager of Bentong Toll Plaza supplied the data encompassing the activities of 15 toll collectors during March 2022. This dataset comprises details of various shifts, including morning(05:45 a.m. to 01:45 p.m.), evening(01:45 p.m. to 09:45 p.m.), and night(09:45 p.m. until 05:45 a.m.), along with cumulative shift counts and days off. Once the data had been gathered, further investigation and observations were conducted to figure out a solution to the scheduling problem.

3.2 Development of Suggested Schedule

This study proposes for the implementation of a new schedule comprising of three shifts, which cover the morning shift, evening shift and night shift in order to get the best solution result whereby each shift is made up of six hours of working. Furthermore, the schedule has been constructed for 15 toll collectors in 15 working days which will be extended to 225 days for the cyclic schedule. Within the framework of goal programming, both hard and soft constraints are incorporated. Hard constraints are based on Bentong Toll Plaza's policies and must be met whereas soft constraints aim to meet toll collectors' satisfaction. To facilitate the creation of a more impartial and efficient shift arrangement, this study employs the LINGO software. The following notations and decision variables were used to construct the model.

Notation

n = number of days in schedule (n=15)

m = number of toll collectors available (m=15)

i = index for days, i = 1, 2, 3…n

k = index for each toll collector, k = 1, 2, 3…m

A_i = number of toll collectors required for the morning shift of day i (i=1…n)

B_i	= number of toll collectors required for the evening of day *i* (*i*=1…*n*)
C_i	= number of toll collectors required for the night shift of day *i* (*i*=1…*n*)

Decision Variables

$$M_{i,k} = \begin{cases} 1, & \text{if toll collector k is assigned morning shift for day i} \\ 0, & \text{otherwise} \end{cases}$$

$$E_{i,k} = \begin{cases} 1, & \text{if toll collector k is assigned evening shift for day i} \\ 0, & \text{otherwise} \end{cases}$$

$$N_{i,k} = \begin{cases} 1, & \text{if toll collector k is assigned night shift for day i} \\ 0, & \text{otherwise} \end{cases}$$

$$K_{i,k} = \begin{cases} 1, & \text{if toll collector k is assigned day} - \text{off shift for day i} \\ 0, & \text{otherwise} \end{cases}$$

Hard Constraints

Hard constraints are based on Bentong Toll Plaza's policies and must be met. This outlet imposes four hard constraints. The first constraint ensuring that the minimum number of toll collectors needed for each shift with at least 4 toll collectors required for the morning shift, 5 toll collectors on the evening shift, and at least 3 toll collectors on the night shift must be met. The second constraint is that each toll collector works only one shift per day. The third constraint is that each toll collector may not work more than 5 consecutive days. The fourth constraint is that each toll collector must work between 11 to 13 days in 15 days schedule.

Soft Constraints and Binary Constraints

The soft constraints involve the preferences of toll collectors and can be considered as goals. Soft constraints are described as below.

Soft constraint 1: Avoid working a night shift followed by a morning shift the next day.

$$N_{i,k} + M_{i,k} \le 1, \quad i = 1,2,\dots,n-1 \text{ and } k = 1,2,\dots,m \qquad (1)$$
$$N_{n,k} + M_{1,k+1} \le 1, \quad k = 1,2,\dots,m-1$$
$$N_{n,k} + M_{1,1} \le 1$$

Soft constraint 2: Avoids working in an evening shift followed by a morning shift the next day.

$$E_{i,k} + M_{i,k} \le 1, \; i = 1,2,\dots,n-1 \text{ and } k = 1,2,\dots,m \qquad (2)$$
$$E_{n,k} + M_{1,k+1} \le 1, \quad k = 1,2,\dots,m-1$$
$$E_{n,k} + M_{1,1} \le 1$$

Soft constraint 3: All toll collectors have the same amount of total workload.

