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Optimizing Waste Transport Efficiency in Langsa City, Indonesia: A Dynamic Programming Approach

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Abstract
The ever-growing urban population intensifies waste management challenges, particularly in waste transportation logistics. Langsa City, Indonesia, exemplifies this problem, with limited daily waste collection fleets requiring route rotation across different drivers and teams. This study investigates the effectiveness of Dynamic Programming (DP) in optimizing waste transport routes in Langsa City, focusing on minimizing travel time, distance, and fuel consumption. Data collection involved route observations, driver interviews, and fuel consumption calculations for six operating fleets across Langsa City. DP was then applied to generate optimized routes for each fleet. The results demonstrate that DP significantly improved route efficiency. Optimized routes yielded mileage reductions between 0.2-2.9 km, translating to 2-19 minutes of time savings per shift. Furthermore, a cumulative fuel saving of 0.903% was achieved across all vehicles for a single change. These findings highlight the effectiveness and applicability of DP in optimizing waste transport routes in Langsa City, potentially leading to cost reductions, improved service delivery, and reduced environmental impact.

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1. Introduction
Waste is a complex problem facing the world in both developing and developed countries. In Indonesia, it is now a problem in all major cities (Fernando, 2019; Fitri, Ati, & Suyeno, 2019; Meena et al., 2023). Local governments in Indonesia have done several things to solve waste problems that have widespread economic and health impacts (Kalempouw, 2021; Rashid et al., 2023; Yusof, Nawi, & Jabar, 2023). Waste management is a systematic and comprehensive activity that includes containerisation, collection, transportation and final disposal management. Waste management includes technical and non-technical aspects, namely

institutional, regulatory, community role, technological and financial aspects, regulated by the Ministry of Public Works and Human Settlements according to SNI 324:2008 (Ansari, Dutt, & Kumar, 2024; Chu et al., 2023; Riali, 2020).

The waste problem never seems to be adequately solved. The sight of littered rubbish appears commonplace (Ernawaty, Zulkarnain, Siregar, & Bahruddin, 2019; Harirah, Isril, & Febrina, 2020; Rielasari, 2018). Waste that is poorly managed will have an impact on undesirable aspects of the environment. Therefore, great attention must be paid to waste management, especially identifying transport routes. Then, the amount of waste production is calculated based on the number of city residents, and the need for temporary disposal sites (TPS) is calculated based on the amount of waste production (Dianbudiyanto, 2015; Dzakwan, Nia, Sandi, Teknologi, & Tama, 2020; Gani, Zaki, Bahagia, Maghfirah, & Faisal, 2025; Lee et al., 2024).

The operational transport system directly brings waste from around the city of origin to the final processing site or landfill (TPA). The driver is expected to clearly understand waste transport routes to fit the cost to the municipal budget and be relatively economical. The waste transport system of Langsa City is carried out thoroughly on the main roads to the market areas in the city centre of Langsa, which is divided into 3 shifts starting from 07.00 am - 12.00 pm.

Langsa City in Aceh Province, Indonesia, is one of the cities that is not free from waste problems. In Langsa City, the amount of waste generated increased by 10% per year over 10 years from 2008 to 2018. In 2018, waste generation increased to 324 m^3/day, with the capacity to transport only 22% of the total waste. This situation is worrying and will lead to a deterioration in the quality of the environment, which can be characterised by piles of uncollected garbage on the city streets.

Dynamic programming is a mathematical technique commonly used to solve various problems, one of which is to determine the minimum distance between nodes. Dynamic Programming is a problem-solving method that breaks down the solution into steps or stages so that the solution to the problem can be seen as a series of interrelated decisions.

In optimizing waste transport efficiency in Langsa City, Indonesia, a Dynamic Programming approach can be employed to minimize travel time, distance, and fuel consumption. Dynamic Programming is a powerful optimization technique that can be applied to complex problems such as waste collection and transportation (Fitri et al., 2019; Gani, Saisa, et al., 2025; Kalempouw, 2021).

In waste collection, fuel consumption is a significant cost component and is intrinsically variable, while other cost categories, such as labour, are fixed (Selvakumar, Gani, Xiaoxia, & Salleh, 2025; Sousa, Drumond, & Meireles, 2024). Therefore, accounting for the variability of fuel consumption is essential for more refined cost or environmental optimization (Bahagia, Nizar, Yasin, Rosdi, & Faisal, 2025; Lombardi, Di Ilio, Tribioli, & Jannelli, 2023).

