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A BINARY INTEGER LINEAR PROGRAMMING MODEL FOR EMPLOYEE SCHEDULING IN A CONVENIENCE STORE: A CASE STUDY IN NAKHON PATHOM

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ABSTRACT

Convenience stores are workplaces where employees work in shifts. An optimal work schedule for employees is necessary for every convenience store because it enables employees to work more efficiently. This paper considers the employee scheduling of a 24-hour convenience store in Nakhon Pathom. This store divides working hours into three shifts: morning, noon, and night. Each employee is assigned to the same shift for an entire week before rotating to a different shift in the next week. This paper presents a novel binary integer linear programming model for generating an optimal four-week employee schedule for this convenience store. The objective of the proposed model was to prioritize assigning weekend days off to the manager and assistant managers ahead of the regular staff, while adhering to the constraints outlined in the store's regulations. The proposed model was solved using the CPLEX software to generate an optimal schedule for the 15 employees at this convenience store. The model could find an optimal schedule with a computational time of less than three seconds, where the days off for the manager and assistant managers could all be scheduled on weekends. The proposed model also verified that the current number of employees at the convenience store is the minimum required to create a feasible work schedule, and the store needs to increase its staff by at least two employees if each employee is to work the night shift for at most one week within a four-week schedule period. The proposed model can be a practical tool for generating an optimal employee schedule for this convenience store in real-life scenarios.

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1. INTRODUCTION

Nowadays, scheduling is essential in every organization or business, especially in workplaces that operate on shifts, such as convenience stores, restaurants, hotels, hospitals, and gas stations. Employees in these places work during designated times, with each employee rotating through shifts as assigned. Therefore, the administrator of an organization needs an efficient work schedule to properly allocate and manage the workload for employees so that the organization's operations run smoothly and effectively.

Convenience stores are a common business in everyday life. They can quickly meet consumer needs with various services, such as purchasing goods and paying for different customer services. In recent years, the number of convenience stores in Thailand has continuously grown. Since convenience store employees work in shifts, employee scheduling is necessary for every convenience store. The employee schedule may be daily, weekly, biweekly, or monthly, depending on the operational planning of each store branch. Employee scheduling in a convenience store is critical. For employees, a well-designed work schedule helps ensure that each employee has a suitable workload. This enables each employee to work efficiently while experiencing job satisfaction and happiness, which leads to better customer service and may contribute to improved sales at the branch. In addition, a good schedule helps reduce employee fatigue from consecutive shifts, which can negatively affect their health. For the convenience store, a good schedule allows the business to utilize its human resources effectively. It can enable the business to operate long-term and achieve organizational success.

At present, the process of constructing a work schedule for employees so that an organization can satisfy the demand for its goods or services is known as the employee scheduling problem (ESP) [1], personnel scheduling problem [2], or workforce staff scheduling problem [3]. In this paper, we will call it the ESP. There are many research studies in the literature related to the ESP, such as scheduling for convenience stores, restaurants, hotels, and hospitals.

Mongkhonsang et al. [4] studied the ESP at a convenience store in Thailand. They proposed a mathematical model for solving the problem to minimize the workload differences among employees and satisfy labor law regulations. Their proposed model could find an optimal employee schedule that outperformed the manual schedule used by the convenience store. Sintunavarat et al. [5] addressed the ESP at a 7-Eleven convenience store in Pathum Thani. The authors presented a linear programming (LP) model for scheduling employees while satisfying the minimum number of employees required for each shift. Their approach used a G/G/k queuing model to estimate the minimum number of employees needed for each shift to ensure customers did not have to wait. The objective of their proposed model was to minimize the daily labor cost of hiring employees. Lin et al. [6] proposed a mixed integer linear programming (MILP) model for scheduling employees at a retail store in China. Their research aimed to find an optimal employee schedule that maximizes employee satisfaction while adhering to the relevant constraints, such as the workload balance and the minimum and maximum number of workdays for employees. In addition, their proposed model also considered the constraints related to the employees' preferences for working shifts alongside their preferred colleagues. Gusmeroli and Bettinelli [7] investigated employee scheduling in an Italian retail company. In their study, each employee had individual skills and specific time availability, and numerous tasks, each with a defined start and end time, needed to be completed. The authors presented a MILP model for scheduling employees to minimize the number of uncovered tasks. The constraints considered in this study included company policies, such as compatibility between employees and functions, the maximum daily hours, the maximum consecutive working days, and the minimum rest time between two working days.

Ahamad and Ghani [8] examined the scheduling of employees at a fast-food restaurant in Malaysia. They proposed a binary integer linear programming (BILP) model for scheduling employees to minimize the number of employees working daily. The constraints in their proposed model included the minimum number of employees required for each shift in each restaurant department and the break time conditions for employees set by the restaurant. Their proposed model could find a work schedule that required fewer employees per day compared to the current schedule of the restaurant. Nasir et al. [9] considered the ESP at a McDonald's restaurant in Malaysia and solved it using a goal programming approach. The hard constraints of their proposed model included the required number of employees per shift, the number of consecutive workdays, and the number of rest days, all of which had to satisfy the store's regulations. The soft constraint considered in their model was to balance the workload among all the employees.

Kassa and Tizazu [10] presented an integer linear programming (ILP) model for scheduling employees in Ethiopia's Avanti Blue Nile Hotels department. The authors focused on maximizing employee utilization and considered the constraints of the number of employees required per shift, the maximum number of shifts per person, and the rest times specified by the hotel's regulations. Yothee and Bojaras [11] investigated the scheduling of nurses at Fort Sunpasitthiprasong Hospital in Ubon Ratchathani. They developed an ILP model to create a work schedule for nurses that met the hospital's operational requirements. The objectives of their model were to maximize the total number of days off and to minimize the overall workload for all the nurses. Widyastiti et al. [12] presented an ILP model for scheduling nurses using the data from a hospital in Indonesia. Their model aimed to maximize the total number of days off for all the nurses while satisfying the constraints of the hospital's operational requirements.

