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Optimizing Shift Scheduling for Retail Cashiers Using Binary Integer Programming

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ABSTRACT

Workforce scheduling in small-scale retail environments presents operational challenges due to limited staffing flexibility and fairness considerations in shift allocation. Existing scheduling approaches often emphasize large-scale systems and may not adequately address fairness-oriented constraints in compact retail settings. This study develops a Binary Integer Programming (BIP) model to generate a seven-day shift schedule for seven cashiers at a retail outlet (Eco-Shop Balok branch). The model satisfies operational staffing requirements while minimizing violations of soft constraints, including consecutive workdays, excessive full-day assignments, and imbalance in morning shift distribution. Hard constraints ensure daily coverage and regulatory compliance, whereas soft constraints are incorporated through weighted penalty variables in the objective function. The model is implemented using LINGO, and results indicate that the optimized schedule increased morning shift staffing from one staff member working twice the morning shift to three staff to match preferences for lighter workloads and earlier finishes, while decreasing full-day shifts from five to three staff, improving work-life balance. Noon shift efficiency was maintained with a cashier working it three times a week, reduced from two to one. A seven-week cyclical schedule was also proposed to ensure long-term fairness and sustainability. The findings confirm that BIP provides a transparent and computationally efficient framework for small-scale retail workforce optimization, offering practical applicability for similar operational environments.

1. INTRODUCTION

Retail operations rely heavily on effective cashier shift scheduling to maintain service quality while controlling labor costs. At the Eco-Shop's Balok branch, shift scheduling has traditionally been conducted manually using spreadsheets by department supervisors. This approach often results in unbalanced workloads, repeated full-day assignments, and inconsistent shift rotation among staff members. Such

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inefficiencies may affect employee morale and operational performance, particularly in small retail environments where staffing flexibility is limited.

An effective scheduling system must ensure compliance with staffing requirements while maintaining work-life balance in shift allocation. However, manual scheduling is not only time-consuming but also prone to bias and inconsistency, particularly when multiple departments and responsibilities are handled by the same supervisor. Therefore, a structured optimization-based approach is necessary.

Although various optimization techniques such as heuristic algorithms, metaheuristics, and Mixed Integer Linear Programming (MILP) have been widely applied in workforce scheduling, many are designed for large-scale industrial systems. For small retail settings with purely binary assignment decisions (assigned or not assigned), Binary Integer Programming (BIP) provides a more natural and computationally efficient framework. Moreover, limited studies specifically address fairness-driven cashier scheduling in micro-level retail environments.

This study aims to i) Develop a Binary Integer Programming model for weekly cashier scheduling, ii) Minimize violations of fairness-related soft constraints while satisfying all operational requirements and iii) Evaluate the effectiveness of the optimized schedule compared to the manually prepared schedule.

By focusing on a small-scale retail case study, this research extends the practical application of Binary Integer Programming (BIP)to micro-level workforce management.

2. LITERATURE REVIEW

2.1 Scheduling

Problem regarding scheduling has been discussed in many previous papers and the methods used to solve the problem are varied which makes it clearer that each problem has its optimal solution method. A robust scheduling model was developed for library staff that accounted for student preferences and operational limitations. Ang et al. (2019) addressed scheduling for university security personnel. Recognizing that rigid shift patterns contribute to stress, family issues, and poor job satisfaction, the researchers designed an integer programming model to maximize preference satisfaction. The model solved using the LP Solve IDE increased satisfaction scores from 228.33 to 394.33, demonstrating the effectiveness of mathematical scheduling in improving staff well-being.

Sari and Widianiti (2020) applied the Firefly Algorithm in MATLAB to automate employee scheduling at MJ Store, ensuring compliance with legal labor requirements. Their system achieved a 96% success rate, with minimal violations of soft constraints. Testing phases including integration, black-box testing, and user acceptance indicated high system reliability, though further accuracy validation through expert input or historical data was recommended. A mixed-integer linear programming (MILP) approach was proposed to tackle short-term production shift scheduling in mining operations involving both personnel and machinery (Seifi et al., 2021). Implemented in LINGO 18, their two-stage MILP model outperformed heuristic methods based on comparative performance metrics, offering a more efficient solution for complex scheduling in industrial environments.

