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Efficient Model for Waste Load and Route Optimization

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Abstract

Urbanization frequently gives rise to substantial environmental issues, namely in waste management and water quality maintenance. Gross Pollutant Traps (GPTs) are essential in urban stormwater management as they effectively capture substantial pollutants before they enter the central water bodies. Nevertheless, the irregular buildup of trash caused by fluctuating rainfall intensity hinders the effective transfer of garbage from GPTs to their ultimate disposal locations. This research presents a holistic approach to enhancing the efficiency of waste transportation by improving route and load planning. The model utilizes machine learning techniques to forecast the quantity of waste collected by GPTs. We have created an optimization algorithm that uses the forecast outcome from a prior research dataset. This algorithm is designed to efficiently plan the routes and loads for trucks responsible for transporting waste to its final disposal location. The optimization process considered the estimated amounts of garbage, the capacities of the vehicles, and the locations of the disposal sites to reduce transportation expenses and save time. The system adaptively optimized routes using real-time data on the vehicle's origin and destination, ensuring effective allocation of resources and prompt garbage removal. Installing this approach resulted in a substantial decrease in transportation expenses and enhanced compliance with waste pickup timetables. The integration of predictive modeling and route optimization is enhancing urban trash management. Accurate garbage quantity forecasts and optimized transportation logistics can enable municipalities to deploy resources more effectively, decrease operational costs, and improve environmental protection. We chose a subset of 7 days, equivalent to one week, from the projected dataset for our experiment. Subsequently, we conducted numerous trials involving various waste disposal frequencies. The findings suggest that waste disposal every four (4) days is the most advantageous approach. Still, it performs similarly to waste disposal every three (3) days and has negligible environmental consequences. Hence, we select to execute the optimal solution for three (3) days, as it provides exceptional performance when considering the influence of natural pollution.

Keywords

Gross Pollutant Trap, Route Optimization, Load Optimization, Multi-Objective Optimization

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Introduction

The decline in rainwater quality caused by uncontrolled pollution and waste disposal is one of the problems that urban communities continue to face. Many factors can cause urbanization to harm stormwater quality, including unchecked pollution and waste disposal. Currently, we are trying to improve socio-economic life in an area.

We are also faced with several environmental challenges that need to be overcome, such as declining water quality. Therefore, efforts must be made to manage the impact of water quality in cities to protect our environment. One step that needs to be taken is to install gross pollutant traps (GPT) (Mohd et al., 2016).

Gross pollutants are discarded materials with a diameter greater than 5 mm. It includes dirt, debris, and coarse sediment of particles larger than 0.5 mm (Allison et al., 1997). Dirty pollutants such as street rubbish, litter, dirt, and organic materials such as pruned twigs and leaves can have different physical and material characteristics, such as hardness, shape, size, and density. We can classify this waste as a pollutant that harms the environment. Twigs and leaves used in pruning can be used as fertilizer and organic material, while sediment, leaves, and grass clippings are also categorized as dirty pollutants (Madhani & Brown, 2015).

The main aim of GPT is to reduce pollutants carried by rainwater before they reach the main river channel (Fitzgerald & Bird, 2011). Currently, we need to fully understand that tropical climates are always associated with situations where high rainfall occurs suddenly. It makes predicting the amount of waste trapped in the GPT challenging (Mohd Sidek et al., 2014).

Consequently, estimating the volume of waste required for transportation and transfer from the GPT area to the final disposal site (TPA) becomes challenging. As a result, waste collected by GPT frequently accumulates at these locations due to a need for more necessary numbers and capacity of waste vehicles. To ensure proper transportation, we require a model that can accurately predict the amount of waste.

In research conducted by Sari & Kurniawan (2023), a prediction model based on three algorithms produced quite good accuracy values. Among the three algorithms used, the Multiple Linear Regression method provides the smallest MRSE value, which means the prediction results are close to the actual value.

This research aims to continue the study conducted by Sari and Kurniawan (2023). Once the daily amount of waste that GPT may capture can be predicted well, it is necessary to plan and optimize the process of loading waste into trucks and determine the shortest route for each truck so that waste can be transported effectively and efficiently.

The capacity of the transport truck determines the amount of waste it can transport. Often, a single truck can only transport part of the waste. For this reason, it is necessary to determine which waste from GPT will be loaded into which truck so that an optimization process (load optimization) can be carried out. According to research by Lenitasari et al. (2023), the optimization process is necessary to minimize the number of trucks required.

In addition, it is necessary to consider the shortest distance between each GPT that needs to be visited by one truck (this can be done using the clustering with constraint process) so that efficiency can be achieved in terms of time and the optimal amount of waste capacity that can be transported.

Next, after obtaining waste from any GPT that will be put into one truck, it is necessary to find the shortest path for the truck to visit each GPT on its transport list (route optimizations) so that the truck can save travel time and costs (use of petrol or diesel and truck maintenance costs).

This research is based on the data collection process by Zahari et al. (2016), which measured the amount of waste captured by each GPT over four (4) years from 2019 to 2022. Next is research conducted by Sari & Kurniawan (2023), which added accompanying data in the form of rainfall amounts and population around the GPT. The prediction or regression process uses this data to estimate the GPT's future waste collection capacity.

