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Evaluation of Waste Transportation Routes in Salatiga City

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ABSTRACT

The problem of waste transportation is a major challenge in waste management in Salatiga City. With the amount of daily waste generated reaching 457.81 m³ and the volume transported only around 327.33 m³, the level of waste transportation has only reached 71.72%. This study aims to evaluate and optimize the current waste transportation route through a spatial approach using QGIS software. The methods used include field observation, primary and secondary data collection, and spatial analysis of the distribution of routes and workloads of the transport fleet consisting of 9 arm roll units and 1 dump truck unit, with a total average daily trip reaching 58 trips. The results of the comparison between the existing route and the planned route show a daily route length efficiency of 10.57 km (1.15%) and a time efficiency in waste transport operations of 25 minutes. The volume of transported waste also increased from 83,730 kg/day to 89,500 kg/day (up 6.89%), which was achieved through more optimal route planning, additional trips to TPS Boja and Tingkir, and equalizing the workload between drivers. The results of this study confirm that GIS-based route optimization can increase the efficiency of distance, and productivity of the waste transportation system as a whole in Salatiga City.

1. INTRODUCTION

The waste problem is a complex challenge in various cities in Indonesia, including Salatiga City. Population growth, urbanization, consumer lifestyles, and increasing economic activities have driven a significant increase in waste generation (Nafilah, D., & Kamaly, 2025). This condition requires an efficient waste management system, starting from the collection stage, transportation, to the final processing site.

One important aspect in waste management is transportation from the Temporary Shelter (TPS) to the Final Processing Site (TPA). Optimal transportation is characterized by efficiency in distance, travel time, and operational costs. Inefficiencies in transportation routes can cause delays, low iterations, and increased operational burdens, resulting in high volumes of untransported waste (Siregar, FH, & Pharmawati, 2024)

In 2024, Salatiga City generated approximately 450.99 m³ of waste per day, while only 323.46 m³ reached the TPA, resulting in a transportation ratio of 71.72% (DLH, 2024). The city operates 23 active TPS and one final disposal site, TPA Ngronggo. This condition illustrates that existing transportation systems still face gaps in route efficiency, trip iteration, and fleet workload distribution, which have not been comprehensively analyzed in previous local studies.

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To overcome these problems, an evaluation of the current transportation system is needed. This evaluation is carried out using a spatial approach using QGIS software through the network analysis method, to map and determine the best route from TPS to TPA . The results of this route analysis are expected to produce a more efficient transportation pattern in terms of distance and travel time, as well as increase the amount of waste that can be transported each day.

Based on the background, the research question posed is: "What is the existing condition of domestic waste transportation in Salatiga City and is the waste transportation route in Salatiga City appropriate and efficient?". The purpose of this study is to analyze the existing condition of waste transportation from TPS to TPA Ngronggo Salatiga and to evaluate and design a more optimal waste transportation route using network analysis in QGIS.

The study is expected to contribute in two key aspects. Theoretically, it enriches models of GIS-based route optimization for medium-sized urban areas, filling the empirical gap in spatial waste transport evaluation. Practically, it offers strategic and technical recommendations for local governments to improve fleet performance, reduce operational costs, and lower vehicle emissions through data-driven route planning. Implementing the proposed route optimization will support a more efficient, environmentally responsible, and sustainable waste transportation system in Salatiga City.

2. METHODS

Types and Approaches of Research

This research is a quantitative descriptive study with a spatial approach, which aims to analyze the existing conditions and optimize the waste transportation system in Salatiga City. The approach is carried out through the utilization of Geographic Information System (QGIS) software with the network analysis shortest path method and the AHP (Analytical Hierarchy Process) multi-criteria approach to determine priority strategies for increasing efficiency.

Location and Time of Research

The research was conducted in the administrative area of Salatiga City which includes four sub-districts: Sidomukti, Sidorejo, Tingkir, and Argomulyo. Field data collection was carried out from August 2024 to May 2025.