According to hard constraint 4, a toll collector must work between 11 and 13 days per schedule, but worker prefer to have an equivalent working days. Thus, each toll collector will have 12 shifts in the business.

$$\sum_{i=1}^{n}\left(M_{i,k} + E_{i,k} + N_{i,k}\right) = 12, \; i = 1,2,\dots,n \qquad (3)$$

Binary Constraints: For each shift (morning, evening, night) and for each toll collectors, value can be 0 or 1.

$$M = 0 \; or \; 1; \; E = 0 \; or \; 1; \; N = 0 \; or \; 1; \; K = 0 \; or \; 1 \qquad (4)$$

Goals

The goal is established based on the list of soft constraints to determine whether each goal is achieved. The deviation of goals is α (positive deviation) and β (negative deviation). The goals are formulated as follows:

Goal 1: It prevents a toll collector from having a morning shift the next day after working on a night shift that day.

$$\begin{aligned} &N_{i,k} + M_{i+1,k} + \beta 1_k - \alpha 1_k \leq 1, \quad i = 1,2,\dots,n-1 \text{ and } k = 1,2,\dots,m \\ &N_{n,k} + M_{1,,k+1} + \beta 1_{n,k} - \alpha 1_{n,k} \leq 1, \quad k = 1,2,\dots,m-1 \\ &N_{n,m} + M_{1,,1} + \beta 1_{n,m} - \alpha 1_{n,m} \leq 1 \end{aligned} \tag{5}$$

Goal 2: It prevents a toll collector from having a morning shift the next day after working on an evening shift that day.

$$\begin{aligned} &E_{i,k} + M_{i+1,k} + \beta 2_k - \alpha 2_k \leq 1, \quad i = 1,2,\dots,n-1 \text{ and } k = 1,2,\dots,m \\ &E_{n,k} + M_{1,,k+1} + \beta 2_{n,k} - \alpha 2_{n,k} \leq 1, \quad k = 1,2,\dots,m-1 \\ &E_{n,m} + M_{1,,1} + \beta 2_{n,m} - \alpha 2_{n,m} \leq 1 \end{aligned} \tag{6}$$

Goal 3: It ensures that all toll collectors have the same amount of total workload.

$$\sum_{i=1}^{n} \left(M_{i,k} + E_{i,k} + N_{i,k}\right) + \beta 3_k - \alpha 3_k = 12, \quad i = 1,2,\dots,n \tag{7}$$

Priority of each Goal

Thus, the pre-emptive goal programming for this model is defined as follows:

$$\text{Minimize: } \left(\sum_{i=1}^{n}\sum_{k=1}^{m} \alpha 1_{i,k}, \sum_{i=1}^{n}\sum_{k=1}^{m} \alpha 2_{i,k}, \sum_{k=1}^{m} (\beta 3_k + \alpha 3_k)\right) \tag{8}$$

4. Results and Discussion

4.1 Descriptive Statistics

Table 1 displays the schedule generated for a span of 15 days involving 15 toll collectors. The LINGO software was utilized to optimize solutions for each scenario. To begin with, concerning **hard constraints 1**, it is evident that every schedule configuration adheres to the minimum workforce requirement across all three shifts. This confirms the complete fulfilment of these strict conditions. Additionally, the **hard constraint 2** is also achieved, as no employee within the schedules presented in Table 1 is assigned to work more than one shift on any given day. Moving forward, **hard constraint 3** presents a situation where 5 out of the 15 toll collectors (T3, T6, T9, T11, and T14) work consecutively for more than five days. Regrettably, this stipulation is not met due to this occurrence.

Table 1. The Scheduling Model using Goal Programming

	SCHEDULE PATTERN														
DAY	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15
1	A	B	C	C	B	A	A	C	B	B	A		B		
2	C			B	B	A	C	C	B	B	A	A		B	A
3	B	A	A		B		B	C		C	C	B	A	B	A
4		A	A	A	C		C	B	A		B	C	B	B	B
5	A	B	C	A		C		B	A	A		C	B	B	B
6	A		B		A	B	A		C	B	A	B	C	C	B
7	B	A	B	B	C	C	A	A	B	C	A		B		
8		A		C	B	C	A	B	B	B	B	A		A	C
9	A	C	A	C		B		B	C		B	A	B	A	B
10	C		A	B	A	B	B		B	A	B	C	C	A	
11	C	C	B	B	A	B	B			A	C	B		A	A
12		B	C		A		B	A	C	A	B	B	A	B	C
13	B	B	B	A	B	A	C	A		C			A	C	B
14	B	B	B	B	C	B		A	A		C	A	A		C
15	B	C		A		A	B	B	A	B		B	C	C	A

A = Morning Shift; B = Evening Shift; C = Night Shift

The summarized shift distribution for each toll collector, as derived from Table 1, is presented in Table 2. Consequently, the previously mentioned stringent requirement, referred to as **hard constraint 4**, dictating that each toll collector's schedule should span between 11 and 13 days, has been successfully met.