The optimization of waste collection systems has been a research subject, with studies focusing on minimizing costs, greenhouse gas emissions, and negative environmental impacts (Kalempouw, 2021). For instance, Miranda et al. developed a mixed integer linear optimization model for a waste collection system to reduce costs and greenhouse gas emissions (Kalempouw, 2021). Zhang et al. proposed a queuing system for inert construction waste management on a reverse logistics network, considering facility locations and vehicle routes while accounting for carbon footprint (Riali, 2020).

In waste-collecting fleets, eco-driving practices have been shown to reduce fuel consumption and emissions. For example, Goes et al. observed an average fuel economy decrease ranging from 0.8% to 7.1% after training drivers in Rio de Janeiro, Brazil (Rielasari, 2018). However, the impact of eco-driving practices on waste-collecting fleets has been less explored, and further research is needed to understand its potential benefits (Dzakwan et al., 2020; Maghfirah, Yusop, & Zulkifli, 2025).

In summary, the literature highlights the importance of optimizing waste transport efficiency in Langsa City, focusing on minimizing travel time, distance, and fuel consumption. Dynamic Programming can be a valuable approach to address these challenges, and further research is needed to explore the potential benefits of eco-driving practices in waste-collecting fleets.

2. Methodology

2.1. Collection Data

This research included exploratory and quantitative research. Exploratory was used to understand and capture the actual condition of waste in Langsa City. The existing waste collection situation also requires exploratory research, collecting vital data through the study of secondary data, observing the condition of waste collection vehicles, and interviewing waste truck drivers, janitors, and related communities. At the same time, the quantitative method is carried out to process and analyse quantitative data to get an effective transportation route that saves fuel and economical waste transportation costs.

The waste collection pattern currently implemented by the Langsa City Environmental Service is the Hauled Container System (HCS) and the Stationary Container System (SCS). The challenge in transporting waste in Langsa City is the limited fleet of trucks. Trucks must be used in shifts with different drivers and crews each day, and the fleet has to be used in turn, as shown in Table 1.

Table 1. Waste collection vehicle and route data

No.	Time Start	Plate number	Truck type	Name of the road
1.	07.00 AM	BL 8063 F	*Dump-truck*	Pool – Jl. Masjid Ibrahim – Jl. Sudirman – Jl. Syiah Kuala – Sp. A. Yani
2.	07.00 AM	BL 8065 F	*Dump-truck*	Pool - Jl. Iskandar Muda - Jl. Pajak Pisang - Pabrik Es – Jl. Depan LATOS - T. Umar – Jl. Iskandar sani
3.	07.00 AM	BL 8461 JT	*Dump-truck*	Pool – Jl. Masjid Ibrahim – Sp. Komodor – Jl. A. Yani
4.	07.00 AM	BL 8050 F	*Dump-truck*	Pool – Jl. A. Yani – Sp. Bungong Seulanga – Sp. RSUD – Jl. Panglima Polem – Jl. Kp. Jawa Belakang - Jl. Lilawangsa
5.	07.00 AM	BL 8062 F	*Dump-truck*	Pool - Simpang Tk Bungong Seulanga - Tugu Lantas - Balik Simpang Polres - Simpang Jl. Lilawangsa
6.	07.00 AM	BL 8051 F	*Dump-truck*	Pool – Sp. Jl Lilawangsa – Sp. Komodor - Perumnas Paya Dalam

2.2 Data processing

Data processing to obtain the results of the level of addition and subtraction as well as the average distance travelled has been received by following the route directly using Google Maps, and the next coordinate point is to adjust to the existing formula equations that are determined explicitly for waste transportation facilities.

$$\min_{i,\dots,n}\{(\text{shortest distance to point } i) + (\text{shortest distance from point } i \text{ to point } n)\} \quad (1)$$

When calculating costs, operating and maintaining waste collection costs are considered. This analysis is based on expenses incurred by the government to increase the number of trips, waste transportation time, and improve route efficiency. You can use the formula for calculating gasoline costs (Eq. 1).

$$\frac{10}{\text{Starting distance}} = \ \dots \text{ litre/Km} \quad (2)$$

$$\text{Route results of dynamic programming method x results of formula 2} = \cdots \text{liter} \quad (3)$$

2.3 Implementation of Dynamic Programming Algorithms

To obtain an effective and efficient transportation system, waste transportation operations should use transportation routes that are as short as possible, with as few obstacles as possible, and use vehicles with the maximum possible carrying capacity supported by fuel-efficient cars. Data processing in this research uses a quantitative method by creating a calculation model to determine the optimal routes. This method obtains images or conceptual models of waste transportation routes in Langsa City. Descriptive qualitative and quantitative analysis research aims to explain a problem using mathematical calculation techniques. The data processing and analysis technique used in this research is the Dynamic Programming method.

