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AN APPLICATION OF OPTIMIZATION IN DISTANCE AND TIME TRAVEL OF SOLID WASTE COLLECTION IN TANGERANG MUNICIPALITY

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ABSTRACT

Solid waste management has become a major challenge due to strong urban population growth in many developing countries. As one of Indonesia's highest-density population cities, Tangerang City faces the disorganization of the solid waste management system handled by the government. This study aims to create an alternative solid waste disposal transportation by modelling the route and the number of trips. The initial step in reducing the unnecessary distance is redesigning the landfill area's vehicle pool. The vehicles should start and end the activity at the landfill. The calculation of OD pair distance uses Google API in the specific departure time by inputting coordinate data such as longitude and latitude. The application simultaneously applied the documentation of distance and time to 338 waste collection points. The data result is compiled in the distance matrix to find the closest destination between the collection point. The combination of collection points must meet the capacity requirement. Lastly, the new vehicle task is taken from the optimized routes. Compared to the current system, the new collection plan can achieve a reduction of 8% in the distance driven and 4% in the collection time. The development model is beneficial in shortening the distance driven and the travel time.

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1. Introduction

Recently, developing countries have dealt with massive waste management issues, especially in urban areas. In 2017, The UN World Urbanization Prospect found that 55% of people live in urban areas. This condition creates a big responsibility for the municipal government to manage solid waste, especially in budgeting. A municipal solid waste management system is an extensive system that begins with waste collection, pre-treatment, distribution, component reuse, material recycling, energy recovery, and disposal (SNI, 2008). Due to a large number of workers and intensive use of vehicles, waste collection and transportation are significant and costly parts of the operation (Amponsah and Salhi, 2004). To be specific, solid waste transportation and collection costs contribute to 60-80% of the municipal waste management budget. It means a high chance of saving a solid waste management budget by optimizing the waste transportation and collection system (Wu et al., 2020).

Tangerang, one of Indonesia's densest cities, consumes 76% of the MSWM budget for waste collection and transportation. The city has collected 1,248 m3 of solid waste per day in 2020 (BPS,2020). According to the Indonesian Ministry of Environment, this number is twice the national average of the total amount of waste for the city area (SPSN,2021). The Tangerang Municipality collects solid waste twice daily, from each vehicle pool to the collection points. After several visits to collection points, the vehicles unload the collected waste in the landfill at the full capacity of the container. The collection process uses 104 dump trucks with a 6 m^3 container capacity per truck. The second trip starts from the landfill area to the following collection points, then empties the container at the landfill. All vehicles are required to end at the pool in different sub-district offices. This system creates an unbalanced workload since the vehicle with the nearest route to the landfill will finish earlier than the longer route.

Moreover, since the waste management in Tangerang has double authority between the sub-districts and the municipality government, the solid waste disposal system is weak and uncontrolled. In addition, the fuel budget allocation is the same for all vehicles without considering their distance driven. These conditions indicate that their waste management is less than efficient.

The development of an optimization scheme to shorten the distance travel is needed to improve the collection system and balance the workload of the vehicles (Das et al., 2015). For instance, research by Ghose et al. (2006) substantially cut operational costs by 66.4% for the worker salary, fuel consumption, truck maintenance, and landfill maintenance in Ansasol, India. They also design and develop appropriate storage, distribution, and disposal plan for the Asansol Municipality Corporation (AMC) of West Bengal State (India). The researchers mapped out the new route by using an app to shorten the distance and lessen the fuel consumption by analyzing: the population, the size of waste, the road network system and the type of road, nodes of collection points, and types of vehicles. Within the next ten years, there will be actual savings in the MSWM budget and a reduction in CO2 emissions than recent.

This study focuses on modeling the solid waste collection and household waste transfer from each collection point to the landfill site in Tangerang Municipality. The analysis tools use the nearest distances analysis by inputting some data information, including the amount of waste, nodes of collection point allocation, the distances between each waste collection point, the driving time, and types of transportation. The GIS software is used to depict the new route into a new map waste collection route. Furthermore, Hoke and Yacinkaya (2021) mention that various research shows that GIS models for route optimization positively result in reorganizing the collection points and solid waste routes. By the same approach, they successfully decreased the collection time and the number of working shifts in southeast Izmir, Turkey.