Table 2. Summary of Number of Shifts for Every Toll Collector

Toll Collector (T)	Total Morning Shifts	Total Evening Shifts	Total Night Shift	Total Days off	Total Number of Shifts
1	4	5	3	3	12
2	4	5	3	3	12
3	4	5	3	3	12
4	4	5	3	3	12
5	4	5	3	3	12
6	4	5	3	3	12
7	4	5	3	3	12
8	4	5	3	3	12
9	4	5	3	3	12
10	4	5	3	3	12
11	4	5	3	3	12
12	4	5	3	3	12
13	4	5	3	3	12
14	4	5	3	3	12
15	4	5	3	3	12

Most toll collectors have nearly achieved **Goal 1**, which stipulates that a toll collector who completes a night shift should not be assigned a morning shift the subsequent day. However, T15 in Table 1 stands as the sole schedule configuration where morning shifts follow a night shift, indicating a partial fulfilment of Goal 1. This outcome significantly impacts toll collector preferences, as they are deprived of sufficient rest before embarking on their next shift.

Moving on to **Goal 2**, which requires that a toll collector who has worked an evening shift on a given day should not be scheduled for a morning shift the following day. According to the outcomes outlined in Table 1, the schedules adhere to this requirement for most cases, barring T4 and T6. These two instances fall short of meeting Goal 2, representing a minor deviation from the overall objective. Meanwhile, **Goal 3** is accomplished by ensuring that each toll collector bears an equivalent workload totalling 12 shifts, as evidenced in Table 2.

There are variations between the schedules of toll collectors and the 0-1 goal programming approach for the number of working days within 15 days. The number of working days per toll collector from the manual timetable method is not balanced because some toll collectors work 12 out of every 15 days while others work 13 out of every 15 days. The manual schedule changes each month, resulting in variations in the toll collectors' overall workload. Some of the toll collectors have worked more than the maximum number of days due to the schedule's inconsistencies. The schedule is significantly more balanced than the manual schedule since it uses a 0-1 Goal Programming model to ensure that toll collectors have an equal number of working days on each schedule. With to the balanced distribution of working days, it greatly enhances the sense of satisfaction among toll collectors. This would result in toll collectors being more pleased with their occupations and thus leading to better performance of their duties at a higher quality level.

4.2 Cyclical Schedule

A cyclical schedule is one that is repeated at scheduled times. The cyclical toll collector schedule will cycle according to a pattern equal to the toll collectors' perceived reasonableness, as shown in Table 3.

Table 3. Cyclic scheduling sets of the toll collectors for 225 days

Toll Collector	SET														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T2	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1
T3	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2
T4	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3
T5	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4
T6	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5
T7	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6
T8	8	9	10	11	12	13	14	15	1	2	3	4	5	6	7
T9	9	10	11	12	13	14	15	1	2	3	4	5	6	7	8
T10	10	11	12	13	14	15	1	2	3	4	5	6	7	8	9
T11	11	12	13	14	15	1	2	3	4	5	6	7	8	9	10
T12	12	13	14	15	1	2	3	4	5	6	7	8	9	10	11
T13	13	14	15	1	2	3	4	5	6	7	8	9	10	11	12
T14	14	15	1	2	3	4	5	6	7	8	9	10	11	12	13
T15	15	1	2	3	4	5	6	7	8	9	10	11	12	13	14

As indicated by the findings, every toll collector is slated to undergo 15 distinct schedules over a span of 225 days before circling back to the initial pattern of the first schedule. This 15-day interval for scheduling was chosen due to the feasibility of reproducing a comparable set for each toll collector within the subsequent 15 days, while still adhering to both stringent and flexible constraints. Through the implementation of the proposed cyclic scheduling system, each toll collector will be exposed to both favorable and unfavorable schedules over the course of 225 days, offering a comprehensive spectrum of work experiences.