Furthermore, Wardani et al. (2021) and Tiandini & Anggraeni (2017) researched to optimize the placement of goods in containers. Their research focused solely on ensuring that the goods' weight and volume were within the transport truck's maximum capacity, also known as a container. This study did not consider the distance between two goods transports, specifically waste. For this reason, the author attempts to merge the issue of loading waste into trucks with the problem of transporting waste from one GPT point to another GPT point. Li et al. (2022) proposed using clustering methods as a solution.

For this reason, an algorithm will be built based on k-means clustering, which is modified by applying a limit in the form of the maximum amount of waste transported by each truck (according to the truck capacity). With the clustering process based on the geolocation of each GPT, it is hoped that several clusters will be formed (depending on how many trucks will be used, as the k value in k-means one truck represents one cluster), where the location of the GPT as a cluster member will be adjacent to the area of the cluster centroid point. We will then implement the closest trace search process for each cluster. Once the clustering concludes, we identify the shortest path for all GPT within a single cluster. We implement the TSP algorithm to achieve that.

Methodology

A clustering approach optimizes the distance between GPT points in one cluster (or, in this research, one truck). That can be transported beyond the maximum truck capacity, the k-means algorithm with constraints will be proposed, as in research conducted by Gao et al. (2023), to maintain the maximum number of kg of waste.

Steps to be taken in the research:

1. Collect data on transported waste items. The data contains the weight of waste.
2. Collect vehicle data. The data contains vehicle type and capacity (maximum weight in kg.
3. Add up the total volume of waste and the total weight of waste.

4. Match the available vehicle capacity to the waste transported from each GPT.

As shown in Figure 1 below, the research design is described.

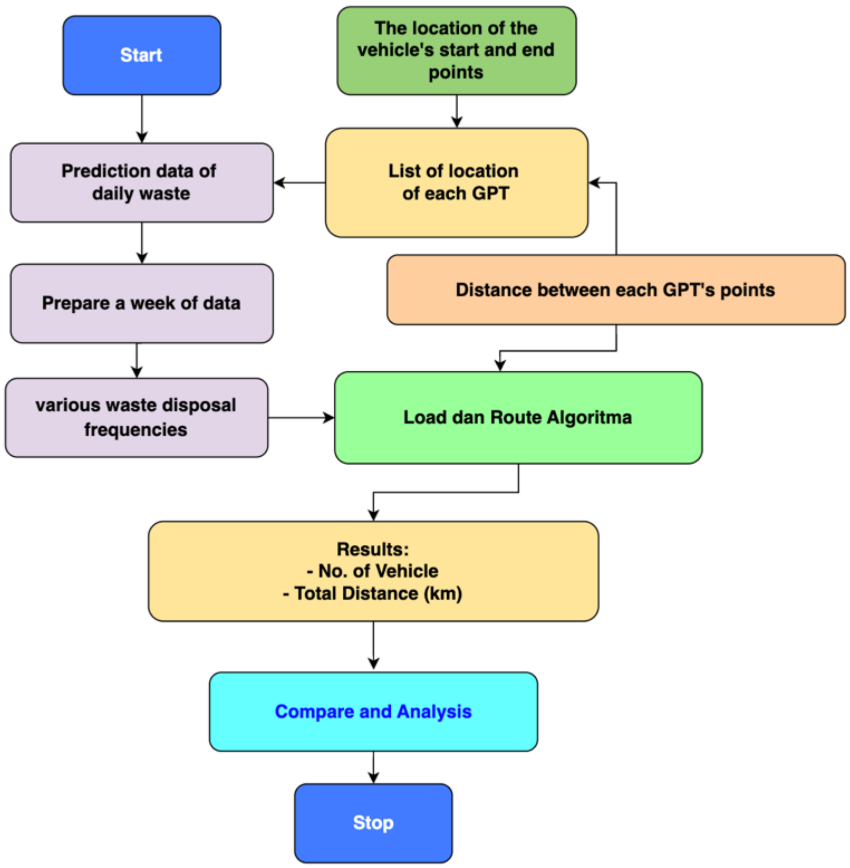

Figure 1. Research methodology framework

The process begins in Figure 1 with data collection on the amount of waste based on the predictions made in the research by Lenitasari et al. (2023). In addition to the waste amount, we also require information about the location of each GPT and the starting and ending points of the truck journey that will transport the waste. Based on the haversine formula (Kettle, 2021), we calculate the distance between each GPT point and the next truck's start and end points (or depo). We will need this data to calculate the shortest distance each truck can travel. Meanwhile, the number of trucks depends on how efficient the algorithm for loading waste into the trucks is.

Next, the load and route optimization algorithm results will be compared between various waste disposal frequencies. We chose a subset of seven (7) days, equivalent to one week, from the projected dataset for our experiment. Subsequently, we conducted numerous trials involving various waste disposal frequencies. For each subsequent dataset, we run our algorithm to measure the number of vehicles and total distance truck travel for all trucks to dispose of the total waste for that day. For example, frequency is every day, that is, [01/12/2024], [02/12/2024], [03/12/2024], and so on. Then disposal for every two (2) days [01/12/2024, 02/12/2024], [03/12/2024, 04/12/2024], [05/12/2024, 06/12/2024], and so on. The results from each dataset are then compared and analyzed to decide which solutions get the best results and give the best solution, as shown in Table 1.