3. Result & Discussion

Based on observations in the field, there was a buildup of waste related to the limited number of dump trucks and costs available for fuel, as well as less than optimal transportation routes.

3.1 Dump Truck (BL 8051 F)

There are three stages, and it can be concluded that the shortest route that can be taken from point 1 to point 6 is 1-2-4-6 or 19.7 Km, as presented in **Fig. 1**.

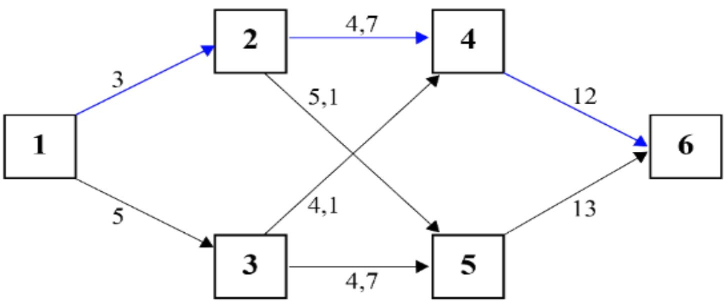

Fig. 1. Dump Truck Transport Line (BL 8051 F)

3.2 Dump Truck (BL 8065 F)

From the three stages, it can be concluded that the shortest route that can be taken from point 1 to point 6 is 1-2-5-6 or 13.8 Km, as presented in **Fig. 2**.

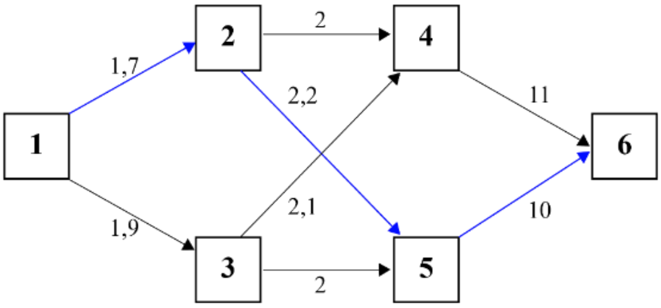

Fig. 2. Dump Truck Transport Line (BL 8065 F)

3.3 Dump Truck (BL 8050 F)

From the three stages, it can be concluded that the shortest route that can be taken from point 1 to point 6 is 1-2-5-6 or 15.4 Km, as presented in **Fig. 3**.

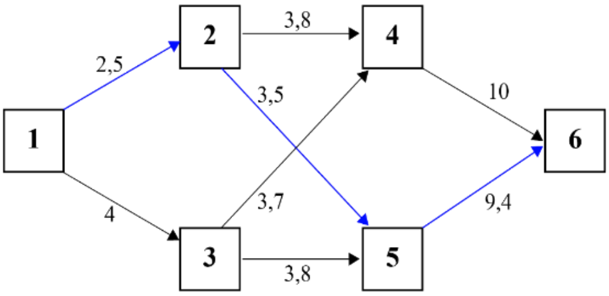

Fig. 3. Dump Truck Transport Line (BL *8050 F*)

3.4 Dump Truck (BL 8461 JT)

From the three stages, it can be concluded that the shortest route that can be taken from point 1 to point 6 is 1-2-5-6 or 19.2 Km, as presented in **Fig. 4**.

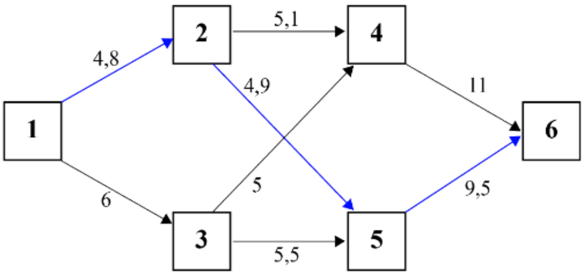

Fig. 4. Dump Truck Transport Line (BL *8461 JT*)

3.5 Dump Truck (BL 8062 F)

From the three stages, it can be concluded that the shortest route that can be taken from point 1 to point 6 is 1-2-5-7 or 16.3 Km, as presented in **Fig. 5**.