Data and Data Sources

This study uses two main types of data: Primary Data: Results of direct observation of waste transportation routes, TPS locations, and transportation fleets; Measurement of travel time and trip length was carried out using a stopwatch, GPS, and Avenza Maps; Interviews with expertise for the purpose of assessing criteria in the AHP method. Respondents consist of experts who understand the waste transportation system, such as staff from the Environmental Service, academics, and waste management practitioners. Secondary Data: Data on the amount of waste generated, the number and capacity of the fleet, and the itinerary schedule from the Salatiga City Environmental Service. Basic map of the administrative area of Salatiga City and distribution of TPS from related agencies.

Research Instruments

No	Tool	Function	Parameters Measured
1	GPS	Determines coordinates and route path	Location coordinates
2	Stopwatch	Measures travel time	Time (minutes)
3	Laptop	Processes data, runs analysis software	—
4	Camera	Visual documentation in the field	—
5	QGIS Software	Software Spatial analysis of routes and distribution of TPS points	Route length, shortest route

6	Avenza Maps	Records and navigates actual waste transportation routes in the field	Distance traveled, travel time
7	Expertise Interview	Giving preference weights to several transportation efficiency criteria by experts	AHP criteria preference assessment
8	Expert Choice Software	Processes data from AHP criteria weighting results from expert respondents	Priority value, criteria weight, CR

Data collection technique

Data collection techniques in this study were carried out through several approaches. First, a literature study was used to obtain a theoretical basis for the waste transportation system, route optimization, and the application of network analysis methods and the Analytical Hierarchy Process (AHP). Second, direct field observations were carried out to obtain primary data, such as TPS location points, transportation routes, daily trips, and travel time. This observation was complemented by the use of GPS devices and stopwatches to record the distance and duration of each trip. In addition, secondary data was collected from the Salatiga City Environmental Service in the form of administrative maps, number of fleets, vehicle capacity, transportation schedules, and distribution of TPS. Third, direct interviews were conducted with truck drivers and experts to obtain in-depth information about the existing conditions of transportation and to weight the criteria in the AHP. The weighting was presented in the form of a questionnaire and processed using Expert Choice software.

Research Procedures

This research procedure was carried out through several systematic stages. The first is the planning stage, which includes preparing a proposal, determining the formulation of the problem, and collecting relevant literature to support the analysis. The next is the data collection stage, where primary data is collected through direct observation in the field, measuring trips and travel time, and recording TPS coordinates using GPS and the Avenza Maps application. Secondary data was obtained from related government agencies.

After the data was collected, processing and analysis were carried out. This stage includes spatial analysis using QGIS to map existing routes and simulate alternative routes based on the shortest path method through network analysis. Then, efficiency calculations were carried out in terms of distance, and time. To develop a priority strategy for increasing efficiency, multi-criteria decision-making was carried out using the AHP method involving experts through interviews and questionnaires, then analyzed using Expert Choice software. The last stage is the report preparation stage, which includes writing research results, discussions, conclusions, and recommendations.

Data Analysis Techniques

The data obtained were analyzed using quantitative and spatial approaches. Spatial analysis was carried out using QGIS software using the Network Analysis (Shortest Path) method to evaluate existing waste transportation routes and design more efficient alternative routes based on distance and travel time criteria. In addition, daily itineraries, and volume of waste transported per fleet to assess operational transportation performance.

To determine priority strategies for increasing waste transportation efficiency, the Analytical Hierarchy Process (AHP) method is used. Weighting data is obtained through interviews with experts who have experience in waste management and transportation. This weighting is analyzed using Expert Choice software, which allows for the calculation of consistency and priority ranking based on predetermined criteria. The final results of this analysis are used as a basis for providing strategic recommendations for the Salatiga City Environmental Service.

3. RESULT AND DISCUSSION

Waste Container

Waste storage is the activity of temporarily storing waste in an individual or communal container at the waste source. The types of individual containers used by the people of Salatiga City in collecting waste include plastic bags, trash cans, trash baskets, used buckets, used sacks, etc. as seen in Figure 4.3. These types of containers are used because they are easy to obtain and economically cheaper.