Additionally, research in Southern Mexico Town by Carmen-Nino et al. (2023) proposes intensifying the service time despite insufficient preference routes. The optimization results are increasing in the service by about 2 hours less per day, and while the distance driven remains the same, the collection points visitation rises 58%. They monitor all the formal and informal routes based on the vehicle's GPS; georeference and digitize the route by GIS software; analyze the route network and spatial scope; and interview their driver to analyze their experience towards the route networks and spatial scope.

Unlike prior research, this study ignores the driver behavior analysis since it requires all vehicles installed with the GPS-based device and the driver experience to find the route based on the device's direction (Bazzan et al., 2015). Meanwhile, not all drivers know GPS in Tangerang, and not all vehicles are installed with GPS. In addition, this study excludes the actual traffic data due to the usage of Google API. The pandemic in 2020 has influenced this condition, making field observation difficult. Depending on the problems and focuses, this study aims to evaluate the planning route by shortening the distance to provide the best route for solid waste disposal in Tangerang Municipality, Indonesia.

2. Literature Review

2.1 Solid Waste Collection

Waste collection is collecting waste from individual containers, communal (shared) containers, or both. Then, transferring it to designated points or locations, either directly or indirectly. Meanwhile, the waste is solid waste formed of biological and inorganic components considered obsolete. It must be handled so that the environment is not damaged and development investments are not jeopardized (SNI, 2008). Route planning integrates all of these operations into a unified network, substantially impacting the efficiency and efficacy of the municipal solid waste management system. Each task can be modeled as a municipal solid waste management system node. The management must accurately select the node's position to optimize the MSWS (Yu and Solvang, 2016).

The waste transfer process must consider the shape of the waste, including the nature and quantity, the distance traveled, and whether it will be recycled or landfilled. Consequently, the management can choose its system's most appropriate vehicle and distribution scheme. Moreover, there are two types of waste collection systems, which are Hauled Container System (HCS) and the Stationery Container System (SCS) (Mondal et al., 2013). The HCS transfer carries the waste to the landfill, starting from the pool in an empty container to waste collection points. At this point, they take the full capacity from the waste collection point and replace it with the empty container they are carrying. The vehicle then transfers the whole container to the landfill, unloads the waste, then drives to the next collection point, which has the filled container. The process continues until the vehicles visit all collection points. Usually, the vehicle for the manual system is an arm roll, and the mechanical system is a compactor.

Meanwhile, the SCS process fills the container in the truck with the waste from the collection points and loads the waste from it. After collecting them from several containers, the vehicles unload the waste at the disposal site at full capacity. Solid waste transportation in Tangerang Municipality uses a Stationary Container System with dump trucks as their type of transportation. This system also affects the number of workers who become a significant part of the waste transportation system cost (Environment Agency, 2021). Moreover, the waste route planning model has some network attributes that need to be considered, such as fuel consumption, travel time, the type of road, speed limit, the nature of transport, and coordination of local accessibility (Tavares et al., 2009).

2.2 The Optimization of Solid Waste Transportation

Optimization systematically obtains the minimum or maximum value from a function, opportunity, or finding other values in various cases. This analysis is beneficial in almost all fields to conduct business effectively and efficiently to achieve the target results (Diwekar, 2003). The waste transportation system has the same activities as any other transportation. The waste-moving process must acknowledge the shape of the waste, including the type and the size, the kilometer driving, and whether it will be processed or dumped in a landfill (Miro, 2005). Therefore, the management can decide the system's most relevant vehicle and distribution pattern. The Regulation of Indonesian Public Works Ministry Decision No.3 the Year 2013, chapter 23 mentions that the frequency of waste collection trips should be efficient and effective; the vehicle should drive through the shortest route with minor obstacles and at full capacity.

The distance traveled in disposal transportation is the total length of the daily trip starting from the pool to the following collection, then the landfill, and ends at the pool for one vehicle. Meanwhile, the time travel is the total time taken to transfer the waste in a day, including the travel time from the pool to each collection point, landfill, and back to the pool; the time to load the waste to the vehicle in each collection points; and the time to unload the waste in a landfill for one vehicle.

To summarize, the optimization seeks the shortest and quickest route between the pool, collection point, and landfill with the minimum obstacle to lower the waste collection cost. This cost includes fuel consumption, the worker's salary, and vehicle maintenance.