Al-Yakoob and Sherali [13] addressed the ESP for gas stations owned by the Kuwait National Petroleum Corporation. They proposed a mixed integer programming (MIP) model for scheduling employees across 86 gas stations distributed throughout Kuwait. The model's objective was to minimize the number of required employees while considering the company's requirements, regulations, and employee satisfaction. They solved the problem in two steps. The first step was to assign employees to stations based on the needs of each station, while the second step was to specify the shifts and days off for the employees. In addition, they also proposed an alternative MIP model for this problem [14] and solved the model using a column generation technique. The results showed that their alternative model could solve more test problems than the previous model [13] and solve large-scale problems within a reasonable time.

Ağralı et al. [15] considered the ESP in a large healthcare organization in Belgium and formulated it as an MIP model. In their problem, each employee belonged to one of various skills. Moreover, each service requirement had a weight indicating its priority level and the specific skill needed to deliver the service. The objective of their model was to minimize the total amount of service demand that was not satisfied. The constraints in their problem included assigning tasks based on each employee's skills and ensuring that the work hours and the rest requirements complied with government regulations and labor union guidelines. Batista et al. [16] conducted a study on employee scheduling during the COVID-19 pandemic. The problem aimed to balance workplace occupancy and the risk of infection while maintaining regular operations. In this context, an employee could work on-site or remotely (from home). The authors proposed an MILP model to schedule employees in the workplace. The model aimed to determine which employees should be allocated on-site to minimize the risk of infection, while satisfying organizational constraints such as workload demand coverage.

Ang et al. [17] investigated the scheduling of security staff at the Universiti Tun Hussein Onn Malaysia and solved the problem using an ILP approach. They aimed to maximize the preference of the security staff by allowing them to choose their preferred shifts and days off, while adhering to the shift conditions, the number of working days, and the number of days off stipulated by the university's restrictions. The results showed that the work schedule generated by their proposed model had a higher employee preference value than the university's current work schedule.

Cappanera et al. [18] studied the ESP at a large airport in Italy. In their work, the problem was formulated into an MILP model to schedule ground staff in the airport. The model objective was to minimize the idle time of employees. The constraints considered in their model were typical of most large airports. They included assigning tasks to suitable employees, ensuring that each employee's daily working hours and weekly working days complied with their employment contract, and adhering to the rest periods mandated by the airport policy.

Furthermore, several metaheuristic approaches have been used in the literature to solve the ESP. For example, Xue et al. [19] proposed a memetic algorithm for scheduling workforces in a real-world retail store. Amindoust et al. [20] used a genetic algorithm (GA) to schedule nurses in a hospital in Iran. Simulated annealing (SA) was employed to schedule nurses in various healthcare institutions in Northern Italy [21] and in hospitals in Norway [22]. Both ant colony optimization and particle swarm optimization (PSO) were developed to address work-life balance scheduling for healthcare workers in a hospital in Turkey [23]. Moreover, PSO was utilized to schedule logistics service employees [24]. An application of the tabu search algorithm was presented for scheduling employees associated with the Leicestershire Police [25]. Additionally, an artificial bee colony algorithm and SA were applied to scheduling call center employees in References [26] and [27], respectively.

In addition, Bansal et al. [28] presented a heuristic algorithm based on the classic bin packing problem to schedule crews in railways using the data from the Mumbai Division in Indian Railways. Rossum et al. [29] used the Benders Decomposition technique to schedule crews for a large passenger railway operator using real-life instances from the Netherlands Railways. Furthermore, hybrid metaheuristics of GA and PSO have also been developed to schedule medical doctors in a public hospital in Malaysia [30].

After an extensive review of the literature on the ESP, it was found that scheduling employees in any workplace is complicated due to the regulations of each specific workplace. This paper investigates the ESP at a convenience store in Nakhon Pathom, which represents a new real-world application that has not been previously examined in the literature to the best of our knowledge. At this store branch, the manager manually creates an employee schedule based on his experience to meet the store's requirements and operational regulations. However, the manual schedule may not be optimal due to many constraints. Therefore, this study aimed to generate an optimal employee schedule that satisfies the constraints of the convenience store using a BILP approach. Note that the scope of this study is limited to examining the work schedule of the regular employees of this convenience store only and excludes part-time employees.

2. RESEARCH METHODS

This paper aims to formulate a novel BILP model for scheduling employees at a case study of a 24-hour convenience store in Nakhon Pathom. The mathematical background for BILP is introduced in Section 2.1. The problem description of the ESP in this case study is described in Section 2.2, while the proposed BILP model for this problem is presented in Section 2.3. In addition, the test problems used to evaluate the proposed model are presented in Section 2.4.

2.1 LP and BILP

LP is a class of optimization problems. The basic components of LP include the objective function, constraints, and decision variables. The objective function in LP is linear and can represent either a maximization or a minimization problem. The constraints in LP are also linear and can be inequalities or equalities. According to Hillier and Lieberman [31], the general form of an LP model can be stated as follows.

$$
\begin{aligned}
\max \quad z = \quad & c_1x_1 + c_2x_2 + \cdots + c_nx_n \\
\text{s.t.} \quad & a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \le b_1 \\
& a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \le b_2 \\
& \quad \vdots \\
& a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \le b_m \\
& x_1 \ge 0, x_2 \ge 0, \dots, x_n \ge 0
\end{aligned}
$$

The meaning of each notation in the LP model is shown below.

z The objective function.

x_j The decision variable, where $j = 1,2, \dots, n$.

c_j The coefficient of the decision variable x_j in the objective function, where $j = 1,2, \dots, n$.

a_{ij} The coefficient of the j^{th} decision variable in the i^{th} constraint.

b_i The right-hand side (RHS) value of the i^{th} constraint, where $i = 1,2, \dots, m$.