Figure 1. Trash Containers in the Community

Based on the results of field observations, containers in high-density residential areas more often use plastic bags and used sacks because they are easier to dispose of/move to the TPS, while for medium-density residential areas or regular housing, containers are predominantly made of trash baskets, trash cans or used buckets.

In addition, there is also a communal container in the form of TPS. The container in TPS is different from the container at the waste source. Communal container in TPS is for temporary storage before the waste is transported to TPA. In general, the container in TPS is in the form of a container with a container volume used in Salatiga City of 6 m3 as seen in Figure 1.

Figure 2. Communal Containers at TPS

Containers and mini containers are generally placed on the roadside adjacent to residential areas, so that local people can dispose of waste to the TPS or as a waste transfer location from carts. The distribution of TPS in Tasikmalaya City can be seen in Figure 2 and in the Appendix.

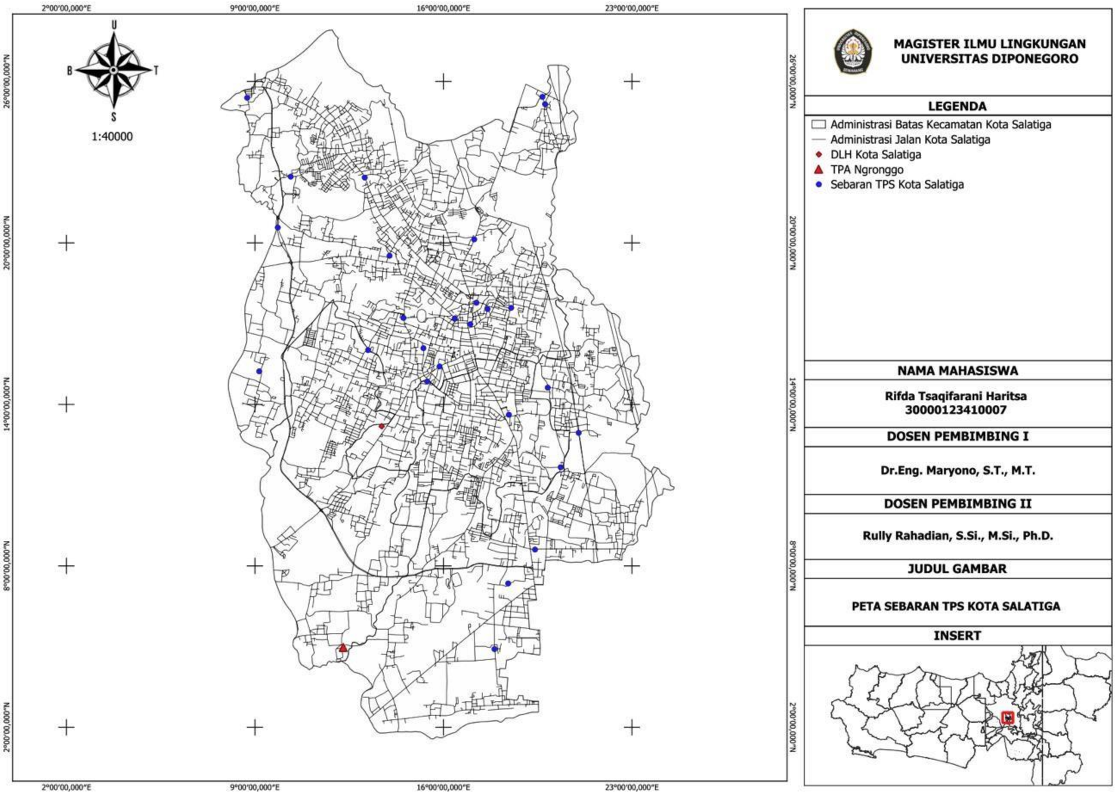

Figure 3. Map of Polling Station Distribution in Salatiga City

Figure 3 shows the distribution of Temporary Waste Disposal Sites (TPS) in the administrative area of Salatiga City. Based on the map, TPS are spread across four sub-districts, namely Sidomukti, Sidorejo, Tingkir, and Argomulyo Sub-districts, with higher concentrations in urban areas and community activity centers. This reflects the efforts of the local government in providing equitable waste management facilities, although there are differences in distribution density between regions.