A similar MILP framework to staff scheduling at Iran Hospital is applied (Nobil et al., 2022). Their model succeeded in producing a uniform shift distribution while reducing staffing costs by 10% compared to manual scheduling. The study concluded that MILP could yield substantial cost savings, particularly when applied to larger staffing scenarios.

Moreover, the scheduling problem was solved in another study conducted using the Firefly algorithm method. However, the method used was adapted according to the suitability of each one. The study by Perez-Napalit and Ballera (2023) focused on the application of the modified firefly algorithm to improve the performance of complex optimization problems in terms of their computation cost, efficiency and

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solution quality. The above model was simulated using MATLAB software. The enhanced firefly algorithm yielded less mean movement and a more focused search pattern than conventional Firefly Algorithm models, indicating better optimization performance.

2.2 Binary Integer Programming

Binary Integer Programming (BIP) has been widely applied to various optimization problems and has consistently demonstrated its effectiveness in producing optimal solutions across different domains. Applications include sports lineup optimization, faculty-course allocation, energy load scheduling, and land-use planning. Mahrudinda et al. (2021) applied BIP to determine the optimal starting lineup for Liverpool FC during the 2020/2021 English Premier League season. Using player performance ratings as input data, their model compared several formations and found that a 4-3-3 setup yielded the highest overall team rating. This attacking formation was shown to outperform the more defensive 4-2-3-1 formation, offering greater pace and offensive intensity.

Next, BIP was utilized to address the faculty-course assignment problem, factoring in both faculty preferences and institutional constraints (Torres et al., 2021). The model generated schedules that aligned with policy requirements while allowing instructors to teach subjects within their area of specialization. The approach succeeded in balancing institutional needs with staff satisfaction. In the residential energy domain, Yahia and Kholopane (2018) developed a BIP model to optimize household appliance usage schedules based on consumer preferences. Their model achieved up to 55% reductions in electricity costs and a significant reduction in computation timeabout 99.94% compared to alternatives of Mixed-Integer Nonlinear Programming (MINLP). Compared to previous models in the literature, the BIP approach offered at least 31% greater efficiency in energy consumption.

Meanwhile, (Türk & Zwick, 2019) applied BIP to land use management within urban and regional planning. Their objective was to maximize the suitability of land assignments across multiple planning scenarios. The model allocated each land cell to use with the highest suitability score, resulting in total benefit values of 826,067; 808,185; and 801,533 for the three respective models. These outcomes demonstrated BIP’s capability to yield high-quality solutions in spatial planning applications.

2.3 Scheduling using Binary Integer Programming

Ahamad and Ghani (2023) developed a Binary Integer Programming (BIP) model to minimize staffing requirements while maintaining equal working hours and break times in a fast-food restaurant in Johor. The model successfully generated a revised schedule using only 11 employees instead of 12, meeting all operational constraints. According to their findings, BIP can significantly enhance scheduling efficiency, reduce labor costs and all of which will increase the restaurant's competitive advantage within the food service industry.

Teixeira et al. (2010) addressed production scheduling in market-driven foundries that manufacture various metal alloys on a small scale. These environments face challenges in synchronizing the molding, pouring, and finishing stages, often leading to inefficiencies, high inventory levels, and quality issues. The researchers proposed BIP formulations in both standard and relaxed versions in order to coordinate production phases and optimize resource use. Computational experiments demonstrated that the models effectively produced near-optimal solutions, validating their usefulness as decision-support tools in dynamic foundry operations.