2.3 The Overview of Tangerang Municipality

Geographically, Tangerang Municipality is located between 106°36’-106°'42' east longitude and 6°'6'- 06°'13' south latitude, with an area of 164.55 km^2 or 1.59% of the area of Banten Province. It is the smallest city in Banten Province after south Tangerang Municipality. The population in Tangerang Municipality in 2020 was 1.895 million (BPS, 2021). Administratively, Tangerang City constitutes 13 districts and 104 sub-districts with the borderline: North: Tangerang Regency. South: Tangerang Regency and Jakarta; East: Jakarta; West: Tangerang Regency.

Tangerang Municipality is guided by the Regional Law of Tangerang Municipality No. 3, 2009- as a regulation to handle their waste, especially household waste. Waste management in Tangerang City is an organized, extensive, and continuous activity which serves waste collection and reduction. Five waste management handling activities in Tangerang begin with sorting, collecting, transporting, recycling, and processing.

The Cleaning Division of the Environment Agency handles the waste management activity. There are three sections that have specific tasks in handling the waste. Those sections are the Operational Section which manages the waste collection and transportation; the Final Processing Section manages the waste treatment in the landfill; and the Waste Reducing Section manages every necessary action to lessen the amount of waste carried to the landfill. The landfill is the final treatment site that handles the waste that cannot be processed anymore. The landfill is in Rawakucing and is called TPA Rawakucing. TPA Rawakucing has a burial site, a compost recycling facility, and a renewal energy treatment facility that processes plastic waste.

3. Research Method

The measurement of the proposed model is distance and time. Therefore, the methods are divided into two sequential stages with different objectives: reducing the length and time. Figure 1 explains the steps in the research method process. The comprehensive methods will be explained in the following discussion.

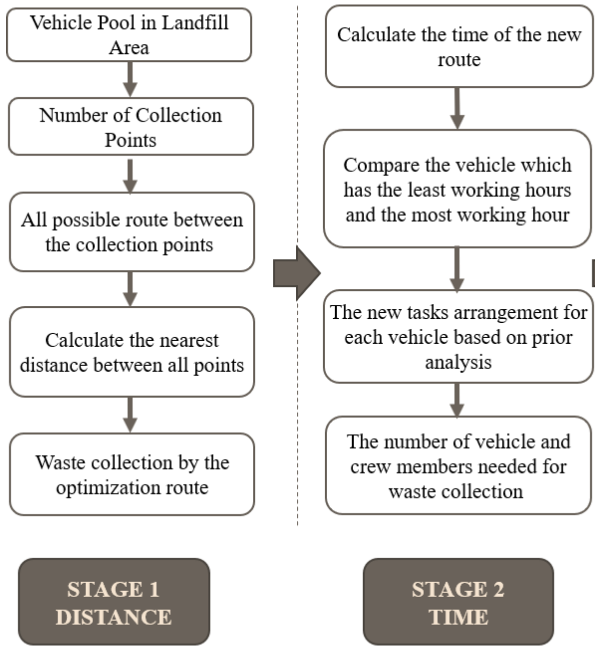

Figure 1. Two Stages of Method Process

3.1 Distance Reduction

3.1.1. Identifying the Existing Route of Solid Waste Collection

This research evaluates 104 sub-districts in Tangerang Municipality. There are 338 waste collection points in the Tangerang municipality's whole area. The source of the location data is the Environment Agency of Tangerang Municipality for the year 2021. The waste transportation in Tangerang City uses a single-trip category as their travel pattern; the frequency is two trips in each vehicle route.

In early 2020, the world faced the pandemic situation of COVID-19. WHO reports 79 million cases and over 1.7 million deaths globally since the pandemic started on December 29th, 2020 (WHO, 2020). This condition is a limitation for the author to do field observation in data gathering. The database information about distance and time travel is collected online using the Google API application. Google company accumulated this data from smartphones conducted by GPS. This method estimates the distance to the origin and destination, the average fluctuation of the daily travel time, and the travel time variability.

Google Maps Distance Matrix API is a product that measures the distance and travel time from the origin to a destination (OD) at a particular departure time (Dumbliauskas et al., 2016). The user gets the recommended route from origin to destination based on the Google API Matrix calculation. The query should be sent through a script, which compiles the URL (Uniform Resource Locator) using the following information, such as:

a. Longitude of origin (required);
b. Latitude of origin (required);
c. Longitude of destination (required);
d. Latitude of destination (required);
e. Mode of travel (optional);
f. Date and time of departure (optional).