Existing Waste Transportation Routes

Waste transportation in Salatiga City is carried out from final collection points to the Final Processing Site (TPA), using a trip-based (*ritasi*) system that begins with empty vehicles until they return fully loaded. Two transport systems are implemented: the Hauled Container System (HCS) and the Stationary Container System (SCS). Based on field observations, HCS records a higher frequency of 6 to 7 trips per day, with an average of 58 daily trips. In contrast, SCS consistently achieves only 2 trips per day.

The types of vehicles used for waste transport include arm roll trucks and dump trucks. According to data from the Salatiga City Environmental Office (DLH), there are 9 arm roll trucks and 1 dump truck in operation. These vehicles serve various temporary waste collection sites (TPS) distributed throughout the city. Transport routes vary daily and are repeated every three to six days after the previous service.

Each vehicle differs in trip frequency and routes depending on the location of TPS and the number of containers to be transported. Routes cover various road networks, including national roads, provincial roads, and neighborhood roads. Arm roll trucks are assigned to serve residential areas, commercial zones, and public facilities, while the single dump truck is dedicated to market waste collection. The operating time for each vehicle is approximately 8 hours per day. The number of waste transportation vehicles in Salatiga City can be seen in Table 1 below.

Table 1. Garbage Transport Vehicles in Salatiga City

No	Type of Transport Vehicle	Amount (Unit)

1	Arm Roll Truck	9
2	Dump Truck	1

Source: DLH, 2024

The average amount of waste transported to the TPA reaches 83,761.78 kilograms daily, or approximately 323.46 cubic meters. This figure reflects the high intensity of waste transport services, considering the limited vehicle capacity and working hours. However, several technical and operational challenges still hinder the overall efficiency of the waste transport system.

The main problems observed in the field include vehicle overloading, which leads to waste spillage during transportation. In addition, there is an unequal distribution of workloads among drivers. Although the number of trips appears similar, the route distances and travel durations vary significantly. As a result, some drivers travel longer distances and operate for extended periods compared to others.

This imbalance highlights the need for improvements in scheduling and route distribution systems. The impacts are not only on fleet efficiency but also on the fairness of workload and driver fatigue. Moreover, the absence of backup vehicles presents an additional risk when breakdowns occur. Therefore, a comprehensive evaluation of fleet management is needed to enhance efficiency, ensure equitable workloads, and strengthen operational resilience.

