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Operational Cost Optimization on Solid Waste Collection Using Goal Programming

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ABSTRACT

Waste collection is the waste management, comprising storage, collection, transportation, and disposal, is the most expensive aspect of waste management, involving resources in strategy, execution, and oversight. Even in Perlis, the smallest state in Malaysia, waste management has become a concern due to population growth and increased industrial activities. This study aims to determine the optimal operational cost by utilizing the Goal Programming approach. Data from E-Idaman Kangar Sdn. Bhd, a private company managing solid waste in Perlis, was utilized. The goal is to achieve an optimization rate by formulating an objective function and utilizing Lingo software version 18.0. The study aims to achieve five objectives regarding operational cost which are minimizing labor cost, minimizing collection cost, minimizing vehicle cost, minimizing consumable cost and minimizing the financial statement of operation for each route. The research results indicate that E-Idaman Kangar's collection expenses are already at an optimal state. It showed that the cost of each vehicle included in the collection activity is optimized. The objective value shows that the total spending can still be reduced by RM3, which is a decrease of 0.01%. In conclusion, this can be seen that the organization accomplishes collection in an ideal manner. The outcomes of this study are poised to contribute towards achieving sustainable Solid Waste Collection (SWC) across the entirety of Perlis state, thereby upholding a clean and healthy environment for its residents. Additionally, through meticulous budgeting and strategic planning prior to each monthly collection, companies can effectively manage their finances and bolster profitability.

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1. Introduction

Solid waste is the term used to describe unwanted materials generated by commercial, industrial, and residential operations. It is significant to recognize that not all waste is considered solid waste. Putting aside the huge amount of waste daily, waste is categorized into a few forms, including food waste, marine litter, and microplastic [1]. Indeed, integrated solid waste management is necessary to reduce the waste-related issue’s negative effects on both human health and the environment. This type of management includes waste prevention, recycling,

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composting, collecting, transportation, burning, and disposal. With an increase in the number of Malaysian populations by 32.8 million, a massive amount of solid waste is being produced, estimated at around 38,427 metric tons per day in the year 2021, which is disposed of at a rate of 82.5 percent in landfills [2]. The amount of municipal solid waste (MSW) that will be collected by 2022 will be over 14 million tons, which is enough to fill the Petronas Twin Tower every seven days. The nature of the solid waste produced has changed because of rapid industrialization and urbanization. The rising rates of annual waste generation are brought on by Malaysians' desire for a higher standard of living [3].

The most expensive part of waste management systems is waste collection. Direct and indirect costs both play a role in the overall expenditure on waste collection. All direct costs made in the management of solid waste in an area are included which covers the resources employed in the planning, implementation, and management of waste management (storage, collection, transportation, and disposal). Meanwhile, indirect costs are the outside expenses involved when using the current waste management techniques which include the cost of hazardous waste collection, storage, and disposal techniques causing environmental harm [4]. Thus, proper, and effective waste management is necessary to maintain a good environment, health, and economic stability. In addition to preserving the environment and public health, research on solid waste disposal methods is necessary to keep costs associated with waste collection and cleaning low.

The smallest state in Malaysia, Perlis Indera Kayangan, is situated in Peninsular Malaysia's northern region. As of 2020, there were 254,700 residents. There are significant environmental issues in Perlis because of the growth in population and industrial activity. One of the issues facing the environment is solid waste. The Environmental Department of Perlis reported Perlis produced 7,816 tons of scheduled waste overall in 2019, up from the 2,536 tons reported in 2018 [5]. To address this environmental issue, the department of cleanliness and the environment conducts waste collection activities.

A collection of solid waste in Perlis is conveyed by E-Idaman Sdn Bhd (E-Idaman). The collection is carried out daily or weekly, while the final disposal of waste from the entire Perlis region takes place at the Padang Siding landfill. There are six main functional components to solid waste management. These include waste production, storage, collection, transport, recycling, processing, and disposal of waste. With the help of the goal programming method, it is hoped that the results of this study will help obtain the optimal cost for solid waste collection.