Table 1. Subsequent dataset for experiment

No	Subsequent dataset	# Day(s)
1	[01/12/2024], [02/12/2024], [03/12/2024], [04/12/2024], [05/12/2024], [06/12/2024], [07/12/2024]	1
2	[01/12/2024 - 02/12/2024], [03/12/2024 - 04/12/2024], [05/12/2024 - 06/12/2024], [07/12/2024]	2
3	[01/12/2024 - 02/12/2024 - 03/12/2024], [04/12/2024 - 05/12/2024 - 06/12/2024], [07/12/2024]	3
4	[01/12/2024 - 02/12/2024 - 03/12/2024 - 04/12/2024], [05/12/2024 - 06/12/2024 - 07/12/2024]	4

The algorithm first decides how many trucks with different capacities should be used to carry out the waste from the GPT location to the disposal location. This process runs randomly to give the chance to do the optimization process. Whenever the algorithm cannot find the solution due to insufficient capacity, we will add a new truck with random capacity, or if one truck can be combined with another, we will remove the smallest truck's capacity.

Based on the available trucks, we try clustering the location of all GPTs using a k-means constraint algorithm with k as an equal number of trucks. We process each GPT and find the cluster's centroid nearest to the GPT. Then, we add the waste (kg) into that cluster and decrease the truck's unused space for garbage. If the nearest centroid cluster cannot load the waste to this cluster, first, we try to move out the GPT that has the farthest distance to the second nearest centroid cluster; if not, we will choose the second nearest centroid cluster for that GPT; then, the algorithms will continue until all GPTs are processed.

The process will be stopped until the algorithm reaches a specific number of iterations or if the stopping criteria are met (in this scenario, the cluster members are not changed anymore). Next, based on the clustering result, we try to find the shortest path for each cluster member. In this process, we use the ORTools library from Google. The distance of the truck paths should be calculated for each truck, and then the summation should be made for all trucks.

The results for every step will be compared with those from different frequent disposal scenarios regarding the number of vehicles, the amount of unused truck capacity, and the total distance traveled by all trucks. Then, the analysis will be done.

Results and Discussion

In this experiment, we used a dataset; Table 2 shows the raw dataset before we created different subsequent for the disposal process. Figure 2 shows the location of each GPT (the blue circle, with the number of the GPT) and the location of the depo (the black circle, with zero (0) number), as well as the location of each truck that will be started on the map.

Table 2. The dataset with kg waste for each GPT per day

GPT	[01/12/2024]	[02/12/2024]	[03/12/2024]	[04/12/2024]	[05/12/2024]	[06/12/2024]	[07/12/2024]
GPT001	68.43	79.46	74.56	74.56	74.56	77.01	89.27
GPT002	164.70	167.66	167.29	167.29	165.07	168.77	165.07
GPT003	178.53	174.25	175.10	171.25	167.40	171.25	172.96
GPT004	166.91	158.55	159.48	166.91	167.84	159.48	150.18
GPT005	197.45	197.45	194.47	191.48	198.95	197.45	203.43
GPT006	115.21	112.74	125.07	123.84	115.21	122.61	126.31
GPT007	200.82	200.82	197.64	193.82	190.63	188.72	185.53
GPT008	100.71	109.53	114.82	106.88	109.53	117.47	114.82
GPT009	80.69	93.63	98.81	88.46	84.57	93.63	98.81
GPT010	93.35	86.59	82.09	81.34	82.09	80.59	85.84
GPT011	139.96	136.73	143.20	150.47	144.81	143.20	141.58
GPT012	123.94	120.74	114.99	118.18	123.94	123.94	122.66
GPT013	182.93	179.67	179.67	179.67	175.61	174.80	170.73
GPT014	140.73	137.64	139.57	143.05	142.66	144.98	142.66
GPT015	161.96	166.43	163.45	159.48	157.49	155.01	155.01
GPT016	119.00	118.28	121.85	118.28	116.14	118.28	116.14
GPT017	68.36	73.82	73.82	72.00	66.55	62.91	63.82
GPT018	156.76	159.15	160.74	162.34	158.35	160.74	158.35
GPT019	162.48	153.94	153.94	153.94	155.65	153.94	155.65
GPT020	127.09	127.09	127.40	127.09	126.46	129.58	131.77
GPT021	168.16	159.58	169.12	164.35	155.77	150.04	155.77
GPT022	152.43	149.81	155.71	149.15	143.26	137.36	134.74
GPT023	141.96	141.17	141.17	133.20	130.01	133.20	126.03
Total	3,212.57	3,204.74	3,233.94	3,197.03	3,152.55	3,164.96	3,167.15