The waste collection points' data location is in coordinate form (longitude and altitude). This data is put in Google API to count the distance and time needed to transfer the waste per trip. Figure 2 explains the sampling process of input and output distance and time data using Google API.

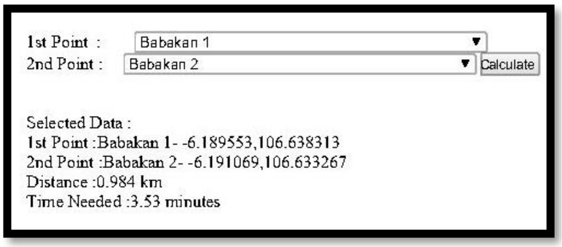

Figure 2. Distance and Time Calculation Using Google API

The coordinates of waste collection point locations are mapped using the GIS application. GIS provides the shortest path feature to seek the shortest route between two points OD. The origin coordinate is portrayed as x location, while the destination is y location. The route is generated automatically based on the x and y points. This step is then applied to all collection points. The map of the existing routes is used from the Environment Agency data. Meanwhile, the map of the optimized routes is based on the distance-matrix results.

3.1.2 Centralized Authority for Solid Waste Disposal Transportation

Solid waste transportation in Tangerang Municipality serves all collection points with a 6 m^3 capacity of dump trucks. The total number of a vehicle is 104 dump trucks since the vehicle authority is in the sub-districts government. The pool in the sub-district office gives the extra distance to visit all the collection points. The direct transfer of waste from landfills and the waste collection lead to a reduction in distance. The missing distance from the pool to the first collection point and landfill to the pool is the first distance reduction as the first step of optimization. Figure 3 visualizes the proposed plan for solid waste transportation flow.

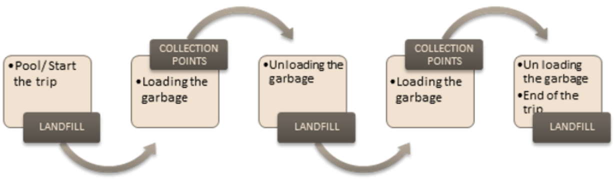

Figure 3. Proposed Solid Waste Transportation Flow

The relocation scheme requires a new parking area in the landfill. There is already a built parking lot for the fleet. Around 3,000 m2 will be used for the optimized number of vehicles pool.

3.1.3 Nearest Distance Modeling

The optimization scheme lowers the total distance of all dump trucks for waste collection trips. Therefore, the closeness to the landfill defines the order of the collection points, as the landfill is the last to visit. The data result from Google API is organized from the smallest to most extended distances to a database. Furthermore, the amount of the capacity point is critical information in this database. All of the collection points are coded to make the selection easier.

The waste collection points have four different capacities, which are 1 m^3, 2 m^3, 3 m^3, and 6 m^3. All dump trucks must carry full capacity (6 m^3) to unload the waste in the landfill. The total amount of collected waste is 1,248 m^3 per day from the accumulation of 104 vehicles and 208 trips. Currently, there are seven combinations of waste collection points route:

a. 1 m^3–1 m^3–1 m^3–1 m^3–1 m^3–1 m^3
b. 1 m^3–1 m^3–1 m^3–1 m^3–2 m^3
c. 1 m^3–1 m^3–1 m^3–3 m^3
d. 1 m^3–1 m^3–2 m^3– 2 m^3
e. 1 m^3 – 2 m^3 – 3 m^3
f. 2 m^3 –2 m^3 –2 m^3
g. 3 m^3 – 3 m^3

In addition, the data classification based on the capacity of the point is for simplifies the planning stage. This modeling rearranges the route by ignoring the point with a 6 m^3 capacity and mixing the 1 m^3, 2 m^3, and 3 m^3 point capacity. The total capacity of the route must be 6 m^3 per trip. The goal is to transfer the waste from the nearest points to prevent landfill visitation from lesser-capacity vehicles.

The distance matrix is then filled with the listed distance data. The matrix arrangement is that the distance and travel time from the OD is the same as the reverse. All vehicles are prohibited from revisiting the same point; only a single trip is allowed. Table 1 explains the sample distances of some solid waste points in Tangerang Municipality due to landfill proximity. The smaller number is on the left matrix, while the bigger one is on the right side.