The Bentong Toll Plaza manager will allocate duties to toll collectors in accordance with the cyclic scheduling pattern. The toll collectors' routines will follow a cycle, with each collector adhering to the pattern of a specific schedule every 225 days (equivalent to 15 schedules). After completing these 15 schedules, each toll collector will return to the initial schedule, thus ensuring a well-rounded rotation.This scheduling framework guarantees both stability and comprehensiveness, catering to the needs of toll collectors while factoring in equitable distribution. Through this approach, every toll collector will experience shifts based on both favorable and less favorable schedule patterns, promoting a balanced and inclusive work arrangement.

Toll collectors will be required to adhere to all scheduling patterns, even if some of them are less appealing than others. The toll collectors will have the least satisfactory schedule's pattern when they have the patterns T15 because they need to work morning shift the next day after working the night shift that day and patterns T3, T6, T9 and T11 meaning that they work more than five consecutive days. The most satisfactory schedule's pattern is when they have the pattern T1, T2, T4, T5, T7, T8, T10, T12, and T13 with the days of work not exceeding five consecutive days. This form of cyclical scheduling also gives toll collectors more control over their work lives because they know the type of shift schedule they will have in the future, which should have a positive effect on their job satisfaction level.

As a result of the 0-1 Goal Programming method, toll collectors can optimise their total working days over the period of the schedule (15 days). Even though the LINGO software is one of the most effective tools for scheduling, using the LINGO software with a 0-1 Goal Programming approach, some constraints were not met. The following chapter discusses a few suggestions for improving the efficiency of the study.

5. Conclusion

Modelling toll collector scheduling with 0-1 Goal Programming has shown that it can generate schedules that take into consideration all the hard and soft constraints in the scheduling environment. The purpose of this research is to propose a new cyclic scheduling method to assist managers in spending less time creating new schedules on a regular basis. Currently, the toll collectors' schedule is handled manually, which is tedious and time consuming. Using LINGO software, shift schedules for toll collectors may be generated quickly thus saving managers' time and effort.

The next objective was to analyse the working days and days off for each toll collector. From the result, there are fair and equal working and off day for each schedule set, which are 12 working shift and 3 days off. A cyclical schedule will result in a more equitable and balanced schedule by giving each toll collector the same number of working days. There are 15 schedules for toll collectors to follow throughout the course of 225 days. The pattern of the first schedule is then repeated. The pattern of satisfactory and unsatisfactory schedules may be followed by the toll collector without feeling biased, which raises their level of satisfaction. It would not be necessary to create a new plan every month, only when the average daily staff requirements need to be changed.

Furthermore, cyclical scheduling allows toll collectors to have greater control over their work lives since they understand that the type of schedule, they work under has a big impact on their activity satisfaction. In addition, the Goal Programming approach to shift scheduling ensures that the work schedules of all the toll collectors are more equitable. Other advantages include improving work-life balance of toll collectors, increasing their satisfaction, managing toll collector attendance, lowering absenteeism rates, and boosting overall productivity.

For further research, various aspects such as days off on weekends, days off on public holidays, and requested days off can be considered. In this study, only 15 toll collectors were involved. Future research can improve this type of study on cyclical scheduling by considering a greater number of workers. It is also recommended that the study be expanded by using other types of goal programming techniques to overcome scheduling problems, such as Fuzzy Goal Programming, Interval Goal Programming, and Fractional Goal Programming. As a consequence, the findings should be compared to other goal programming techniques for additional analysis in order to determine the efficiency and accuracy of the results.

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Conflict of Interest
The authors declare no conflict of interest in the subject matter or materials discussed in this manuscript.

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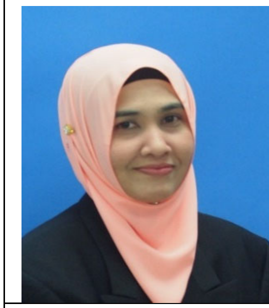
	Diana Sirmayunie Mohd Nasir is a senior lecturer from the Universiti Teknologi MARA Perlis branch. She graduated with a Master’s degree in Mathematics from Universiti Sains Malaysia. Her research interests include optimization and Mathematical Modelling.	Design the research work, interpretation, and draft article.

	Suzanawati Abu Hasan is a senior lecturer at the Universiti Teknologi MARA Perlis campus. She holds a Master of Mathematics degree from Universiti Sains Malaysia. Her research interests include Applied Mathematics, Fuzzy Logic, and Optimization.	Data analysis and interpretation.
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