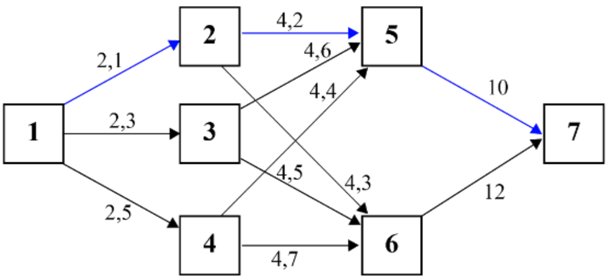

Fig. 5. Dump Truck Transport Line (BL *8062 F*)

3.6 Dump Truck (BL 8063 F)

From the two stages, it can be concluded that the shortest route that can be taken from point 1 to point 4 is 1-3-4 or 11.9 Km, as presented in **Fig. 6**.

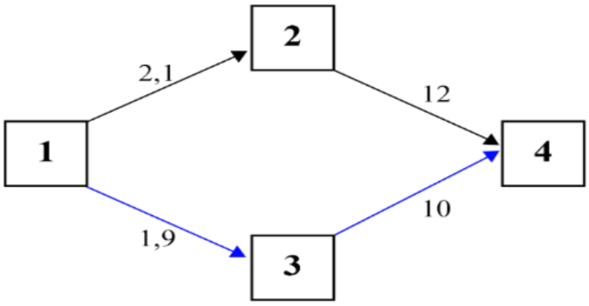

Fig. 6. Dump Truck Transport Line (BL *8063 F*)

The distance results obtained from Google Maps are totalled based on the route taken by the dump truck before and after being calculated using the dynamic programming method with data as in **Table 2**. This research will also discuss fuel costs before and after.

Table 2. Data on the route distance travelled before and after calculation.

Transportation number	Rute		Total Distances (Km)	
	Before	After	Before	After
BL 8051 F	1-2-5-6	1-2-4-6	21.1	19.7
BL 8065 F	1-2-4-6	1-2-5-6	14.7	13.9
BL 8050 F	1-2-4-6	1-2-5-6	16.3	15.7
BL 8461 JT	1-2-4-6	1-2-5-6	20.9	20.7
BL 8062 F	1-4-6-7	1-2-5-7	19.2	16.3
BL 8063 F	1-2-4	1-3-4	14.1	11.9

The following cost savings are obtained by comparing the routes run so far and those resulting from savings calculations. It is assumed that 1 litre of fuel can cover a distance of ± 8 km without obstacles. (Source: Interview Results with Dump Truck Driver, 2023).

Table 3. Amount of fuel used and costs.

Transportation number	Total fuel/*Shift* (litre)		Total cost (Rp./*Shift*)	
	Before	After	Before	After
BL 8051 F	10	9.3	51.500	47.895
BL 8065 F	10	9.4	51.500	48.410
BL 8050 F	10	9.3	51.500	47.895
BL 8461 JT	10	9.7	51.500	49.955
BL 8062 F	10	8.15	51.500	41.972
BL 8063 F	10	8.33	51.500	42.899

Savings obtained from Langsa City DLHK through route efficiency have been applied to vehicles with registration numbers BL 8051 F, 0.93%, BL 8065 F, 0.94%, BL 8050 F, 0.93%, BL 8461 JT, 0.97%, police no. BL 8062 F, 0.815%, and no. BL 8063 F, 0.833%. So, the total savings for day shifts reach 0.903%.

When determining a route, you need to pay attention to several things: the path, route, distance travelled, road conditions, transportation time, collection and transportation patterns, fleet age, and cost aspects. This is necessary to overcome obstacles faced in existing boundaries or conditions. Using the dynamic programming method, the Langsa City Environmental Service can design travel routes to the Langsa City FPS that efficiently minimize transportation costs and speed up waste disposal.

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4. Conclusion

Based on the analysis and discussion results, it can be concluded that the waste transportation route in Langsa City, which is implemented using the Dynamic Programming method, produces more effective and efficient performance. Dynamic programming is applied to transporting waste to the Langsa City Final Processing Site (FPS) by calculating the distance between each point on the route with the minimum distance through dynamic programming. Besides reducing distance, the dynamic programming method can also minimize fuel oil costs because the distance travelled is more efficient. Overall, the total savings for one shift for all vehicles reaches 0.903%.

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