The aim of an LP problem is to determine an optimal solution, which consists of the values of the decision variables $x_1, x_2, \dots, x_n$ that maximize the objective function. The simplex method is a well-known method for solving an LP problem to find an optimal solution [31]. In an LP problem, the decision variables are continuous. If the decision variables are required to be integer, the problem becomes ILP. In addition, if the decision variables are restricted to be binary (0 or 1), the problem becomes BILP. In an ILP or BILP model, if the integer restriction on the decision variables is ignored (the model becomes an LP model), the resulting LP model is called its LP relaxation.

The branch and bound method are a well-known method for solving a BILP problem [31]. This method divides the original problem into smaller subproblems by partitioning the feasible region into smaller subsets (branching). A fathoming criterion is used to check how good the best solution in the subset can be, and discard the subset if it does not contain an optimal solution for the original problem (bounding). The branch and bound algorithm for solving a BILP problem can be summarized as follows:

1. Solve the LP relaxation of the BILP problem. If the optimal solution to the LP relaxation satisfies the integer restriction, it is also an optimal solution for the original BILP problem. Otherwise, treat this problem as the remaining subproblem and go to the next step.
2. Select the most recently created unfathomed subproblem. Choose a fractional variable (branching variable), say x_j. Fix x_j to be 0 and 1, then insert $x_j = 0$, and $x_j = 1$ into the constraints of the subproblem to create the first and second new subproblems, respectively.
3. For each new subproblem, solve its LP relaxation.
4. For each new subproblem, it is fathomed and discarded if one of the following conditions is met,
    a. F1: The optimal objective value of its LP relaxation is worse than that of the incumbent solution (the best feasible solution found so far).
    b. F2: Its LP relaxation is infeasible.
    c. F3: The optimal solution for its LP relaxation is an integer (satisfies the integer restriction). If this solution is better than the incumbent solution, it becomes the new incumbent solution, and F1 is rechecked for all remaining unfathomed subproblems.
5. Stop when there are no remaining unfathomed subproblems; otherwise, return to Step 2.

2.2 Problem Description

This section describes the problem description of the ESP at the 24-hour convenience store that formed this case study, a branch of a well-known convenience store in Thailand. After acquiring the information from the manager of this branch, the data and regulations involved in scheduling employees can be summarized as follows:

1. This convenience store has 15 employees: one manager, four assistant managers, and 10 regular staff members.
2. This convenience store divides each day into three shifts: 8:00 a.m. to 5:00 p.m. (morning shift), 2:00 p.m. to 11:00 p.m. (noon shift), and 11:00 p.m. to 8:00 a.m. (night shift).
3. The employee work schedule will be arranged every four weeks (four-week schedule). Each week, an employee will be assigned to the same shift every day for the entire week. For example, if an employee is assigned to the morning shift in a week, he/she must work the morning shift every allocated day from Monday to Sunday of that week.
4. Each employee works only one shift per day.
5. Each employee has one day off per week, with the manager and assistant managers given priority to have their day off on either Saturday or Sunday before the regular staff, if possible. This store requires this regulation because the number of available weekend days off is limited, and the store aims to assign them to higher-ranking positions first.
6. In each four-week schedule period, each employee will work the morning shift for at least one week and the noon shift for at least one week.
7. The manager will not work the night shift.
8. Each four-week schedule period, each assistant manager will work the night shift for at most one week.
9. Each four-week schedule period, each regular staff member will work the night shift for at least one week.
10. At least one manager or assistant manager will work in each week's shift. The manager or assistant manager on duty supervises the other employees working that shift throughout the entire week.

Moreover, this regulation is required because there are some tasks that only the manager can perform, such as canceling a customer's purchase order (regular staff members cannot perform this task). The assistant manager will be responsible for this duty in the manager's absence.

11. Each day, at least four, five, and three employees work the morning, noon, and night shifts, respectively.

In addition, the following two assumptions are made in this paper. Both assumptions allow the model to focus on shift allocation without external disruptions, which helps simplify and reduce the complication of the model formulation.

1. Each employee has no restrictions based on the work schedule from the previous four-week period, i.e., they are ready to be scheduled for the new period immediately.
2. This study does not consider employee leave days, meaning each employee is assumed to be available to work according to the schedule without taking any leave.

2.3 Proposed Mathematical Model

This section presents the BILP model for the ESP at the convenience store case study as described in Section 2.2. The indices, parameters, sets, decision variables, objective function, and constraints are defined in Sections 2.3.1 – 2.3.3.

2.3.1 Parameters, Sets, Indices, and Decision Variables

Parameters

n The total number of employees of the convenience store ($n = 15$).

w The total number of weeks to be scheduled ($w = 4$).

d The number of days in a week ($d = 7$).

Sets

N The set of all employees, $N = \{1,2, \dots, n\}$.

N' The set of the manager and assistant managers, $N' = \{1,2,3,4,5\} \subseteq N$.

W The set of all weeks in a schedule period, $W = \{1,2, \dots, w\}$.

D The set of all days in a week, $D = \{1,2, \dots, d\}$.

In this paper, we assume that the manager is employee $i = 1$, and the four assistant managers are employees $i = 2,3,4$, and 5, respectively. In addition, we assume that days $k = 1,2, \dots, 7$ represent Monday to Sunday, respectively.

Indices

i The index of employees, $i \in N$.

j The index of weeks, $j \in W$.

k The index of days, $k \in D$.

Decision variables

a_{ij} 1; if employee i is assigned to the morning shift in week j, and 0 otherwise.

b_{ij} 1; if employee i is assigned to the noon shift in week j, and 0 otherwise.

c_{ij} 1; if employee i is assigned to the night shift in week j, and 0 otherwise.