Although Mixed Integer Linear Programming (MILP) has been widely applied in workforce scheduling, the present study adopts Binary Integer Programming (BIP) due to the binary nature of shift assignment decisions. Each cashier can either be assigned (1) or not assigned (0) to a shift, making BIP a natural and computationally efficient modelling framework. Compared to MILP models that include continuous variables, BIP simplifies the decision structure and reduces computational complexity for small-

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to medium-scale retail scheduling problems. Therefore, BIP is more suitable for the Eco-Shop case study, where decision variables are purely binary and do not require fractional allocations.

3. MODEL FORMULATION

3.1 Model development

The primary data for this study were obtained from ECO-Shop Marketing Sdn. Bhd., Balok branch, located in Kuantan, Pahang. Information was provided by the supervisor of the cashier department and included the most recent staff schedule, updated from October 2023. The dataset comprised key details such as the number of cashiers, the number of shifts, types of shift rotations, and the designated off-days allowed per employee each week. Typically, a one-week schedule, which was manually prepared by the department supervisor and reused throughout the month, resulted in limited variation and flexibility among cashier assignments. The scheduling structure consists of seven days with three shift types: Morning (9:30 a.m. to 7:00 p.m.), Noon (1:30 p.m. to 10:00 p.m.), and Full-day (9:30 a.m. to 10:00 p.m.). At the time of the study, seven cashiers were scheduled each week. Over seven days, three shifts were scheduled daily for five days, while only one shift was assigned on the remaining two days. The objective is to minimize violations of fairness-related soft constraints while strictly satisfying all hard operational constraints.

3.1.1 Define the Notations and Decision Variables.

The formulation of the model involved the use of notations as follows:

d = The number of days of working schedule (d = 7)

c = The number of cashiers at the Eco-shop (c = 7)

i = The index number for days (i = 1 … d)

j = The index number for cashiers (i = 1 … c)

Mi = The number of cashiers required for the morning shift of the day i (i = 1 … d)

Ni = The number of cashiers required for the noon shift of the day i (i = 1 … d)

Fi = The number of cashiers required for the full-day shift of the day i (i = 1 … d)

Next, the decision variables are:

$$X_{i,j} = \begin{cases} 1 & \text{if cashier j is assigned morning shift on day } i. \\ 0 & \text{otherwise} \end{cases}$$

$$Y_{i,j} = \begin{cases} 1 & \text{if cashier j is assigned noon shift on day } i. \\ 0 & \text{otherwise} \end{cases}$$

$$Z_{i,j} = \begin{cases} 1 & \text{if cashier j is assigned to full day shift on day } i. \\ 0 & \text{otherwise} \end{cases}$$

$$O_{i,j} = \begin{cases} 1 & \text{if cashier j is off day on day } i. \\ 0 & \text{otherwise} \end{cases}$$

3.1.2 Hard Constraints

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Hard constraints refer to conditions that must be strictly satisfied in an optimization model. In this study, the hard constraints were derived from Eco-Shop's official scheduling policies, which must be strictly followed. Any solution that failed to meet these constraints was considered infeasible. The cashier scheduling model at the Eco-Shop Balok branch incorporated five hard constraints:

i) A minimum number of cashiers must be scheduled each day from Monday to Friday.

ii) A specified number of cashiers must be scheduled on Saturday and Sunday.

iii) No morning or noon shifts are assigned on weekends.

iv) Each cashier can only be assigned one shift (or off-day) per day.

v) Each cashier must receive exactly one off-day per week.

3.1.3 Soft Constraints and Binary Constraints

In worker shift scheduling, soft constraints represented goals or the desirable conditions that should be followed, despite it was not a strict one.