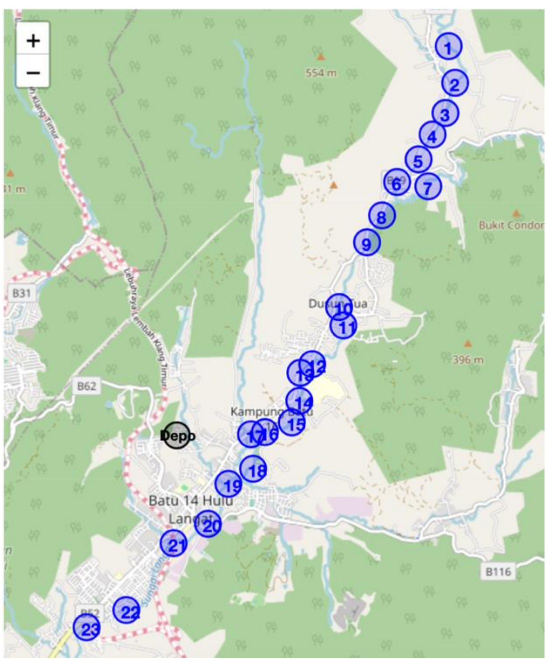

Figure 2. Location of the GPT

As shown in Figure 2, the locations of each GPT are close to each other based on the GPT number. The GPT's location follows the river's flow because it picks up rubbish in the tributary flow before returning to the river. So, GPT is usually installed at the mouth of a river.

Based on the data shown in Table 2, we prepare the first subsequent dataset (disposal every one day), as shown in Table 3, for the experiment and then collect the result as shown in Table 4.

Table 3. First subsequent dataset

No	Date	Wastes (kg)
1	[01/12/2024]	3,212.57
2	[02/12/2024]	3,204.74
3	[03/12/2024]	3,233.94
4	[04/12/2024]	3,197.03
5	[05/12/2024]	3,152.55
6	[06/12/2024]	3,164.96
7	[07/12/2024]	3,167.15
	Total	22,332.94

Table 3 shows the total waste in kg every day for 7 (seven) days. The total waste is 22,332.94 kg.

Table 4. The results from every one-day disposal

Date [01/12/2024]				Total Vehicle	3
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-M	3,000.00	9	1,273.45	12,110.84	0 -> 9 -> 7 -> 3 -> 2 -> 1 -> 4 -> 5 -> 6 -> 8 -> 0
LORRY-L	5,000.00	11	1,492.79	11,348.10	0 -> 10 -> 11 -> 12 -> 13 -> 14 -> 15 -> 16 -> 17 -> 21 -> 22 -> 23 -> 0
4x4	500.00	3	446.33	2,788.99	0 -> 18 -> 19 -> 20 -> 0
Total	8,500.00	23	3,212.57	26,247.93	

Date [02/12/2024]				Total Vehicle	4
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
4x4	500.00	3	468.74	7,00.21	0 -> 6 -> 5 -> 4 -> 0
LORRY-M	5,000.00	10	1,372.96	16,444.17	0 -> 9 -> 8 -> 7 -> 10 -> 11 -> 1 2 -> 13 -> 14 -> 15 -> 23 -> 0
LORRY-S	1,000.00	7	941.67	5,703.46	0 -> 17 -> 16 -> 18 -> 19 -> 20 -> 21 -> 22 -> 0
4x4	5000	3	421.37	8,639.17	0 -> 3 -> 2 -> 1 -> 0
Total	5,000.00	23	3,204.74	37.787.01	

Date [03/12/2024]				Total Vehicle	2
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-L	5,000.00	19	2,794.86	21,639,80	0 -> 8 -> 6 -> 5 -> 4 -> 1 -> 2 -> 3 -> 7 -> 13 -> 14 -> 15 -> 16 -> 17 -> 18 -> 19 -> 20 -> 21 -> 22 -> 23 -> 0
4x4	500.00	4	439.08	5,156.57	0 -> 12 -> 11 -> 10 -> 9 -> 0
Total	5,500.00	23	3,233.94	26,796.36	

Date [04/12/2024]				Total Vehicle	4
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-S	1,000.00	6	871.39	8,900.21	0 -> 9 -> 7 -> 4 -> 5 -> 6 -> 8 -> 0
LORRY-M	3,000.00	6	890.07	5,700.78	0 -> 18 -> 19 -> 20 -> 21 -> 22 -> 23 -> 0
LORRY-M	3,000.00	8	1,022.48	4,423.39	0 -> 17 -> 16 -> 15 -> 14 -> 13 -> 12 -> 11 -> 10 -> 0
4x4	500.00	3	413.10	8,639.17	0 -> 3 -> 2 -> 1 -> 0
Total	7,500.00	23	3,197.03	27,663.55	

Date [05/12/2024]				Total Vehicle	4
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-S	1,000.00	4	496.69	2,699.75	0 -> 19 -> 18 -> 16 -> 17 -> 0
VAN	500.00	2	282.23	2,351.40	0 -> 20 -> 21 -> 0
LORRY-M	3,000.00	15	2,100.36	13,450.54	0 -> 15 -> 14 -> 13 -> 12 -> 11 -> 10 -> 7 -> 3 -> 2 -> 1 -> 4 -> 5 -> 6 -> 8 -> 9 -> 0
4x4	500.00	2	273.27	3,982.85	0 -> 22 -> 23 -> 0
Total	5,000.00	23	3,152.55	22,484.55	

Date [06/12/2024]				Total Vehicle	2
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-L	5,000.00	20	2,747.93	18,568.21	0 -> 9 -> 8 -> 6 -> 5 -> 4 -> 7 -> 10 -> 11 -> 12 -> 13 -> 14 -> 15 -> 16 -> 17 -> 18 -> 19 -> 20 -> 21 -> 22 -> 23 -> 0
4x4	500.00	3	417.03	8,639.17	0 -> 3 -> 2 -> 1 -> 0
Total	5,500.00	23	3,164.96	27,207.38	