2. Literature Review

A few studies have been conducted on solid waste collection management. Many different methods were used to obtain optimal time and cost for solid waste collection. As an example, researchers in [6] stated that the state's government invests a sizable sum of money each year in solid waste management but lacks practical means of minimizing or reducing it. It can be inferred from the information above that operational costs are high. Meanwhile, studies from [7] show that solid waste collection can be optimized by investigating route optimization using a Geographical Information System (GIS). Five (5) routes in Ipoh and Perak were selected, and the current route can be optimized as the routes reduce and affect the time needed for waste collection. The analysis was based on the needs and constraints of the collection service. Since then, the GIS-ArcView application for route optimization in Ipoh city has shown a reasonable improvement in route length and travel time reduction.

To facilitate long-term planning of waste management activities in the city of Tianjin, the interval joint-probabilistic mixed-integer programming (IJMP) method is created. Researchers in [8] stated that in the IJMP, few joint-probabilistic constraints were introduced into an interval-parameter mixed-integer programming framework. The uncertainties expressed in terms of interval values and random variables can be considered. The created model may help address the solid waste management system's dynamic, interactive, and uncertain characteristics and can effectively link system cost and system failure risk. Another problem under uncertainty is identifying optimal waste-flow-allocation schemes. A Stepwise Interactive Algorithm (SIA) was used by [9] in a case study of waste allocation problems under uncertainty as an advanced to a generalized fuzzy linear programming (GFLP) method. From the results, reasonable solutions resulted in planning waste allocation practices and the GFLP can provide more detailed information. From there, the decision-makers can construct trade-offs for system stability and plausibility. This can also identify desired policies for any solid waste problems under uncertainty.

Besides, a study has been made to optimize the logistic network and transportation system of Integrated Solid Waste Management (ISWM). This is where it is formulated as a tri-echelon ISWM logistic network. The mixed-integer linear programming (MILP) was used by [10] to formulate the ISWM system in the Fleet Size and Mix Vehicle Routing Problems with the Time Windows framework. This study successfully supports a cost-effective ISWM transportation system, and this proposed approach was successfully applied to real-world problems in southern Tehran, Iran. This approach has obtained the optimal economic cost of the system under uncertainty. The results confirmed the method's strength and effectiveness when the estimated and real amounts of the uncertain parameter differed by larger amounts and when the system network experienced unforeseen disturbances.

Meanwhile, many researchers have studied goal programming, which has been successfully applied to a wide range of real-world problems. [11] proposed the method, which is now accepted as a basic mathematical programming method for solving decision-making problems with multiple objectives. To begin with, the lexicographic goal programming technique was used by [12] to solve the multi-objective optimization model. Three objectives have been considered: Cost reduction, final waste disposal to landfill reduction, and environmental impact reduction are all priorities. As decision makers' preferences, the goal of cost minimization was considered more important than minimizing greenhouse gas emissions and the final amount of waste to the landfill in this problem. The GLPK Integer Optimizer was used to run the model and obtain the optimal solution. The final formulated objective function produces results in which all deviation variables are zero, indicating that all goals are perfectly satisfied.

Subsequently, researchers in [13] conducted a study on time and cost optimization using the goal programming methods for port container handling to reduce the costs incurred and the length of time the queue optimization is performed on the scheduling at the port. The objective was to find the reason for which activity caused a delay in loading and unloading activities. From the result, the average was used as the target of the activity to be optimized and the maximum value as the input value to obtain the optimal value. The researcher determined that goal programming will be used to optimize time and costs for data with higher complexity and sample size in future work.

Next, [14] uses goal programming to optimize waste management. Some of the primary objectives (goals) are utilized interchangeably in this study to demonstrate the model's use as a tool in the planning process. The model is also a highly valuable tool for analyzing the cost-effectiveness of various priority orders, such as those led by environmental protection, cost minimization, energy recovery maximization, or resource recovery maximization. With the specified priority hierarchies, what is presented can be utilized to plan a long-term waste management system or to optimize waste management activities.

3. Methodology

3.1 Waste Sources Data

The study relies on data generously supplied by E – Idaman Sdn. Bhd, a private firm specializing in solid waste management, is responsible for overseeing the solid waste system in Northern Malaysia. The data, sourced specifically from their branch in Majlis Perbandaran (MP) Kangar, pertains to January 2023. There are three routes of data with two routes of collection and three types of vehicles used. The route obtained is the Beseri and Kangar to Jalan Santan route. These vehicles include the regular vehicle and the vehicle with an arm roll where the Kangar to Jalan Santan route performs collection using both normal and arm roll included vehicles. Arm roll is the machinery that can help lift bins and dumps without the need for manpower. Based on the data, five types of costs were obtained from each vehicle which are collection cost, labor cost, vehicle cost, consumable cost, and financial statement of operation. Table 1 shows the cost statement for E-Idaman Kangar in January 2023.