Soft constraint 1: No cashier shall be assigned identical shift types on consecutive days.

$$X_{i,j} + X_{(i+1,j)} \leq 1, i = 1,2, \dots ,5 \text{ } and \text{ } j = 1, \dots , c \tag{1}$$

$$Y_{i,j} + Y_{(i+1,j)} \leq 1, i = 1,2, \dots ,5 \text{ } and \text{ } j = 1, \dots , c \tag{2}$$

$$Z_{i,j} + Z_{(i+1,j)} \leq 1, i = 1,2, \dots ,5 \text{ } and \text{ } j = 1, \dots , c \tag{3}$$

Soft constraint 2: Each cashier should be assigned 1–2 morning shifts per week.

$$\sum_{j}^{c} X_{i,j} \geq 1, \quad i = 1,2 \dots ,5 \tag{4}$$

$$\sum_{j}^{c} X_{i,j} \leq 2, \quad i = 1,2 \dots ,5 \tag{5}$$

Soft constraint 3: Each cashier worked at most 3 full-day shifts per week.

$$\sum_{j}^{c} Z_{i,j} \geq 1, \quad i = 1,2 \dots ,5 \tag{6}$$

$$\sum_{j}^{c} Z_{i,j} \leq 3, \quad i = 1,2 \dots ,5 \tag{7}$$

Binary Constraint: For each shift (morning, noon, full-day, off day) and for each shift of a cashier, the value can be 0 or 1.

$$X_{i,j} = 0 \text{ or } 1 \text{ ; } \quad Y_{i,j} = 0 \text{ or } 1 \text{ ; } Z_{i,j} = 0 \text{ or } 1; 0_{i,j} = 0 \text{ or } 1 \tag{8}$$

3.1.4 Objective Functions

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The objective of this study is to minimize scheduling imbalance and violations of soft constraints while satisfying all hard constraints.

The objective function is formulated as:

$$\text{Minimize } Z = \sum_{i}^{d}\sum_{j}^{c}\left(X_{i,j} + Y_{i,j} + Z_{i,j}\right) \tag{9}$$

4. RESULT AND DISCUSSION

The BIP model was made to develop a schedule of 7 days for 7 cashiers only. It was easier to ensure that this study obtained the optimal work schedule. When an optimal schedule was achieved, only then could the research objectives be fulfilled.

4.1 Lingo output

Lingo software was utilized to solve the optimization problem based on the constructed mathematical model. Once the model was error-free and a global optimal solution was identified, the results were displayed in the Lingo Solver Status. The output provided detailed information, including model feasibility, the objective function value, and the values of the decision variables. The model required less than one second of computational time, indicating practical applicability for small-scale retail operations. These results, as shown in Fig. 1, demonstrate that the solver successfully addressed both the scheduling constraints and the objectives of the study.

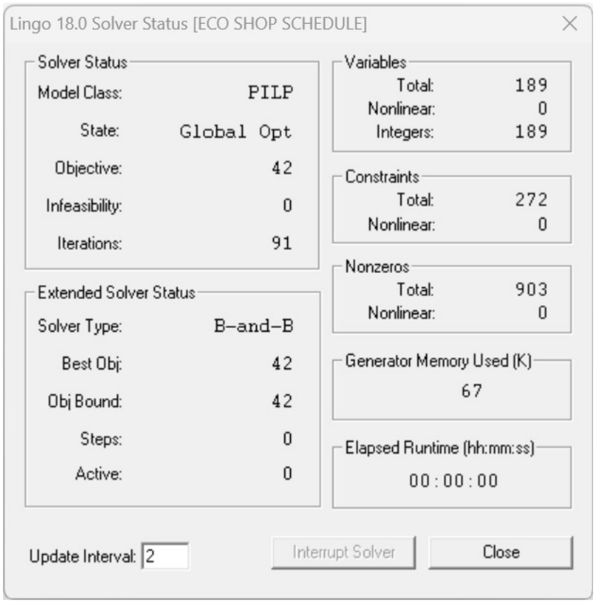

Fig. 1. LINGO Solver Status

4.2 Generated schedule

Table 1 presents a sample of the binary output produced by the LINGO optimization model, where each row corresponds to a specific cashier, and each column represents a shift on a particular day. The

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binary values indicate whether a cashier is scheduled (1) or not scheduled (0) for that shift. To demonstrate how the binary output is interpreted into a readable shift schedule, Table 2 provides the converted schedule for Day 1. It shows which cashier is assigned to which shift based on the binary values, offering a clearer view of how the optimization results translate into actual work assignments. These values serve as the foundation for constructing the full weekly schedule and can be used to verify the model's consistency in meeting constraints and ensuring fair distribution of shifts.