Date [07/12/2024]				Total Vehicle	4
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path

LORRY-S	1,000.00	8	998.45	4,423.39	0 -> 17 -> 16 -> 15 -> 14 -> 13 -> 12 -> 11 -> 10 -> 0
LORRY-M	3,000.00	9	1,306.39	12,110.84	0 -> 9 -> 7 -> 3 -> 2 -> 1 -> 4 -> 5 -> 6 -> 8 -> 0
LORRY-L	5,000.00	3	416.54	4,124.75	0 -> 21 -> 22 -> 23 -> 0
4x4	500.00	3	445.77	2,788.99	0 -> 18 -> 19 -> 20 -> 0
Total	9,500.00	23	3,167.15	23,447.97	

Table 4 shows the results obtained based on the first dataset, which shows daily waste disposal at the endpoint. The result shows the list of vehicles with their type, capacity, members of GPT belonging to theirs, the total weight of waste, distance vehicles travelled, and the route of paths. Next, Table 5 will show the summary of these results.

As a result, on [01/12/2024], the members of each cluster (each GPT picked up by each truck) and the shortest paths (the order in which GPT should be picked up first, second, and so on), including started from and ending to the depo location are shown in Figure 3 below. There are three (3) clusters with the route of paths are:

1. 0 -> 9 -> 7 -> 3 -> 2 -> 1 -> 4 -> 5 -> 6 -> 8 -> 0
2. 0 -> 10 -> 11 -> 12 -> 13 -> 14 -> 15 -> 16 -> 17 -> 21 -> 22 -> 23 -> 0
3. 0 -> 18 -> 19 -> 20 -> 0

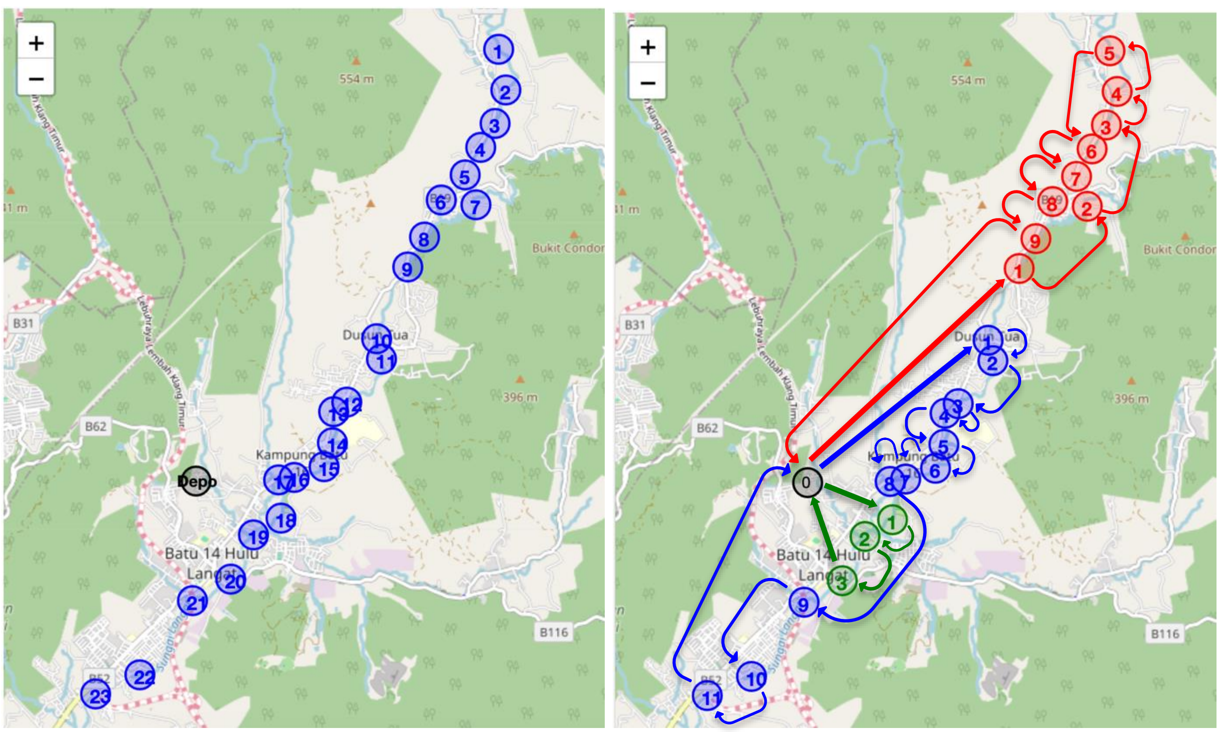

Figure 3. Route for data [04/12/2024] from Table 4

Table 5. The results summary for every one-day disposal dataset

No	Date	Distance (m)	# of Vehicles	Total Capacity of Vehicles (kg)	Total Waste (kg)	Unused Space of Vehicle (kg)	Unused (%)
1	[01/12/2024]	26,247.93	3	8,500.00	3,212.57	5,287.43	62.21
2	[02/12/2024]	37,787,01	4	5,000.00	3,204.74	1,795.26	35.91
3	[03/12/2024]	26,796.36	2	5,500.00	3,233.94	2,266.06	41.20
4	[04/12/2024]	27,663.55	4	7,500.00	3,197.03	4,302.97	57.37
5	[05/12/2024]	22,484.55	4	5,500.00	3,152.55	2,347.45	42.68
6	[06/12/2024]	27,207.38	2	5,500.00	3,164.96	2,335.04	42.46
7	[07/12/2024]	23,447.97	4	9,500.00	3,167.15	6,332.85	66.66
	Total	191,634.76	23	46,500.00	22,332.94	24,167.06	
	Average	21,978.25					51.97