A_{ijk} 1; if employee i is assigned to work the morning shift on day k in week j, and 0 otherwise.

B_{ijk} 1; if employee i is assigned to work the noon shift on day k in week j, and 0 otherwise.

C_{ijk} 1; if employee i is assigned to work the night shift on day k in week j, and 0 otherwise.

x_{ijk} 1; if employee i has a day off on day k in week j, and 0 otherwise.

2.3.2 Objective Function

The objective of the proposed model was to ensure that the manager and assistant managers receive their days off on Saturday or Sunday before the regular staff members. This can be expressed as the objective function shown in **Equation (1)**.

$$max \sum_{i=1}^{5}\sum_{j=1}^{4}\sum_{k=6}^{7} x_{ijk} \tag{1}$$

The objective function in **Equation (1)** maximizes the number of days off weekends for the manager and assistant managers. From this objective, the model will first attempt to set the variable x_{ijk} to 1 for $k \in \{6,7\}$, because this increases the objective value, while setting x_{ijk} to 1 for $k \in \{1,2,3,4,5\}$ does not. This means that, if possible, the days off for the manager and assistant managers will be assigned to a Saturday or Sunday first. With this objective, the manager and assistant managers are given priority to have their days off on a weekend day before the regular staff, as desired.

2.3.3 Constraints

1. Each employee will be assigned to one shift in each week.

$$a_{ij} + b_{ij} + c_{ij} = 1 \qquad \forall i \in N, \forall j \in W \tag{2}$$

2. During the four-week schedule period, each employee will be assigned to the morning shift for at least one week and to the noon shift for at least one week.

$$\sum_{j=1}^{w} a_{ij} \geq 1 \qquad \forall i \in N \tag{3}$$

$$\sum_{j=1}^{w} b_{ij} \geq 1 \qquad \forall i \in N \tag{4}$$

3. The manager will not work the night shift.

$$\sum_{j=1}^{w} c_{1j} = 0 \tag{5}$$

4. During the four-week schedule period, each assistant manager will be assigned to the night shift for no more than one week.

$$\sum_{j=1}^{w} c_{ij} \leq 1 \qquad \forall i \in N' - \{1\} \tag{6}$$

5. During the four-week schedule period, each regular staff member will be assigned to the night shift for at least one week.

$$\sum_{j=1}^{w} c_{ij} \geq 1 \qquad \forall i \in N - N' \tag{7}$$

6. In each shift of each week, at least one manager or assistant manager will be on duty.

$$\sum_{i=1}^{5} a_{ij} \geq 1 \qquad \forall j \in W \tag{8}$$

$$\sum_{i=1}^{5} b_{ij} \geq 1 \qquad \forall j \in W \tag{9}$$

$$\sum_{i=1}^{5} c_{ij} \geq 1 \qquad \forall j \in W \tag{10}$$

7. If employee i is assigned to the morning shift in week j, then he/she cannot work the noon shift or night shift on any day during week j.

$$a_{ij} \leq 1 - B_{ijk} \qquad \forall i \in N, \forall j \in W, \forall k \in D \tag{11}$$

$$a_{ij} \leq 1 - C_{ijk} \qquad \forall i \in N, \forall j \in W, \forall k \in D \tag{12}$$

Note that, if employee i is assigned to the morning shift in week j ($a_{ij} = 1$), then both variables B_{ijk} and C_{ijk} are equal to 0 according to the constraints in **Equation (11)** and **Equation (12)**, respectively. This means that employee i cannot work any noon or night shift on any day in week j as desired (employee i can only work the morning shift every allocated day from Monday to Sunday of week j).

8. If employee i is assigned to the noon shift in week j, then he/she cannot work the morning shift or night shift on any day during week j. Both constraints in **Equation (13)** and **Equation (14)** can be interpreted in a similar way to those in **Equation (11)** and **Equation (12)**.

$$b_{ij} \leq 1 - A_{ijk} \qquad \forall i \in N, \forall j \in W, \forall k \in D \tag{13}$$

$$b_{ij} \leq 1 - C_{ijk} \qquad \forall i \in N, \forall j \in W, \forall k \in D \tag{14}$$

9. If employee i is assigned to the night shift in week j, then he/she cannot work the morning shift or noon shift on any day during week j. Both constraints in **Equation (15)** and **Equation (16)** can also be interpreted in a similar way to those in **Equation (11)** and **Equation (12)**.

$$c_{ij} \leq 1 - A_{ijk} \qquad \forall i \in N, \forall j \in W, \forall k \in D \tag{15}$$

$$c_{ij} \leq 1 - B_{ijk} \qquad \forall i \in N, \forall j \in W, \forall k \in D \tag{16}$$

10. Each day, an employee must either work a shift or take a day off.

$$A_{ijk} + B_{ijk} + C_{ijk} + x_{ijk} = 1 \qquad \forall i \in N, \forall j \in W, \forall k \in D \tag{17}$$

11. In each week, each employee has one day off.

$$\sum_{k=1}^{d} x_{ijk} = 1 \qquad \forall i \in N, \forall j \in W \tag{18}$$

12. Each day, at least four, five, and three employees will be on duty for the morning, noon, and night shift, respectively.

$$\sum_{i=1}^{n} A_{ijk} \geq 4 \qquad \forall j \in W, \forall k \in D \tag{19}$$

$$\sum_{i=1}^{n} B_{ijk} \geq 5 \qquad \forall j \in W, \forall k \in D \tag{20}$$

$$\sum_{i=1}^{n} C_{ijk} \geq 3 \qquad \forall j \in W, \forall k \in D \tag{21}$$

13. The last constraint defines the decision variables, where all of them are binary.

$$a_{ij}, b_{ij}, c_{ij} \in \{0,1\} \qquad \forall i \in N, \forall j \in W$$

$$A_{ijk}, B_{ijk}, C_{ijk}, x_{ijk} \in \{0,1\} \qquad \forall i \in N, \forall j \in W, \forall k \in D$$