To break it down, the labor cost encompasses salaries for the management team, including the supervisor and manager, along with the wages for the driver and collection crew. Following that, the collection cost factors in the collection rate for each bin per route. Moving on, the vehicle cost encompasses maintenance, fuel consumption, road tax, and insurance. Lastly, consumable costs include expenses for tools such as scoops, rakes, and gloves used by the crew monthly.

Notably, the cost for the Kangar to Jalan Santan route with an arm roll is notably lower than the other routes, owing to reduced manpower requirements for collection due to the presence of an arm roll on the vehicle.

Table 1. Cost Statement in Ringgit Malaysia (RM) for E-Idaman Kangar, January 2023

Route	Labor Cost	Collection Cost	Vehicle Cost	Consumable Cost	Total
Beseri	16086.97	10114.97	6955.00	65.67	33222.61
Kangar – Jalan Santan	15558.17	12085.84	9685.00	65.67	37394.68
Kangar – Jalan Santan + arm roll	8937.36	7846.35	5057.50	52.67	21893.88
Total	40582.50	30047.16	21697.50	184.01	92511.17

3.2 Generate goal programming model.

In the following statement, decision variables, goals and constraints for the model are defined.

The decision variables are shown as follows:

x_j : the type of vehicles, j = 1,2,3 where;
x_1 = vehicle 1 (route Beseri)
x_2 = vehicle 2 (route Kangar – Jln Santan)
x_3 = vehicle 3 (route Kangar – Jln Santan + armroll)

The process of establishing and defining the objectives that a goal programming model seeks to accomplish is known as goal formulation. This study focuses on five goals which are outlined below:

Labor Cost Optimization

Minimize the salary expenses of labor.

$$\sum_{(i=1)}^{5} S_i x_j \leq T_S \tag{1}$$

$$\sum_{(i=1)}^{5} S_i x_j + d_1^- - d_1^+ = T_S \tag{2}$$

Where S_i is the salary paid for labor each month.
T_S is the target salary expenses of labor
d_1^- underachievement from the minimum labor cost per vehicle
d_1^+ overachievement from the minimum labor cost per vehicle

Collection Cost Optimization

Minimize the collection cost.

$$\sum_{(i=1)}^{5} C_i x_j \leq T_c \tag{3}$$

$$\sum_{(i=1)}^{5} C_i x_j + d_2^- - d_2^+ = T_C \tag{4}$$

Where C_i is the collection cost each month.
T_C is the target collection cost
d_2^- underachievement from the minimum collection cost per vehicle
d_2^+ overachievement from the minimum collection cost per vehicle

Vehicle Cost Optimization

Minimize the vehicle cost of the collection.

$$\sum_{(i=1)}^{5} V_i x_j \leq T_V \tag{5}$$

$$\sum_{(i=1)}^{5} V_i x_j + d_3^- - d_3^+ = T_V \tag{6}$$

Where V_i is the cost of vehicle collection each month.
T_V is the target vehicle cost for collection.
d_3^- underachievement from the minimum vehicle cost per vehicle
d_3^+ overachievement from the minimum vehicle cost per vehicle

Consumable Cost Optimization

Minimize the consumable cost.

$$\sum_{(i=1)}^{5} M_i x_j \leq T_M \tag{7}$$

$$\sum_{(i=1)}^{5} M_i x_{(j)} + d_4^- - d_4^+ = T_M \tag{8}$$

Where M_i is the consumable cost each month.
T_M is the target consumable cost.
d_4^- underachievement from the minimum consumable cost per vehicle
d_4^+ overachievement from the minimum consumable cost per vehicle

Financial Statement Optimization

Minimize the financial statement of operation.

$$\sum_{(i=1)}^{5} F_i x_j \leq T_F \tag{9}$$

$$\sum_{(i=1)}^{5} M_i x_j + d_5^- - d_5^+ = T_F \tag{10}$$

Where F_i is the financial statement of operation each month.