Table 5 shows that 23 vehicles with a total capacity of 46,500 kg are listed, and 51.97% of that capacity is unused when transporting the waste in those 7 (seven) days. Next, we continue with the second dataset, which transports every two (2) days.

Based on the data shown in Table 2, we prepare the second subsequent dataset (disposal every two days), as shown in Table 6, for the experiment and then collect the result, as shown in Table 7.

Table 6. Second subsequent dataset (every two days)

No	Date	Waste (kg)
1	[01/12/2024, 02/12/2024]	6,417.31
2	[03/12/2024, 04/12/2024]	6,430.97
3	[05/12/2024, 06/12/2024]	6,317.52
4	[07/12/2024]	3,167.15
	Total	22,332.94

Table 6 shows the detailed waste in kg every two days for seven (seven) days.

Table 7. The results from disposal every two days

Date [01/12/2024, 02/12/2024]				Total Vehicle	3
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-L	5,000.00	11	3,290.35	19,824.56	0 -> 13 -> 12 -> 11 -> 14 -> 15 -> 18 -> 19 -> 20 -> 21 -> 22 -> 23 -> 0
LORRY-M	3,000.00	10	2,747.50	12,709.13	0 -> 10 -> 7 -> 3 -> 2 -> 1 -> 4 -> 5 -> 6 -> 8 -> 9 -> 0
4x4	500.00	2	379.46	1,569.59	0 -> 17 -> 16 -> 0
Total	8,500.00	23	6,417.31	25,103.28	

Date [03/12/2024, 04/12/2024]				Total Vehicle	6

Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
VAN	500.00	1	254.48	1,664.75	0 -> 20 -> 0
LORRY-M	3,000.00	7	2,042.96	8,544.20	0 -> 12 -> 11 -> 10 -> 7 -> 4 -> 5 -> 6 -> 0
VAN	500.00	2	408.97	5,333.46	0 -> 9 -> 8 -> 0
VAN	500.00	1	346.36	7,430.38	0 -> 3 -> 0
LORRY-M	3,000.00	10	2,894.50	8,859.37	0 -> 13 -> 14 -> 15 -> 16 -> 17 -> 18 -> 19 -> 21 -> 22 -> 23 -> 0
4x4	500.00	2	483.69	8,640.35	0 -> 2 -> 1 -> 0
Total	8,000.00	23	6,430.97	40,436.50	

Date [05/12/2024, 06/12/2024]				Total Vehicle	5
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-S	1,000.00	3	849.65	4,124.75	0 -> 21 -> 22 -> 23 -> 0
VAN	500.00	2	485.41	8,604.35	0 -> 2 -> 1 -> 0
LORRY-L	5,000.00	5	1,248.62	3,565.13	0 -> 17 -> 16 -> 18 -> 19 -> 20 -> 0
LORRY-L	5,000.00	11	3,392.97	10,458.76	0 -> 15 -> 14 -> 13 -> 12 -> 11 -> 7 -> 3 -> 4 -> 5 -> 6 -> 8 -> 0
4x4	500.00	2	340.88	4,901.30	0 -> 10 -> 9 -> 0
Total	12,000.00	23	6,317.52	31,653.29	

Date [07/12/2024]				Total Vehicle	5
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
VAN	500.00	3	452.42	7,031.31	0 -> 9 -> 5 -> 4 -> 0
VAN	500.00	3	427.31	8,639.17	0 -> 3 -> 2 -> 1 -> 0
LORRY-M	3,000.00	10	1,368.02	8,914.57	0 -> 13 -> 15 -> 16 -> 17 -> 18 -> 19 -> 20 -> 21 -> 22 -> 23 -> 0
VAN	500.00	4	492.75	4,146.01	0 -> 14 -> 12 -> 11 -> 10 -> 0
4x4	500.00	3	426.66	6,833.21	0 -> 8 -> 7 -> 6 -> 0
Total	5,000.00	23	3,167.15	35,564.27	

Table 7 displays the findings derived from the second dataset, which shows the endpoints for trash disposal every two days. The result lists the vehicles, their kind, capacity, GPT members that belong to them, total weight of garbage, distance driven, and path route. Table 8 will next include an overview of these findings.