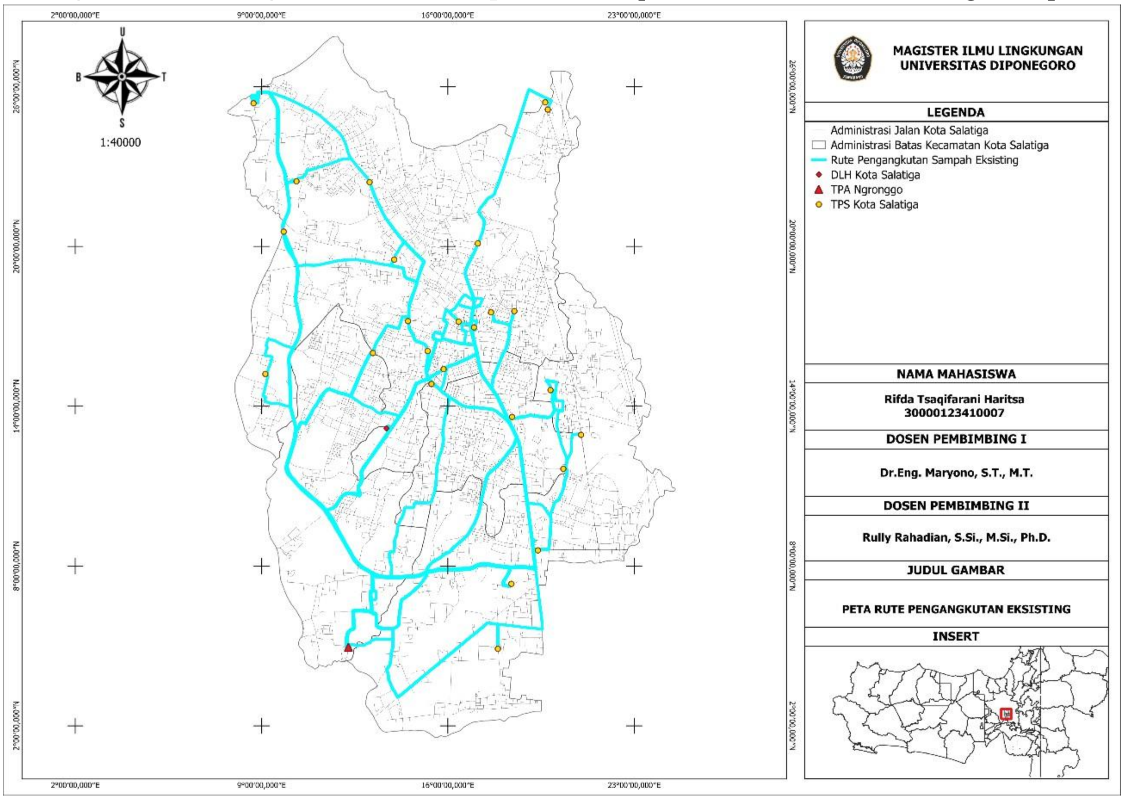

Figure 4. Map of Existing Waste Transportation Routes in Salatiga City

Waste Transportation Plan Route

Analysis of waste transportation routes is carried out as an effort to identify transportation routes with the shortest travel distance, in order to support increased efficiency in the waste management system. Although this approach does not directly touch all aspects of optimization, finding the shortest route can provide positive economic and environmental impacts, especially in terms of travel time efficiency, and reduced travel distance.

The analysis process is carried out by utilizing QGIS software, through the Network Analysis feature, especially Shortest Path Analysis. This feature is used to model and evaluate transportation routes based on the principle of selecting the shortest path connecting the starting point of transportation (TPS) to the end point (TPA). In the context of waste transportation, the best route is defined as the shortest path that can connect waste collection locations to the TPA efficiently.

The analysis focuses on dump trucks and arm roll trucks that operate routinely in Salatiga City. All existing routes are re-modeled in QGIS to be compared with the shortest route resulting from spatial analysis. The aim is to find out whether the current routes are efficient based on travel distance, or whether there is still potential for improvement.