T_F is the target statement cost.

d_5^- underachievement from the minimum financial statement cost per vehicle

d_5^+ overachievement from the minimum financial statement per vehicle

Based on the goals derived from the equations (1) – (10) above, the corresponding achievement function is as below:

$$\text{Minimize} = P_1 d_1^+ + P_2 d_2^+ + P_3 d_3^+ + P_4 d_4^+ + P_5 d_5^+ \tag{11}$$

Where P_k : the priority coefficient for the kth priority level, k = 1,2,3,4,5

Lingo will employ the goal constraint to yield the desired outcomes. These achieved goal constraints are established based on the data set provided by E-Idaman Sdn. Bhd and the goal formulation derived from equations (2), (4), (6), (8), and (10).

4. Results and Discussion

4.1 Data Analysis

Upon executing the model in the Lingo software, the outcome of the model's performance is presented in the Lingo solver output as shown in Figure 1 and the comprehensive solution is detailed in the Lingo Optimization Report as shown in Figure 2. The Lingo solver furnishes the objective value achievable through the optimal solution. The Lingo solution report shows the detailed value of each deviation in achieving the goal and the value of the deviations that can be reduced.

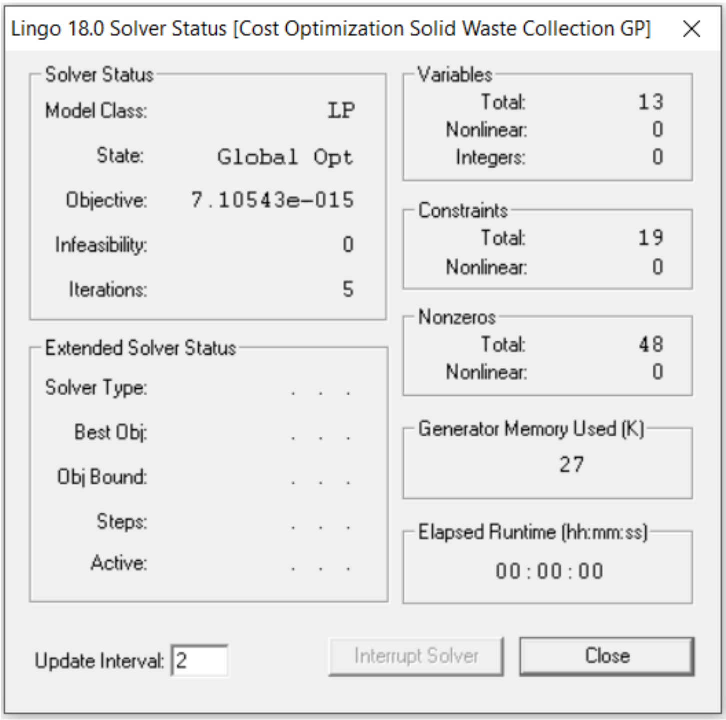
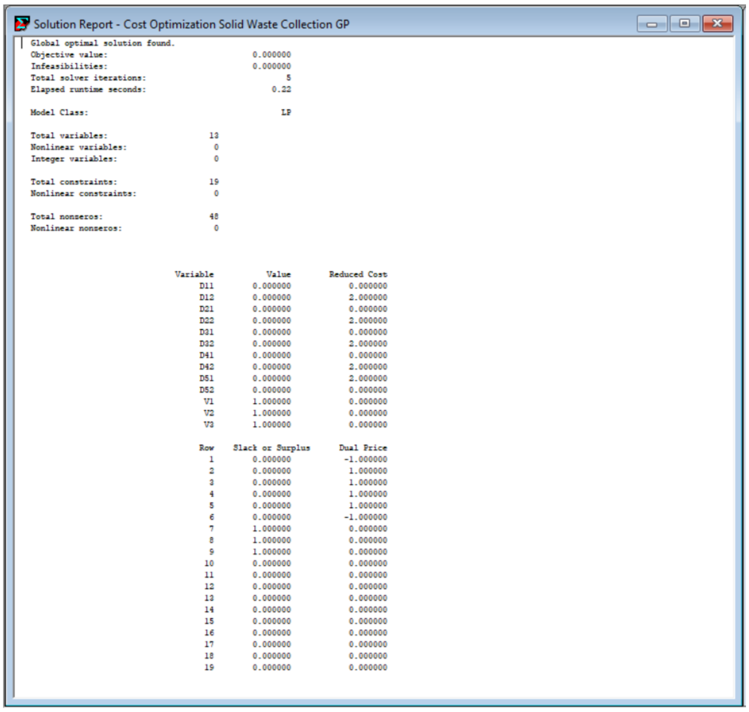