Table 1. The Sample of Nearest Distance Matrix for Solid Waste Transportation in Tangerang Municipality

			Capacity	3	6	6	6	6	3	6	3	6	6	6
			Code	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Capacity	**Landfill**	**Code**	**Landfill**	0.50	0.96	1.16	1.31	1.76	2.04	2.06	2.59	3.49	3.98	4.74
3	0.50	**1**		0	0.494	0.661	1.347	2.262	1.54	1.867	3.09	4.579	4.948	5.011
6	0.96	**2**			0	1.002	0.853	2.716	1.881	1.373	3.545	5.011	5.32	5.781
6	1.16	**3**				0	1.856	2.924	0.863	1.791	3.752	5.502	5.811	6.272
6	1.31	**4**					0	2.411	2.735	1.036	3.239	4.674	4.983	5.444
6	1.76	**5**						0	3.82	3.161	0.828	2.316	2.685	2.749
3	2.04	**6**							0	1.994	4.631	5.936	6.244	6.706
6	2.06	**7**								0	3.989	3.638	3.946	4.407
3	2.59	**8**									0	1.646	2.016	2.079
6	3.49	**9**										0	1.22	1.681
6	3.98	**10**											0	1.13
6	4.74	**11**												0
3	5.12	**12**												
6	5.16	**13**												
6	5.27	**14**												
6	5.30	**15**												
2	5.36	**16**												
6	5.37	**17**												
3	5.69	**18**												
6	5.72	**19**												

The table shows the first potential points for the optimization are numbers 1, 6, 8, 12, 16, and 18, which have 2 m^3 and 3 m^3 of waste capacity. Specifically, the shortest distance from point 1 is point 6, which is 1.54 km. Those points are selected since both of them have 3 m^3 of capacity. Point 2 is ignored since it has a 6 m^3 capacity. The calculation of distance travel per trip is landfill– point 1– point 6 – landfill is 0.5 km + 1.54 km + 2.04 km = 4.08 km. The rest collection points with less than 6 m^3 capacity are combined using the previous step. However, if the nearest point is selected before, the second nearest point will be the best candidate for the next route selection.

3.2 Time Reduction

The Google API analysis also provides the driving time data. The nearest distance analysis creates the new path model to calculate the optimization-driving time. This data results then rated from the least to the longest time for solid waste disposal transportation. The new driving time will determine the route task per vehicle by scrutinizing the Indonesian government's maximum number of trips and working hours requirement.

Indonesian Law No.13/2003, article 77, paragraph 1, conduct a worker has to fulfill:

a. Seven working hours a day or 40 working hours a week for six working days in a week; or,

b. Eight working hours a day or 40 working hours a week for five working days a week.

The organization of the new worker task in each vehicle uses this regulation as a basic rule. However, the model takes the requirement of 40 hours, which is 6 hours or 360 minutes per day for seven days, since solid waste transportation disposal is operated daily.

The total time calculation includes the time taken to load and unload the waste. The loading time is the average time required to carry the waste into the container trucks at the waste collection points. Meanwhile, the unloading time is the average time to empty the container trucks in the landfill. The rest of the route applies these rules until it builds several trips. The combination of several trips in one route should not exceed by 6 hours of working hours requirement. The maximum trip per route is six, starting from the landfill to load the waste in collection points and ending with unloading the waste in the landfill. The number of trips created provides the vehicles needed for solid waste disposal transportation. Vehicle optimization is any number of vehicle reductions from the current condition.

4. Result and Discussions

4.1 Route Optimization

The distance travel data explain the output of the Google API algorithm in terms of the distance needed to reach each collection point. The total current route that serves all waste collection points is 6,332.72 km. The least total distance travel compares to all vehicles is 5.52 km (Kedaung Wetan dump trucks), while the longest is 131.22 km (Larangan Selatan dump trucks). The average distance driven is 59.37 km. Figure 4 depicts all the existing collection points, and the routes using GIS apps.