Table 8. The results summary for every two-day disposal dataset

No	Date	Distance (m)	# of Vehicles	Total Capacity of Vehicles (kg)	Total Waste (kg)	Unused Space of Vehicle (kg)	Unused (%)
1	[01/12/2024, [02/12/2024]	25,103.28	3	8,500.00	6,417.31	2,082,69	24.50
2	[03/12/2024, [04/12/2024]	40,436.50	6	8,000.00	6,430.97	1,569.03	19.61
3	[05/12/2024, 06/12/2024]	31,653.29	5	12,000.00	6,317.52	5,682.48	47.35
4	[07/12/2024]	35,564.27	5	5,000.00	3,167.15	1,832.85	36.66
	Total	132,757.35	19	33,000.00	22,332.94	10,667.06	
	Average	33,189.34					32.32

Table 8 shows that 19 vehicles with a total capacity of 33,000 kg are listed, and 32.32% of that capacity is unused when transporting the waste in those 7 (seven) days. Next, we continue with the third dataset, which transports every three (3) days.

We prepare the third subsequent dataset (disposal every three days) for the experiment, as illustrated in Table 9, using the data from Table 2. Subsequently, we collect the results, as described in Table 10.

Table 9. Third subsequent dataset (every three days)

No	Date	Waste (kg)
1	[01/12/2024, 02/12/2024, 03/12/2024]	9,651.25
2	[04/12/2024, 05/12/2024, 06/12/2024]	9,514.54
3	[07/12/2024]	3,167.15
	Total	22,332.94

Table 9 shows the detailed waste in kg every three days for seven (seven) days.

Table 10. The results from disposal every three days

Date [01/12/2024, 02/12/2024, 03/12/2024] Total Vehicle 4

Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-L	5,000.00	11	4, 878.54	9,216.07	0 -> 13 -> 12 -> 14 -> 15 -> 16 -> 18 -> 19 -> 20 -> 21 -> 2 2 -> 23 -> 0
LORRY-S	1,000.00	2	722.09	8,640.35	0 -> 2 -> 1 -> 0
LORRY-L	5,000.00	9	3,834.62	10,563.14	0 -> 11 -> 10 -> 7 -> 3 -> 4 -> 5 -> 6 -> 8 -> 9 -> 0
4x4	500.00	1	216.00	1,310.11	0 -> 17 -> 0
Total	11,500.00	23	9,651.25	29.693.67	

Date [04/12/2024, 05/12/2024, 06/04/2024] Total Vehicle 7

Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
VAN	500.00	1	383.13	1,664.75	0 -> 20 -> 0
VAN	500.00	1	333.88	5,316.48	0 -> 8 -> 0
LORRY-M	3,000.00	3	1,296.35	4,124.75	0 -> 21 -> 22 -> 23 -> 0
LORRY-M	3,000.00	6	2,892.43	8,932.45	0 -> 7 -> 5 -> 4 -> 3 -> 2 -> 1 -> 0
4x4	500.00	1	361.66	5,948.02	0 -> 6 -> 0
LORRY-L	5,000.00	10	3,980.43	5,473.76	0 -> 19 -> 18 -> 17 -> 16 -> 15 -> 14 -> 13 -> 12 -> 11 -> 10 -> 0
4x4	500.00	1	266.66	4,788.38	0 -> 9 -> 0
Total	13,000.00	23	9,514.54	36,248.60	

Date [07/12/2024]				Total Vehicle	4
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
4x4	500.00	3	427.31	8,639.17	0 -> 3 -> 2 -> 1 -> 0
LORRY-S	1,000.00	7	936.51	5,129.40	0 -> 17 -> 16 -> 15 -> 18 -> 19 -> 20 -> 21 -> 0
LORRY-M	3,000.00	10	1,367.27	17,025.69	0 -> 23 -> 22 -> 11 -> 10 -> 7 -> 4 -> 5 -> 6 -> 8 -> 9 -> 0
4x4	500.00	3	436.06	3,214.19	0 -> 14 -> 12 -> 13 -> 0
Total	5,000.00	23	3,167.15	34,008.45	

Table 10 displays the findings derived from the third dataset, which shows the endpoints for trash disposal every three days. The result lists the vehicles, their kind, capacity, GPT members that belong to them, total weight of garbage, distance driven, and path route. Table 11 will next include an overview of these findings.

Table 11. The results summary for every three-day disposal dataset

No	Date	Distance (m)	# of Vehicles	Total Capacity of Vehicles (kg)	Total Waste (kg)	Unused Space of Vehicle (kg)	Unused (%)
1	[01/12/2024, 02/12/2024, 03/12/2024]	29.693.67	4	11,500.00	9,651.25	1,848.75	16.08
2	[04/12/2024, 05/12/2024, 06/12/2024]	36,248.60	7	13,000.00	9,514.54	3,485.46	26.81
3	[07/12/2024]	34,008.45	4	5,000.00	3,167.15	1,832.85	36.66
	Total	99,950.72	15	29.500.00	22,332.94	7,167.06	
	Average	23,419.02					24.30

Table 11 shows 15 vehicles with a total capacity of 29,500 kg, with 24.30% of that capacity unutilized during garbage transportation during those seven days. We then continue with the third dataset, which moves every four (4) days.

Next, we build the fourth dataset (disposed of every four days) for the experiment, as shown in Table 12. We then compile the results, as shown in Table 13.

Table 12. Four subsequent datasets (every four days)

No	Date	Waste (kg)
1	[01/12/2024, 02/12/2024, 03/12/2024, 04/12/2024]	12,848.28
2	[05/12/2024, 06/12/2024, 07/12/2024]	9,484.66
	Total	22,332.94

Table 12 displays the seven (seven) days' detailed waste in kg per four days.