Table 1. Sample of how the interpretation of a binary result into schedule

Morning shift		Noon shift		Full day shift		Off day	
Variable	**Value**	**Variable**	**Value**	**Variable**	**Value**	**Variable**	**Value**
M(1, 1)	0.00000	N(1, 1)	0.000000	F(1, 1)	0.000000	O(1, 1)	1.000000
M(1, 2)	0.000000	N(1, 2)	1.000000	F(1, 2)	0.000000	O(1, 2)	0.000000
M(1, 3)	0.000000	N(1, 3)	0.000000	F(1, 3)	1.000000	O(1, 3)	0.000000
M(1, 4)	1.000000	N(1, 4)	0.000000	F(1, 4)	0.000000	O(1, 4)	0.000000
M(1, 5)	0.000000	N(1, 5)	1.000000	F(1, 5)	0.000000	O(1, 5)	0.000000
M(1, 6)	1.000000	N(1, 6)	0.000000	F(1, 6)	0.000000	O(1, 6)	0.000000
M(1, 7)	0.000000	N(1, 7)	1.000000	F(1, 7)	0.000000	O(1, 7)	0.000000

Table 2. Generated schedule

CASHIERS	DAYS							M	N	F	OFF	TOTAL
	1	**2**	**3**	**4**	**5**	**6**	**7**					
	M	**T**	**W**	**T**	**F**	**S**	**S**					
1	OFF	N	M	N	M	F	F	2	2	2	1	7
2	N	OFF	F	N	M	F	F	1	2	3	1	7
3	F	N	OFF	M	N	F	F	1	2	3	1	7
4	M	F	N	OFF	N	F	F	1	2	3	1	7
5	N	M	N	M	OFF	F	F	2	2	2	1	7
6	M	N	M	N	F	OFF	F	2	2	2	1	7
7	N	M	N	F	N	F	OFF	1	3	2	1	7
M	2	2	2	2	2	0	0					
N	3	3	3	3	3	0	0					
F	1	1	1	1	1	6	6					
TOTAL	**6**	**6**	**6**	**6**	**6**	**6**	**6**					

Table 2 presents the optimized seven-day shift schedule generated by the developed model. The schedule ensures that each cashier is assigned to seven shifts per week while respecting designated off-days, resulting in a fair and balanced workload distribution. The schedule comprises three shift types which were morning (M), noon (N), and full day (F)which structured to meet operational requirements effectively. Full-day shifts were primarily assigned on weekends to satisfy Hard Constraint 2, while weekday assignments followed Hard Constraint 1, which required two cashiers for the morning shift, three for the noon shift, and one for the full-day shift. To prevent employee burnout and ensure fairness, each cashier was limited to one shift per day, in line with Hard Constraint 4, and granted at least one day off per week, fulfilling Hard Constraint 5. The result is an efficient, rule-compliant schedule that supports both staff well-

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being and operational needs.

The schedule further demonstrates that the model effectively balanced workload across all cashiers. As reflected at the bottom of Table 2, the shift distribution per day consistently met operational requirements. The model not only fulfilled all hard constraints but also ensured equitable scheduling and adequate coverage for every shift throughout the week.

4.3 Comparison between the current and generated schedule

Table 3 shows the total number of each shift type assigned to each cashier in both the current and generated schedules.