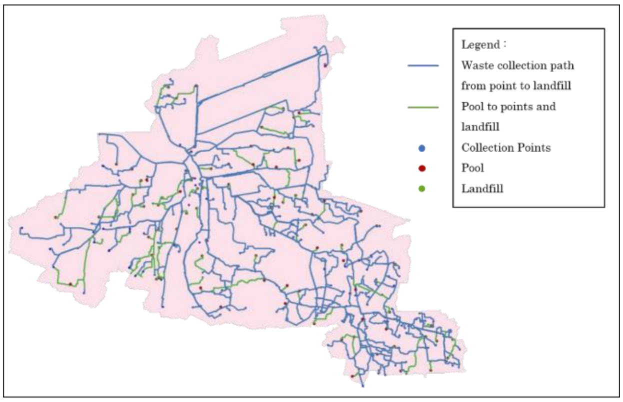

Figure 4. Current Solid Waste Collection Route in Tangerang Municipality

The data of Google API extraction is then ranked in a table without including the data from the collection point, which has a 6 m^3 capacity. Table 2 is a sample of simplifying data using codification before inputting them in the nearest distance matrix.

Table 2. Sample of the Distance Between Selected Collection Points and Landfill

CODE	Collection Point	Distance (km)	Capacity (m^3)
1	Kedaung Baru 1	0.50	3
6	Kedaung Baru 2	2.04	3
8	Neglasari 3	2.59	3
12	Sukaasih 2	5.12	3
16	Sukarasa 2	5.36	2
18	Sukaasih 1	5.69	3
21	Sukarasa 1	5.87	2
22	Sukarasa 3	5.90	2
26	Sukaasih 4	6.73	3
.	.	.	.
.	.	.	.
.	.	.	.
331	Parung serab 4	30.12	1
332	Paninggilan Utara 2	30.26	3
333	Larangan Selatan 2	31.03	3
334	Pondok Pucung 2	38.24	2
335	Parung serab 6	40.99	2
336	Parung serab 2	41.19	2
337	Parung serab 1	41.21	2
338	Parung serab 5	41.88	2

The nearest distance matrix reduces the total distance from the existing route, which creates the optimized model. The total length of the optimization model is 5848.73 km. This result means the optimized route is less than 483.99 km or 7.64 % less than recent. The average distance driven is 56.24 km. On the contrary, the number of optimized routes is constant, with 208 routes. The new routes are processed in the GIS to visualize the path of each vehicle to the collection points based on the optimization results. Figure 5 shows some missing routes compare to the existing ones (figure 4) due to pool removal.

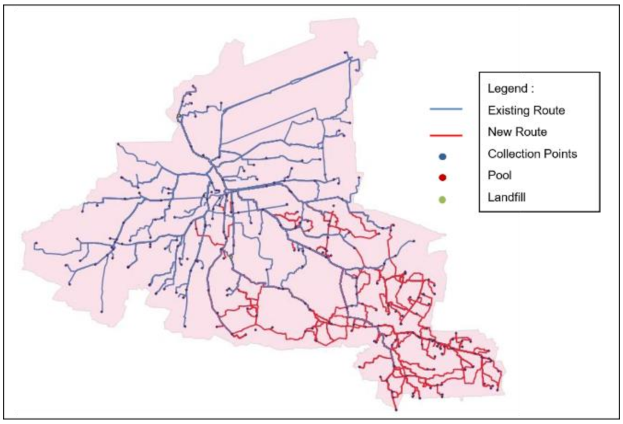

Figure 5. The Optimized Route of Solid Waste Collection Using Nearest Distance Analysis

By comparing both maps, it can be seen that the route in the green lines (figure 4) is erased in the optimized model (figure 5). In the meantime, the red lines in the optimized route illustrate the reorganized route. There are some reductions and redirections of the routes.

4.2 Time Optimization

The current route spent 16,066.20 minutes carrying all the waste in 338 collection points. This driving time must be summed up as loading at all waste points and unloading waste in the landfill area. The total loading and unloading times are 2,715 and 6,240 minutes, which makes the total waste collection time 25,016.18 minutes. The average driving time is 151.24 minutes, and the average speed is 22.47 km/h. This result means that more than 50% of vehicles go to collect waste less than the average.

Similarly, the driving time order is identical to the distance driven. For instance, the least driving time is Kedaung Wetan trucks, with 105.43 minutes, and the most driving time is the Larangan Selatan trucks, with 363.24 minutes. The result means that the longer the route, the more driving time the vehicle needs.