Figure 1: Lingo Solver Status



Variable	Value	Reduced Cost
D11	0.000000	0.000000
D12	0.000000	2.000000
D21	0.000000	0.000000
D22	0.000000	2.000000
D31	0.000000	0.000000
D32	0.000000	2.000000
D41	0.000000	0.000000
D42	0.000000	2.000000
D51	0.000000	2.000000
D52	0.000000	0.000000
V1	1.000000	0.000000
V2	1.000000	0.000000
V3	1.000000	0.000000

Row	Slack or Surplus	Dual Price
1	0.000000	-1.000000
2	0.000000	1.000000
3	0.000000	1.000000
4	0.000000	1.000000
5	0.000000	1.000000
6	0.000000	-1.000000
7	1.000000	0.000000
8	1.000000	0.000000
9	1.000000	0.000000
10	0.000000	0.000000
11	0.000000	0.000000
12	0.000000	0.000000
13	0.000000	0.000000
14	0.000000	0.000000
15	0.000000	0.000000
16	0.000000	0.000000
17	0.000000	0.000000
18	0.000000	0.000000
19	0.000000	0.000000

Figure 2. Lingo Optimization Report

From the Lingo Optimization Report in Figure 2, the result for goal achievement on the optimal solution was analyzed as presented in Table 2.

Table 2. Goals Achievement

Goals	Output value	Goals achievement
G1	d_1^+=0	Fully achieved
G2	d_2^+=0	Fully achieved
G3	d_3^+=0	Fully achieved
G4	d_4^+=0	Fully achieved
G5	d_5^+=0	Fully achieved

Based on findings illustrated in Figure 2, D12 is the deviation for labor cost to achieve the goal, where D22 is for collection cost, D32 is for vehicle cost, D42 is for consumable cost, and lastly, D51 is for financial statement operation. Based on the result shown in Table 2 for the five deviations, the total cost can be minimized when the cost of each vehicle is optimized.

Table 3. Results for deviations

Goals	d_i^+	d_i^-
G1	0	0
G2	0	0
G3	0	0
G4	0	0
G5	0	0

According to the data presented in Table 3, all goals (G1, G2, G3, G4, and G5) exhibit both positive and negative deviations, with d_1^+=d_1^-=d_2^+=d_2^-=d_3^+=d_3^-=d_4^+=d_4^-=d_5^+=d_5^-= 0. This means that all the goals are fully achieved. Also, based on the negative deviations for all the goals, it shows that the cost is already at its optimal level. This indicates the full achievement of all goals. In other words, there is no further need to minimize the company's labor, collection, vehicle, consumable costs, and the financial statement of operation for solid waste collection, as they are already in their optimal form.

5. Conclusion

Malaysia is facing a growing problem with solid waste, largely due to the country's rapidly increasing population and rising living standards. Malaysia's current waste management system is insufficient to cope with the increasing amount of waste being produced. Out of the number of states in Malaysia, Perlis is also rapidly increasing waste collection, leading to an environmental issue. A private solid waste collection company called E-Idaman Sdn. Bhd. conveys the collection surrounding the whole Perlis state. This study focuses on optimizing the cost for cost reduction and optimizing the cost of solid waste collection by goal programming. Actual data was taken from the company, and three collection routes were analyzed with parameters of labor cost, collection cost, vehicle cost, and consumable cost. From this study, the hopes are to help with the future of financial and budget planning for the company to accomplish an optimal solid waste collection system. This could also create better decision-making and image for the company and the state.

The goal programming method can assist this company in achieving its optimal solution at a lower cost, according to the study's findings. The company has no requirement to reduce expenses since labor, collection, vehicle, and consumable costs are all currently optimized. All things considered, goal programming can assist in obtaining the best answers and cost optimization for the collection of solid waste. It is possible to conclude that the goals have been met from there. It is important to remember that goal programming is not a perfect solution, even with the results attained. It might not always be able to accomplish every objective at the same time.

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

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