Table 3. Comparison of total shifts per cashier: current versus generated schedule

CASHIER	CURRENT SCHEDULE				GENERATED SCHEDULE			
	M	N	F	TOTAL	M	N	F	TOTAL
1	1	2	3	6	2	2	2	6
2	1	2	3	6	1	2	3	6
3	1	3	2	6	1	2	3	6
4	1	2	3	6	1	2	3	6
5	1	2	3	6	2	2	2	6
6	1	2	3	6	2	2	2	6
7	2	3	1	6	1	3	2	6
TOTAL	**8**	**16**	**18**	**42**	**10**	**15**	**17**	**42**

The generated schedule demonstrated notable improvements by aligning more closely with the objective of optimizing shift allocation while maintaining efficient and fair distribution among staff. Both schedules allocated 42 total shifts. However, the optimized schedule achieved a more uniform distribution of shift types.

Several enhancements were introduced in the optimized schedule. The number of employees assigned three full-day shifts per week decreased from five to three, easing the burden of long working hours and supporting better work-life balance. Meanwhile, the number of staff members assigned two morning shifts per week increased from one to three, which allowed employees to finish earlier and avoid working late into the evening. For the noon shift, the number of employees working it three times per week decreased from two employees to one employee, streamlining the allocation while still meeting staffing requirements.

Overall, the optimized schedule provided a more balanced workload, reduced overstaffing in demanding shifts, and aligned better with employee preferences. These adjustments improved distribution equity without altering total staffing levels. The improvements reflect better shift rotation rather than increased staffing.

4.4 Seven-Week Cyclical Schedule

To ensure long-term fairness, the optimized weekly schedule was extended into a seven-week cyclical rotation. Each cashier rotates through different weekly patterns, ensuring equitable exposure to preferred and demanding shifts over time. This cyclical structure enhances sustainability and reduces systematic bias. The structured allocation promotes equitable workload distribution, which may contribute to improved staff satisfaction.

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5. CONCLUSION AND RECOMMENDATION

This study developed a Binary Integer Programming model to improve cashier shift allocation at Eco-Shop Balok. Implemented using LINGO software, the model aimed to maximize shift assignments while satisfying operational constraints such as required staffing levels, shift types, and off days. The resulting 49-day cyclical schedule ensured fair workload distribution, improved consistency, and reduced scheduling conflicts. By incorporating penalty-based soft constraints into the objective function, the model minimized workload imbalance while satisfying all operational requirements.

The optimized schedule achieved a more equitable distribution of morning and full-day shifts without altering total staffing levels. The results confirm that BIP provides an exact, structured, and computationally efficient solution for small retail scheduling problems. Beyond its immediate impact, the study provides a foundation for future applications of optimization-based scheduling in other departments or industries seeking to improve workforce management systems.

To further enhance the cashier scheduling system at Eco-Shop, the BIP model should be adapted to support dynamic conditions such as sudden staff absences or demand fluctuations. Incorporating employee preferences for specific shifts or days off can also increase engagement and satisfaction. The scheduling model could be extended to other departments or branches to promote consistency and efficiency across the organization. Regular performance evaluations based on metrics such as customer satisfaction, productivity, and absenteeism are essential for continuous improvement. Future research may incorporate demand forecasting, dynamic staff availability, and multi-department integration to enhance adaptability.

This study is limited to a single retail branch with a fixed staffing structure and a one-week planning horizon. The model does not incorporate stochastic demand fluctuations or employee preference ranking. Future work may extend the formulation to multi-branch scheduling and dynamic demand environments.

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7. CONFLICT OF INTEREST STATEMENT

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

8. AUTHORS' CONTRIBUTIONS

Diana Sirmayunie and Suzanawati Abu Hasan: conceptualized the study and developed the Binary Integer Programming framework; **Nurtasnim Tihani Mohd Zuki:** responsible for data collection; **Nor Hayati Shafii and Teoh Yeong Kin:** conducted the computational analysis and validation using LINGO. Diana Sirmayunie Mohd Nasir drafted the manuscript. All authors contributed to the result interpretation, manuscript revision, and approved the final version prior to submission.

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