2.4 Test Problems

The test problems for evaluating the proposed BILP model were generated using the convenience store case study data. We also generated other test problems by adjusting the parameter n and some constraints to test the model. The test problems consisted of Problems 1 – 4. Problem 1 used the convenience store data to solve the model, which consisted of 15 employees ($n = 15$), 4 weeks ($w = 4$), and 7 days ($d = 7$). Problem 2 was generated with all parameters as in Problem 1, except n was set to 14. In Problems 3 and 4, we replaced the constraint in **Equation (7)** with the new constraint in **Equation (22)**, as shown below, to examine whether each employee, except the manager, can work the night shift for at most one week within a four-week schedule period. The parameter n in Problems 3 and 4 was set to 16 and 17, respectively. The details of each test problem are summarized in **Table 1**.

$$\sum_{j=1}^{w} c_{ij} \leq 1 \qquad \forall i \in N - N' \tag{22}$$

Table 1. The Details of Each Test Problem

Name	n	Note
Problem 1	15	-
Problem 2	14	-
Problem 3	16	The constraint in **Equation (7)** in the proposed model was replaced with the constraint in **Equation (22)**.
Problem 4	17	

3. RESULTS AND DISCUSSION

In this section, all four test problems were solved using the proposed model implemented in the ILOG OPL CPLEX 20.1 software running on a personal computer with an AMD RADEON R5 2.5 GHz CPU and 8 GB RAM. The model size of each test problem, which included the number of binary variables and constraints, is shown in **Table 2**. The computational results of Problems 1 – 4 are presented in Sections 3.1 to 3.4, respectively.

Table 2. The Model Size of Each Test Problem

Name	Model Size	
	Binary Variable	Constraint
Problem 1	1,860	3,201
Problem 2	1,736	2,994
Problem 3	1,984	3,408
Problem 4	2,108	3,615

3.1 Results of Problem 1

This section presents the results of Problem 1, solved using the proposed BILP model. Problem 1 could be solved to an optimal solution with a computational time of 1.92 s. The results from the proposed model included the values of all decision variables a_{ij}, b_{ij}, c_{ij}, A_{ijk}, B_{ijk}, C_{ijk}, and x_{ijk}. The variables a_{ij}, b_{ij}, and c_{ij}, which were equal to 1 in the optimal solution of Problem 1, are shown in **Table 3**. The variables A_{ijk}, B_{ijk}, and C_{ijk}, which were equal to 1, could be interpreted to the four-week schedule for employees at the convenience store case study, as shown in **Table 4**. Note that the numbers in each cell in **Table 4** represent the employee numbers assigned to the shift corresponding to its column and on the day and week corresponding to its row. The information on the day off in each week for each employee, which can be interpreted from the variable x_{ijk} that was equal to 1, is shown in **Table 5**.

Table 3. The Variables a_{ij}, b_{ij}, and c_{ij}, which are Equal to 1, for Problem 1, Presented According to Employee Numbers

Employee (n)	a_{ij}	b_{ij}	c_{ij}
1	a_{12}	b_{11}, b_{13}, b_{14}	
2	a_{23}, a_{24}	b_{22}	c_{21}
3	a_{31}, a_{33}	b_{32}	c_{34}
4	a_{42}, a_{44}	b_{41}	c_{43}
5	a_{51}	b_{53}, b_{54}	c_{52}
6	a_{63}, a_{64}	b_{62}	c_{61}
7	a_{71}	b_{72}	c_{73}, c_{74}
8	a_{84}	b_{82}, b_{83}	c_{81}
9	a_{91}	b_{93}	c_{92}, c_{94}
10	$a_{10,3}$	$b_{10,1}, b_{10,4}$	$c_{10,2}$
11	$a_{11,1}$	$b_{11,2}, b_{11,4}$	$c_{11,3}$
12	$a_{12,2}$	$b_{12,1}, b_{12,3}$	$c_{12,4}$
13	$a_{13,3}, a_{13,4}$	$b_{13,1}$	$c_{13,2}$
14	$a_{14,2}$	$b_{14,3}, b_{14,4}$	$c_{14,1}$
15	$a_{15,2}$	$b_{15,1}, b_{15,4}$	$c_{15,3}$

According to **Table 3**, the manager (Employee 1) was assigned to the morning shift in Week 2 ($a_{12} = 1$) and the noon shift in Weeks 1, 3, and 4 ($b_{11} = b_{13} = b_{14} = 1$). Employee 2, who is an assistant manager, was assigned to the morning shift in Weeks 3 and 4, the noon shift in Week 2, and the night shift in Week 1. Employee 7, who is a regular staff, was assigned to the morning shift in Week 1, the noon shift in Week 2, and the night shift in Weeks 3 and 4. The other rows in **Table 3** can be interpreted similarly.

From **Table 4**, Employees 3, 5, 7, 9, and 11 were assigned to work the morning shift in Week 1. They all worked simultaneously on Days 1 and 3 of Week 1. These results come from the variables $A_{311} = A_{511} = A_{711} = A_{911} = A_{11,1,1} = 1$ and $A_{313} = A_{513} = A_{713} = A_{913} = A_{11,1,3} = 1$. However, only four employees (Employees 3, 5, 7, and 11) worked the morning shift on Day 2 of this week because Employee 9 had a day off on Day 2 in Week 1 (see **Table 5**), which resulted from $x_{912} = 1$. In addition, since Employees 11, 7, 3, and 5 had days off on Days 4, 5, 6, and 7 in Week 1, respectively (see **Table 5**), the lists of employees working the morning shift on Days 4 – 7 in Week 1 are as shown in **Table 4** (see rows Day 4 – Day 7 of Week 1).