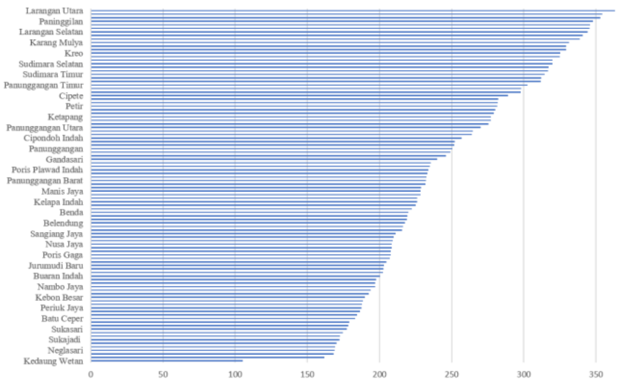

Figure 6. The Driving Time of the Existing Solid Waste Disposal Routes in Tangerang Municipality (in minutes)

Look at the figure above; more than half of trucks' driving time is less than 6 hours daily. Moreover, the farthest location takes four times longer than the closest. This workload is flawed since they all get the operational budget for wages, fuel, and maintenance. The regulation order is to work 40 hours per week. Therefore, all dump trucks are inefficient and ineffective.

The optimization aims to reorganize the route by distance reduction and vehicle task calculation to create a workable balance. The result is that the driving time is lower by 920.73 minutes or 3.7 %, from 25,016.18 minutes to 24,095.45 minutes. Figure 7 displays the driving time of the optimization model. Compared to Figure 6, a significant gap between the least and the most.

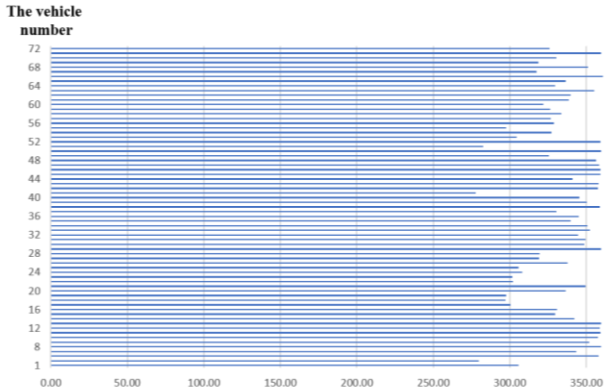

Figure 7. The Driving Time of the Optimization Solid Waste Disposal Routes in Tangerang Municipality (in minutes)

The new arrangement of the vehicle routes balances the workload of the vehicles and increases the work intensity of labor. The time reduction decreases the vehicle by 30.77%, from 104 dump trucks to 72 dump trucks. The chart forward depicts the structured route per vehicle.

Comparing the driving time per route between Figure 6 and Figure 7, the optimization model has equal driving time per vehicle. Though the total time of the waste collection process is lower than before, most employees' working hours increase. The management should handle the possibility of conflict due to the increasing working hours. For instance, the management may rotate the route task per vehicle monthly to balance the long and short journeys.

Currently, the total workers in the waste collection are 104 drivers and 312 crew members. However, the reduction of dump trucks reduced workers to 288 people. This change means the government laid off 128 workers to fulfill the optimization numbers. The management was able to avoid the dismissal by:

a. Reshuffle the employee's schedule; they may collect the waste for six days rather than working 6 hours for seven days. This reduction affects the salary since the payment depends on the working hour. In reverse, the worker gets a day off to rest.

b. Replace the employees to waste recycling and processing facilities since the saved cost from the optimization model will be allocated to them.

c. The dismissal of unproductive workers who reject the prior management offers.

5. Conclusion

In conclusion, the proposed optimization model effectively reduces travel time and distance in the waste collection system. The result shows a 7.64 % reduction in distance driven and a 3.7% reduction in time, providing significant cost savings. However, the model has limitations and only applies to the current situation in

Tangerang municipality, with fixed variables such as the number of collection points, the maximum number of waste collection vehicles, vehicle capacity, and working hours. Future studies can use this model as a reference for similar situations.

As the growing population triggers an increase in waste generation, the Municipality should prepare a solid waste collection investment plan to adapt to the changing needs. The cost saving from the optimization model can be allocated as incentives for the investment. This study highlights the importance of continuous improvement and innovation in waste management to meet the challenges of urbanization and population growth.

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