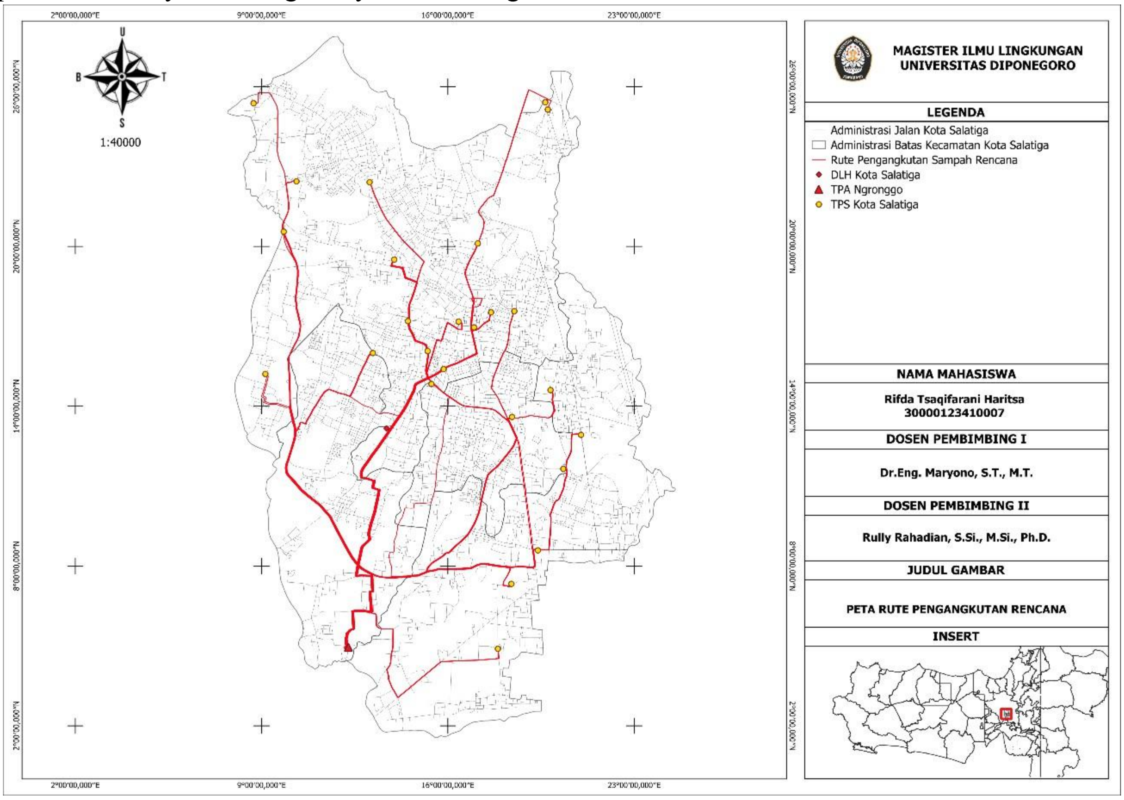

Figure 5. Map of Planne Waste Transportation Routes in Salatiga City

Comparison of Existing and Planned Transportation Routes

This analysis aims to compare the efficiency of waste transportation routes between the existing condition and the planned route generated using the *shortest path* method in QGIS. The application of optimized routing is expected to enhance operational efficiency and reduce fuel consumption. The existing route data were obtained from field surveys using the Avenza Maps application, in which TPS locations and transport trajectories were recorded in real time through GPS tracking. Meanwhile, the street network data for the planned route model were derived from the QGIS base map, which provides a comprehensive and connected road system. The planned routes were automatically generated using the *shortest path* algorithm, connecting each TPS to the TPA through the minimum network distance available.

Table 2. Comparison of Route Length Fuel Consumption of Arm Roll Trucks

Driver Name	Total Route Length		Difference in Route Length (km)	Fuel Consumption/day	
	Exsisting (km)	Planned (km)		Exsisting (km)	Planned (km)
Driver 1	106,90	103,211	3,689	27,69	26,73
Driver 2	89,00	98,128	-9,128	23,05	25,41

Driver 3	104,80	99,114	5,686	27,14	25,67
Driver 4	98,60	117,042	-18,442	25,54	30,31
Driver 5	78,80	75,992	2,808	20,41	19,68
Driver 6	81,40	92,786	-11,386	21,08	24,03
Driver 7	92,80	94,262	-1,462	24,03	24,41
Driver 8	93,30	83,616	9,684	24,16	21,66
Driver 9	144,40	116,127	28,273	37,40	30,08
Total	**890**	**880,278**	**10,569**	**246**	**243,07**

The difference in route length presented in Table 2 indicates the deviation between existing and planned routes. A positive value denotes a shorter and thus more efficient route, while a negative value indicates a longer route. However, an increase in route length does not necessarily reflect inefficiency, as it may result from the redistribution of TPS or trip adjustments to balance the workload among drivers.

For instance, Drivers 2 and 6 experienced longer routes due to additional trips aimed at redistributing workloads more evenly. Conversely, for Drivers 4 and 7, despite an increase in total distance, the actual operational duration decreased, suggesting that the optimized routes offered smoother traffic flow and better road connectivity.

Table 3. Comparison of Route Length Fuel Consumption of Dump Trucks

Driver Name	**Total Route Length**		**Difference in Route Length (km)**	**Fuel Consumption/day**	
	Exsisting (km)	**Planned (km)**		**Exsisting (km)**	**Planned (km)**
Driver 10	31,90	31,053	0,847	15,50	15,09

Tables 2 and 3 demonstrate that route optimization using the *shortest path* method positively impacts operational efficiency. The total route length for all arm roll trucks decreased from 921.90 km (existing) to 911.33 km (planned), achieving a daily distance reduction of 10.57 km (1.15%). This finding confirms that GIS-based routing produces more spatially efficient trajectories compared to conventional routes established by driver habits.