Similarly, from **Table 4**, Employees 2, 6, 8, and 14 were assigned to the night shift in Week 1, each having a day off on Days 6, 3, 5, and 4, respectively (See **Table 5**). In this night shift, Employee 2, an assistant manager, was on duty and responsible for supervising the other employees working in this shift for this week, which satisfied the constraint in **Equation (10)**. The remaining information in **Table 4** can be interpreted in a similar way.

From **Table 5**, we can see that all the days off for the manager and assistant managers (Employees 1 – 5) fall on either Day 6 or Day 7, which are weekends, thereby satisfying the objective of the problem. The objective value of the optimal solution for Problem 1 was 20, indicating that all days off for the manager and assistant managers are on weekends.

3.2 Results of Problem 2

For Problem 2, which has one fewer employee than in Problem 1, the result returned by the CPLEX solver after solving the model was infeasible. This indicates that having only 14 employees is insufficient to create a feasible work schedule. The reason for this can be explained as follows. According to the problem description, the minimum number of employees required for the morning, noon, and night shifts each day is four, five, and three, respectively (the constraints in **Equation (19)** – **Equation (21)**). Therefore, each week, the number of employees assigned to the morning, noon, and night shifts must be at least four, five, and three, respectively.

Table 4. The Four-Week Employee Schedule Derived from an Optimal Solution of Problem 1

Week	Day	Morning shift (8:00 a.m. to 5:00 p.m.)	Noon shift (2:00 p.m. to 11:00 p.m.)	Night shift (11:00 p.m. to 8:00 a.m.)
Week 1	Day 1	3, 5, 7, 9, 11	1, 4, 10, 12, 13	2, 6, 8, 14
	Day 2	3, 5, 7, 11	1, 4, 12, 13, 15	2, 6, 8, 14
	Day 3	3, 5, 7, 9, 11	1, 4, 10, 12, 13, 15	2, 8, 14
	Day 4	3, 5, 7, 9	1, 4, 10, 12, 15	2, 6, 8
	Day 5	3, 5, 9, 11	1, 4, 10, 13, 15	2, 6, 14
	Day 6	5, 7, 9, 11	4, 10, 12, 13, 15	6, 8, 14
	Day 7	3, 7, 9, 11	1, 10, 12, 13, 15	2, 6, 8, 14
Week 2	Day 1	1, 4, 12, 15	2, 3, 6, 8, 11	5, 9, 10, 13
	Day 2	1, 4, 14, 15	2, 3, 7, 8, 11	5, 10, 13
	Day 3	1, 4, 12, 14, 15	2, 3, 6, 7, 11	5, 9, 13
	Day 4	1, 4, 12, 14, 15	2, 3, 6, 7, 8	5, 9, 10, 13
	Day 5	1, 4, 12, 14	2, 3, 6, 7, 8, 11	5, 9, 10
	Day 6	4, 12, 14, 15	3, 6, 7, 8, 11	9, 10, 13
	Day 7	1, 12, 14, 15	2, 6, 7, 8, 11	5, 9, 10, 13
Week 3	Day 1	2, 3, 6, 13	1, 5, 9, 12, 14	4, 11, 15
	Day 2	2, 3, 6, 10, 13	1, 5, 8, 9, 12	4, 7, 11, 15
	Day 3	2, 3, 6, 10, 13	1, 5, 8, 12, 14	4, 7, 11
	Day 4	2, 3, 6, 10	1, 5, 8, 9, 14	4, 7, 11, 15
	Day 5	2, 3, 10, 13	1, 5, 8, 9, 12, 14	4, 7, 15
	Day 6	2, 6, 10, 13	5, 8, 9, 12, 14	4, 7, 11, 15
	Day 7	3, 6, 10, 13	1, 8, 9, 12, 14	7, 11, 15
Week 4	Day 1	2, 4, 6, 8	1, 5, 10, 11, 14, 15	3, 7, 12
	Day 2	2, 4, 6, 8, 13	1, 5, 11, 14, 15	3, 7, 9, 12
	Day 3	2, 4, 8, 13	1, 5, 10, 11, 15	3, 7, 9, 12
	Day 4	2, 4, 6, 13	1, 5, 10, 11, 14	3, 9, 12
	Day 5	2, 4, 6, 8, 13	1, 5, 10, 14, 15	3, 7, 9
	Day 6	4, 6, 8, 13	5, 10, 11, 14, 15	7, 9, 12
	Day 7	2, 6, 8, 13	1, 10, 11, 14, 15	3, 7, 9, 12

However, the number of employees assigned to each shift in each week must be greater than the minimum required since each employee must have one day off per week (the constraint in **Equation (18)**). Suppose the number of employees assigned to a shift in a given week equals to the minimum required for that shift (e.g., only four employees are assigned to the morning shift). In that case, none of those employees can take a day off during the week, which violates the constraint in **Equation (18)**. To ensure that each employee has one day off per week, the actual number of employees assigned to each shift in each week must exceed the minimum number of employees required for that shift by at least one. In other words, the actual number of employees assigned to the morning, noon, and night shifts must be at least five, six, and four, respectively (totalling 15 employees). This implies that 15 employees (in Problem 1) are the minimum required to create a feasible work schedule that meets the current store's regulations, and so only 14 employees (in Problem 2) are insufficient to generate a feasible work schedule. Note that, according to **Table 4**, which shows the results of Problem 1, the actual number of employees assigned to the morning, noon, and night shifts is five, six, and four, respectively, every week.