Table 13. The results from disposal every three days

Date [01/12/2024, 02/12/2024, 03/12/2024, 04/12/2024]				Total Vehicle	6
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-M	3,000.00	4	2,334.46	4,576.54	0 -> 20 -> 21 -> 22 -> 23 -> 0
4x4	500.00	1	476.06	5,948.02	0 -> 6 -> 0
LORRY-M	3,000.00	5	2,680.03	3,577.36	0 -> 19 -> 18 -> 15 -> 16 -> 17 -> 0
LORRY-M	3,000.00	5	2,674.53	4,211.03	0 -> 14 -> 13 -> 12 -> 11 -> 10 -> 0
LORRY-L	5,000.00	8	4,682.41	8,975.33	0 -> 9 -> 8 -> 7 -> 5 -> 4 -> 3. -> 2 -> 1 -> 0
4x4	500.00	0	0	0	This vehicle is not used
Total	15,000.00	23	12,848.28	27,288.29	

Date [05/12/2024, 06/12/2024, 07/12/2024]				Total Vehicle	6
Truck Code	Max Capacity (kg)	# of GPT	Waste (kg)	Distance (m)	Path
LORRY-M	3,000.00	6	2,596.69	5,700.78	0 -> 18 -> 19 -> 20 -> 21 -> 22 -> 23 -> 0
4x4	500.00	1	370.54	2,715.29	0 -> 12 -> 0
LORRY-M	3,000.00	7	2,640.91	4,417.16	0 -> 17 -> 16 -> 15 -> 14 -> 13 -> 11 -> 10 -> 0
LORRY-M	3,000.00	6	2,859.76	9,125.75	0 -> 8 -> 7 -> 3 -> 4 -> 5 -> 6 -> 0
LORRY-S	1,000.00	2	739.75	8,604.35	0 -> 2 -> 1 -> 0
4x4	500.00	1	277.02	4,788.35	0 -> 9 -> 0
Total	11,000.00	23	9.484.66	35,351.71	

Table 13 shows the results from the fourth dataset and the endpoints for garbage disposal every four days. The output compiles the vehicles, their kind, capacity, GPT members, overall trash weight, distance driven, and travel paths. Table 14 will next provide a synopsis of these results.

Table 14. The results summary for every four-day disposal dataset

No	Date	Distance (m)	# of Vehicles	Total Capacity of Vehicles (kg)	Total Waste (kg)	Unused Space of Vehicle (kg)	Unused (%)
1	[01/12/2024, 02/12/2024, 03/12/2024, 04/12/2024]	27,288.29	5	15,000.00	12,848.28	2,151.72	14.34
2	[05/12/2024, 06/12/2024, 07/12/2024]	35,351.71	6	11,000.00	9,484.66	1,515.34	13.78
	Total	62,639.99	11	26,000.00	22,332.94	3,667.06	
	Average	31,320.00					14.10

Table 14 lists eleven trucks with a combined capacity of 26,000 kg, of which 14.10% was unused during waste movement throughout those seven days. We then compared and analyzed all the results, as shown in Table 15.

Table 15. The comparison result for distance and unused capacity

# dataset	Avg. Distance (m)	# best avg. distance ordered	Avg. Unused (%)	# best avg. unused capacity ordered	Total ordered
1	21,978.25	1	51.97	4	5
2	33,189.34	4	32.32	3	7
3	23,419.02	2	24.30	2	4
4	31,320.00	3	14.10	1	4

Table 15 shows the comparison results for route optimization and load optimization. For the first dataset, the smallest average distance (that is, the route optimization) for every complete cycle for taking the garbage from the 23 GPTs and delivering it to the depo (endpoint disposal) locations is 21,978.25 or 21.89 km. The fourth dataset shows the smallest average value for unused capacity, which means the optimized one is 14.10%.

Since we need to know which dataset performed best for two objectives, based on the total ordered value, the third and fourth datasets give similar values, which are 4. The third dataset obtained 23,419.02 for average distance and 24.30% for average unused capacity, and the fourth dataset gave 31,320.00 for average distance and 24.30% for average unused capacity. We chose the third dataset as the best performance compared to the two. It also performs best when considering the influence of natural pollution because it causes less natural damage due to the decay of untransformed waste.

Conclusion

We have developed an optimization method leveraging a predicted result from a past study dataset. This system effectively schedules the paths and loads for vehicles carrying garbage to its final disposal point. To save transportation costs and time, the optimization procedure considered the projected volumes of trash, the vehicle capacities, and the sites of disposal facilities.

The system optimizes paths based on real-time data on the vehicle's origin and destination, guaranteeing efficient resource allocation and timely waste disposal. This method improved garbage pickup schedule compliance and drastically cut transportation costs. Predictive modeling and route optimization combined are improving urban garbage management.

Using accurate waste quantity projections and optimal transportation logistics, municipalities may allow better environmental protection, more efficient use of resources, and lower operating costs.

From the expected dataset for our experiment, we selected a subset of seven days—one week. We then carried out several tests at different garbage disposal frequencies. The results imply that the best strategy is to dispose of garbage every four (4) days. Still, it has little environmental impact and acts like rubbish removal every three (3) days. Therefore, considering the effect of natural pollution, we choose to implement the best solution for three (3) days as it offers outstanding performance.

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