The reduction in distance directly contributes to lower fuel consumption. Assuming a vehicle efficiency of 3.86 km/L (based on data from DLH Salatiga City, where arm roll trucks consume 230.5 L per 7 days), the total daily fuel demand decreased from 230.50 L to 227.98 L, saving approximately 2.52 L per day. Similarly, the dump truck's consumption decreased from 15.50 L to 15.09 L, reflecting both route and fuel performance efficiency of 0.42 km/L. In addition to distance, topography also influences efficiency: flatter routes enable more stable engine performance and better fuel economy compared to hilly areas. Therefore, optimizing routes that consider both distance and terrain contour can effectively reduce operational costs.

Table 4. Comparison of Transported Waste Volume

Driver Name	**Amount of Transported Waste**		**Increase in Transported Waste (kg)**
	Existing (kg)	**Planned (kg)**	

	Arm Roll Truck		
Driver 1	8560	9000	440
Driver 2	9780	10500	720
Driver 3	9910	10500	590
Driver 4	8475	10500	2025
Driver 5	9020	9000	-20
Driver 6	8610	10500	1890
Driver 7	9985	10500	515
Driver 8	5680	6000	320
Driver 9	9950	9000	-950
	Dump Truck		
Driver 10	3760	4000	240
Total	**83.730**	**89.500**	**5770**

Negative differences indicate a reduction in transported waste volume. The total amount of transported waste increased from 83,730 kg to 89,500 kg per day, an increment of 5,770 kg (6.89%). This improvement resulted from a more balanced distribution of TPS points among the fleets, enabling each vehicle to utilize its maximum loading capacity effectively. The maximum capacity of an arm roll truck is 1,500 kg, while the dump truck can carry 2,000 kg.

Table 5. Comparison of Operational Duration

Driver Name	Operational Duration (minutes)		Difference in Operational Duration (minutes)
	Existing	Planned	
	Arm Roll Truck		
Driver 1	249	244	5
Driver 2	162	180	-18
Driver 3	231	221	10
Driver 4	207	206	1
Driver 5	182	181	1
Driver 6	193	206	-13
Driver 7	206	200	6
Driver 8	192	191	1

Driver 9	253	223	30
		Dump Truck	
Driver 10	74	72	1
Total	**1949**	**1924**	**25**

Table 5 compares the operational duration between the existing and planned conditions. The planned routes reduced the total operational duration from 1,949 minutes to 1,924 minutes, achieving a daily efficiency of 25 minutes. This demonstrates that although several routes experienced slight increases in distance, the overall operational performance improved due to smoother traffic flow and reduced obstructions. These results confirm that the spatially shortest route does not necessarily correspond to the longest operational duration.

Overall, the GIS-based route planning significantly improved the efficiency of the waste transportation system in Salatiga City. This approach not only reduced total distance and fuel consumption but also enhanced workload distribution, transported volume, and time performance. Therefore, GIS-assisted optimization is a viable strategy for developing data-driven, cost-efficient, and environmentally sustainable waste transportation management systems in medium-sized urban areas.

Analysis of Work Culture and Behavioral Transport

Field findings show that the working conditions of garbage truck drivers in Salatiga City are greatly influenced by a work culture that has been formed from generation to generation and is not yet supported by an adequate managerial system. Drivers generally do not have officially scheduled rest periods; rest is only taken when conditions permit, such as when the load is not yet full or when there are no urgent transportation requests. In fact, on religious holidays such as Eid al-Fitr, some drivers continue to work until the evening. Work leave, although available administratively, is almost never used due to the unavailability of replacement drivers.