Table 5. The Day off in Each Week for Each Employee in Problem 1

Employee (n)	Week 1	Week 2	Week 3	Week 4
1	6	6	6	6
2	6	6	7	6
3	6	7	6	6
4	7	7	7	7
5	7	6	7	7
6	3	2	5	3
7	5	1	1	4
8	5	3	1	4
9	2	2	3	1
10	2	3	1	2
11	4	4	5	5
12	5	2	4	5
13	4	5	4	1
14	4	1	2	3
15	1	5	3	4

3.3 Results of Problem 3

For Problem 3, the parameter n was 16, and the constraint in **Equation (7)** was replaced with the constraint in **Equation (22)**. The results returned from the CPLEX solver was still infeasible and so even if this convenience store hires one more regular employee, the total number of employees ($n = 16$) would still be insufficient to schedule each employee to work at most one night shift week every four weeks.

3.4 Results of Problem 4

In Problem 4, the constraint in **Equation (7)** in the proposed model was replaced with the constraint in **Equation (22)**, and the parameter n was set to be 17. Problem 4 could be solved to an optimal solution with a computational time of 2.41 s. Thus, if the manager wants each employee to work the night shift for no more than one week every four weeks, then the manager needs to increase the total number of employees by at least two ($n = 17$) from the current 15 employees. The list of shifts that each employee must work in each week could be interpreted from the variables a_{ij}, b_{ij}, and c_{ij}, which were equal to 1, as shown in **Table 6**. Note that, in the last column of **Table 6**, there is only one element of c_{ij} that is equal to 1 in each row because each employee works the night shift for no more than one week, as dictated by the constraint in **Equation (22)**. The four-week employee schedule for Problem 4, which could be interpreted from the variables A_{ijk}, B_{ijk}, and C_{ijk}, is shown in **Table 7**. Moreover, the list of the day off in each week for each employee, which could be interpreted from the variable x_{ijk}, is shown in **Table 8**. The information in **Table 6** – **Table 8** could be explained similarly as **Table 3** – **Table 5**. The objective value of the optimal solution for Problem 4 was 20, which implies that all days off for the manager and assistant managers are also on weekends (see **Table 8**).

3.5 Discussion

This paper presents a BILP model for scheduling employees at a 24-hour convenience store in Nakhon Pathom. The solution returned from the proposed BILP model specifies which shift each employee must work in each week of a four-week schedule period and the specific days they must work within each week. Moreover, it also specifies which day each employee has off each week. This information is valuable and can be used to create the employee work schedule for the given convenience store in a real-life situation.

Table 6. The Variables a_{ij}, b_{ij}, and c_{ij}, which are Equal to 1, for Problem 4, Presented According to Employee Numbers

Employee (n)	a_{ij}	b_{ij}	c_{ij}
1	a_{12}, a_{13}, a_{14}	b_{11}	
2	a_{21}	b_{22}, b_{24}	c_{23}
3	a_{32}, a_{33}	b_{31}	c_{34}
4	a_{43}	b_{42}, b_{44}	c_{41}
5	a_{51}, a_{54}	b_{53}	c_{52}
6	a_{62}, a_{64}	b_{61}	c_{63}
7	a_{71}, a_{73}	b_{74}	c_{72}
8	a_{82}, a_{83}	b_{84}	c_{81}
9	a_{93}	b_{91}, b_{92}	c_{94}
10	$a_{10,3}$	$b_{10,2}, b_{10,4}$	$c_{10,1}$
11	$a_{11,2}$	$b_{11,3}, b_{11,4}$	$c_{11,1}$
12	$a_{12,2}$	$b_{12,1}, b_{12,3}$	$c_{12,4}$
13	$a_{13,4}$	$b_{13,1}, b_{13,3}$	$c_{13,2}$
14	$a_{14,1}, a_{14,4}$	$b_{14,3}$	$c_{14,2}$
15	$a_{15,2}$	$b_{15,1}, b_{15,4}$	$c_{15,3}$
16	$a_{16,1}$	$b_{16,2}, b_{16,3}$	$c_{16,4}$
17	$a_{17,1}, a_{17,4}$	$b_{17,2}$	$c_{17,3}$

The proposed model can also determine whether a work schedule can be generated when the number of employees or some store's regulations are changed by adjusting some parameters or constraints in the model. This is useful because the generated work schedule gives the store manager options to meet some desired conditions before making a decision in real-life situations. For example, suppose the manager requires each employee to work the night shift for at most one week. In that case, the manager can use the proposed model (as in Problem 4) to determine whether increasing the staff by two employees (compared to Problem 1) allows this condition to be met. The manager can see from the results of Problem 4 that it is feasible and can then proceed to announce the recruitment of two additional positions as the next step if they wish to meet this condition.

In practice, furthermore, the schedule generated by the proposed model can also be used as an initial schedule that can be adjusted in the real situation if needed. For example, from **Table 4**, Employees 3, 5, 7, 9, and 11 are assigned to work the morning shift in Week 1. From **Table 5**, Employee 9 has a day off on Day 2 in Week 1. In addition, Employee 9 has to work on Day 3 of Week 1 (see **Table 4**). Suppose Employee 9 has to do some errands on Day 3 and is, therefore, unable to work on that day. Employee 9 can inform the manager to request a change in their day off. According to **Table 4**, the manager can assign Employee 9 to work on Day 2 instead and change Employee 9's day off this week to Day 3. In this case, the number of employees on Days 2 and 3 still meets the minimum required for the morning shift (the constraint in **Equation (19)**), and Employee 9 still has one day off (the constraint in **Equation (18)**), which allows Employee 9 to have the appropriate day off to handle the errands as desired.

As for the computational time, the proposed model could solve Problems 1 and 4 with a computational time of less than 3 seconds. This shows that the proposed model is efficient and applicable for finding an optimal employee schedule for this convenience store. As of today, the manager takes approximately 30 minutes to create a four-week schedule manually, but the proposed model can generate an optimal four-week schedule within a few seconds. Thus, the proposed model would be helpful in real-life situations since it can save time and reduce the manager's task in creating a work schedule for his employees.