This kind of work culture indicates structural pressure in the organization of waste transportation operations. High dependence on permanent personnel without backup causes the system to be unresilient to personal disruptions such as illness, family needs, or physical fatigue. This condition has the potential to reduce long-term performance and threaten work safety, because the operational load is not balanced with recovery time.

Furthermore, the discipline of departure times and task execution also shows variation between individuals. There are drivers who start their activities since dawn, but there are also those who arrive late. This situation indicates that there is no standard operating procedure (SOP) that is consistently enforced regarding working hours, rest, and personnel rotation.

When associated with the results of QGIS-based optimal route planning, a gap was found between technical planning and operational realization in the field. Route optimization requires certainty of departure time and accuracy of implementation at each service point. If the work culture is not in line with the technical planning parameters, then the expected efficiency in terms of distance, time, and volume of waste transported will be difficult to achieve optimally.

In addition, the community as an external party has actually shown quite disciplined behavior in disposing of waste at the specified time. This shows that the main obstacle in the transportation system is not on the community side, but lies on the internal operational side. Thus, the technical planning that has been designed needs to be supported by work culture reform and human resource management. The addition of reserve workers, the determination of proper working and rest hours, and humane work rotation are urgent strategic steps to create a transportation system that is not only technically efficient, but also socially and institutionally sustainable.

Research Limitations

This study has several interrelated limitations. First, the model used is static and does not consider time dynamics or changes in daily operational conditions, so the analysis is carried out based on a fixed situation at the time of data collection. Second, the object of study is limited to the transportation of domestic waste from official TPS to TPA Ngronggo in Salatiga City, without including other types of waste such as commercial or industrial. Third, in route modeling, traffic conditions are assumed to always be smooth, without significant congestion or obstacles, so that the optimization results have not considered the reality of travel time fluctuations in the field. Fourth, the types of fleets analyzed only include dump trucks and arm rolls owned by the Salatiga City Environmental Service, without including the possibility of using alternative fleets. Finally, the optimization approach used only considers travel distance efficiency as the main indicator, so it has not included other factors such as time, operational costs, or vehicle load capacity in detail. These limitations are important to note because they mutually influence the results and scope of research generalization.

Taking these things into consideration, the results of this study still provide significant contributions in terms of route optimization, but remain open to further, more comprehensive development and evaluation.

4. CONCLUSION

The evaluation results show that the existing waste transportation system from Temporary Shelters (TPS) to the Final Processing Site (TPA) Ngronggo has not yet operated optimally. Waste collection is carried out using nine arm roll trucks and one dump truck with an average of six to seven trips per day; however, only about 71.72% of the total waste volume can be transported daily. Several fleets operate beyond their ideal capacity, creating potential risks of waste spillage and accelerated vehicle damage. Moreover, the workload among drivers remains unbalanced, as there are considerable differences in route distance and operational duration despite a similar number of trips. The system also lacks a backup fleet, which makes operations vulnerable to disruption when vehicle breakdowns occur.

Through the application of QGIS-based network analysis using the *shortest path* method, significant improvements in efficiency were achieved. The optimized routes reduced the total daily travel distance by 10.57 km (1.15%), shortened the operational duration by 25 minutes, and lowered fuel consumption by 2.52 liters per day. Furthermore, the transported waste volume increased from 83,730 kg/day to 89,500 kg/day (6.89%), resulting from a more balanced distribution of TPS points, better utilization of vehicle capacity, and additional trips to TPS Boja and Tingkir. These findings confirm that GIS-assisted optimization enhances distance efficiency, time performance, and the overall productivity of waste transport operations.

To improve future system performance, several recommendations are proposed. The Salatiga City Government through the Waste Management Unit (UPT Persampahan) should gradually implement the optimized routing plan, as its measurable impacts on workload balance and transported volume can strengthen operational effectiveness. Pilot testing of alternative routes—through zoning or route redesign—should be conducted to ensure adaptability to local conditions. In addition, adding transport units and optimizing existing fleets are crucial to expand service coverage and maintain system reliability. Integrating GIS-based route optimization into city-scale spatial planning and digital monitoring systems will further support the realization of an efficient, data-driven, and sustainable waste transportation system for Salatiga City.

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