Table 7. **The Four-Week Employee Schedule Derived from an Optimal Solution of Problem 4**

Week	Day	Morning shift (8:00 a.m. to 5:00 p.m.)	Noon shift (2:00 p.m. to 11:00 p.m.)	Night shift (11:00 p.m. to 8:00 a.m.)
Week 1	Day 1	2, 5, 7, 14, 16, 17	1, 3, 6, 9, 12, 13, 15	4, 8, 11
	Day 2	2, 5, 7, 14, 16	1, 3, 6, 9, 12, 13, 15	4, 8, 10, 11
	Day 3	2, 5, 7, 14, 17	1, 3, 6, 9, 12, 15	4, 8, 10
	Day 4	2, 5, 14, 16, 17	1, 3, 9, 13, 15	4, 8, 10, 11
	Day 5	2, 5, 7, 14, 16, 17	1, 3, 6, 12, 13, 15	4, 10, 11
	Day 6	7, 14, 16, 17	1, 3, 6, 9, 12, 13	4, 8, 10, 11
	Day 7	2, 5, 7, 16, 17	6, 9, 12, 13, 15	8, 10, 11
Week 2	Day 1	1, 3, 6, 8, 11, 12, 15	2, 4, 9, 10, 16	5, 7, 13, 14
	Day 2	1, 3, 6, 8, 11, 12, 15	2, 4, 10, 16, 17	5, 7, 13, 14
	Day 3	1, 3, 6, 11, 12, 15	2, 4, 9, 10, 17	5, 13, 14
	Day 4	1, 3, 6, 8, 11, 12	2, 4, 9, 10, 16, 17	5, 7, 13
	Day 5	1, 3, 6, 8, 11, 12, 15	2, 4, 9, 16, 17	5, 7, 14
	Day 6	3, 8, 12, 15	4, 9, 10, 16, 17	5, 7, 13, 14
	Day 7	1, 6, 8, 11, 15	2, 9, 10, 16, 17	7, 13, 14
Week 3	Day 1	1, 3, 4, 7, 8, 10	5, 11, 13, 14, 16	2, 15, 17
	Day 2	1, 3, 4, 8, 9, 10	5, 11, 12, 14, 16	2, 6, 15, 17
	Day 3	1, 3, 4, 7, 8, 9	5, 12, 13, 14, 16	2, 6, 15
	Day 4	1, 3, 4, 7, 8, 9, 10	5, 11, 12, 13, 16	2, 6, 17
	Day 5	1, 3, 4, 7, 8, 9, 10	5, 11, 12, 13, 14	2, 6, 15, 17
	Day 6	1, 7, 8, 9, 10	5, 11, 12, 13, 14, 16	2, 6, 15, 17
	Day 7	3, 4, 7, 9, 10	11, 12, 13, 14, 16	6, 15, 17
Week 4	Day 1	1, 5, 13, 14	2, 4, 7, 8, 10, 11	3, 12, 16
	Day 2	1, 5, 6, 13, 14, 17	2, 4, 7, 8, 11, 15	3, 9, 12
	Day 3	1, 5, 6, 14, 17	2, 4, 7, 8, 10, 15	3, 9, 12, 16
	Day 4	1, 5, 6, 13, 17	2, 4, 7, 8, 10, 11, 15	3, 9, 16
	Day 5	1, 5, 6, 13, 14, 17	2, 4, 7, 10, 11, 15	3, 9, 12, 16
	Day 6	6, 13, 14, 17	4, 7, 8, 10, 11, 15	3, 9, 12, 16
	Day 7	1, 5, 6, 13, 14, 17	2, 8, 10, 11, 15	9, 12, 16

Moreover, this paper solves the proposed model using the commercial software ILOG OPL CPLEX. However, the model can also be solved using other software tools, particularly open-source software. Free software enables users to solve the proposed model and obtain an optimal or feasible work schedule without incurring software costs, which is also beneficial in real-life applications.

Table 8. **The Day Off in Each Week for Each Employee in Problem 4**

Employee (n)	Week 1	Week 2	Week 3	Week 4
1	7	6	7	6
2	6	6	7	6
3	7	7	6	7
4	7	7	6	7

Employee (n)	Week 1	Week 2	Week 3	Week 4
5	6	7	7	6
6	4	6	1	1
7	4	3	2	7
8	5	3	7	5
9	5	2	1	1
10	1	5	3	2
11	3	6	3	3
12	4	7	1	4
13	3	5	2	3
14	7	4	4	4
15	6	4	4	1
16	3	3	5	2
17	2	1	3	1

4. CONCLUSION

This paper reports an ESP's real-world application at a Nakhon Pathom convenience store. The ESP was formulated as a BILP model to find an optimal four-week employee work schedule. The objective of the proposed model was to maximize the number of weekend days off for the manager and assistant managers while adhering to constraints from the store's regulations. Real data from the convenience store case study were applied to validate the proposed model. The results showed that the proposed model could find an optimal work schedule for employees at this convenience store within a reasonable computational time using the ILOG OPL CPLEX software. The model is helpful for the manager or relevant decision makers responsible for organizing the work schedule for employees at this convenience store. It is a new application for this convenience store and could be used to provide an optimal schedule for their employees in a real situation. It may also be used to find a work schedule for employees at other convenience stores if their constraints are similar to those of this convenience store. Future research could extend the scope of the problem by incorporating additional factors, such as part-time employees, shift preferences, and preferred days off for each employee, and developing a mathematical programming model and a heuristic or metaheuristic method to solve the extended problem.

AUTHOR CONTRIBUTIONS

Teeradech Laisupannawong: Conceptualization, Data Curation, Formal Analysis, Funding Acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing - Original Draft. Chawalit Jeenanunta: Software, Supervision, Validation, Writing - Review and Editing. All authors discussed the results and contributed to the final manuscript.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest to report study.

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