Optimization of Waste Transportation Routes in Samarinda City using GIS-Based Network Analyst: Efficiency of Distance, Cost, and Vehicle Emissions

M. Ibnu Alfaridho[1*], Juli Nurdiana[1], Alvi Rahmawati[1], and Ndaru Widianto[1]

[1] Environmental Engineering, Faculty of Engineering, Mulawarman University, Samarinda, Indonesia
m.ibnualfaridho@layanamultiprana.com

Abstract. The increasing urban Population in Samarinda City has led to a rise in waste generation, creating significant challenges in managing waste transportation. Inefficient waste collection routes contribute to higher operational costs, increased travel distances, and elevated greenhouse gas emissions, all of which have adverse environmental and economic impacts. This study aims to analyze and enhance the efficiency of waste transportation routes using the Network Analyst method based on Geographic Information Systems (GIS). This method compares existing waste transportation routes with optimal routes generated from the analysis, considering distance, cost, and vehicle emissions. The data used in this study include current route information and relevant geographical and operational data. The analysis shows that this method reduces waste transportation route distances by 3.1%, lowers transportation costs by 13,31%, and decreases vehicle emissions by 11,14%. The study concludes that optimizing waste transportation routes using the G.I.S. approach improves operational efficiency and potentially reduces environmental impacts. These findings are expected to contribute significantly to more efficient and environmentally friendly waste transportation planning and management in Samarinda City.

Keywords: GIS, Network analysis, Route efficiency, Transportation, Waste.

1   Introduction

Waste management has become a primary focus in maintaining sanitation and public health. The level of waste in a region reflects the level of human activity. The higher the activity, the higher the amount of waste generated. Samarinda is the largest waste-producing city in East Kalimantan, with a significant annual increase. Based on data from the National Waste Management Information System (SIPSN), Samarinda's annual waste generation has risen sharply. In 2022, the waste generation was around 214,347.89 tons/year, but one year later, it increased by 2.75%, equivalent to 218,799.98 tons/year. This should be a severe concern for the local Government due to Samarinda's rapid rise in waste generation. According to Law No. 18 of 2008, the local

Government ensures proper and environmentally sound waste management. One of the Government's duties in handling and reducing waste is facilitating, developing, and implementing efforts to reduce, manage, and utilize waste

The increase in waste generation needs to be addressed seriously, especially in the waste transportation system. The higher the waste generation, the greater the transportation load for waste collection vehicles. One of the most significant issues in the waste transportation process in this city involves the relatively long distances between sub districts. Naturally, the farther the distance, the higher the transportation costs, primarily due to fuel consumption, which correlates with increased Greenhouse Gas (GHG) emissions per trip [1]. Collection costs can exceed 40% of the total waste management costs, although the expenses vary depending on Population size, density, geography, labour costs, and many other factors.

Meanwhile, vehicle emissions are also influenced by several factors, such as the type of truck, type of fuel, efficiency, and route characteristics [2]. Additionally, other factors that may impact the waste transportation system include traffic congestion, distance, labour (quantity and performance), and the number of Temporary Disposal Sites (TPS) [3]. The complexity of waste transportation problems in a region indicates the need to optimize a more efficient waste transportation system in Samarinda.

Studies on optimizing waste transportation routes have been widely conducted using various approaches such as heuristic methods, Dijkstra's algorithm, and mathematics-based approaches. A study conducted in Jakarta using the Vehicle Route Problem (VRP) method resulted in a 35.64% reduction in fuel costs and a 35.64% reduction in GHG emissions [3]. Meanwhile, research conducted in the United Arab Emirates (UAE), which applied a GIS-based shortest path algorithm for route optimization, achieved a 19% reduction in fuel costs [4]. Another study conducted in India using a GIS-based network analyst method in 13 selected districts, reduced travel distance by 9.93%, saving up to 22.72 million Indian Rupees, equivalent to IDR 4.2 billion per year [5].

Although several previous studies have demonstrated the benefits of using GIS. in route optimization, there still needs to be more debate regarding its effectiveness in various geographic and operational conditions. Moreover, this approach has yet to be widely applied in contexts like Samarinda, with unique topographical characteristics and waste distribution patterns. Therefore, with advancements in information technology, particularly GIS, the network analyst method could be a practical approach to designing more efficient transportation routes, as this method can identify routes with optimal distances using a service area facility approach [6]. GIS enables in-depth spatial analysis and provides more accurate route visualizations that align with field conditions. According to research by Sallem et al., applying the GIS-based network analyst method in waste transportation route management can reduce travel distances, lower operational costs, and decrease vehicle emissions [1].

The main objective of this research is to evaluate and optimize waste transportation routes in Samarinda using the GIS-based network analyst method and highlight its impact on distance efficiency, operational costs, and vehicle emissions. This study is expected to produce findings that will significantly contribute to policy-making in waste management while also providing a foundation for further research in this field.

2   Materials and Methods

2.1   Existing household waste management in Samarinda City

Samarinda is the city with the largest Population in East Kalimantan Province. According to the Badan Pusat Statistik (BPS), the Population of Samarinda in 2023 was 861,878 people. Additionally, the city has ten sub districts, with the highest Population density in Samarinda Ulu, reaching 6,027.62 people/km², while the most prominent sub district is Samarinda Utara, covering an area of 258.27 km². The responsibility for waste management in Samarinda falls under the Dinas Lingkungan Hidup (DLH), with the city's waste management infrastructure already in place. The Population of Samarinda is estimated to generate 599.45 tons of waste per day, and around 79.78% of the waste is managed.
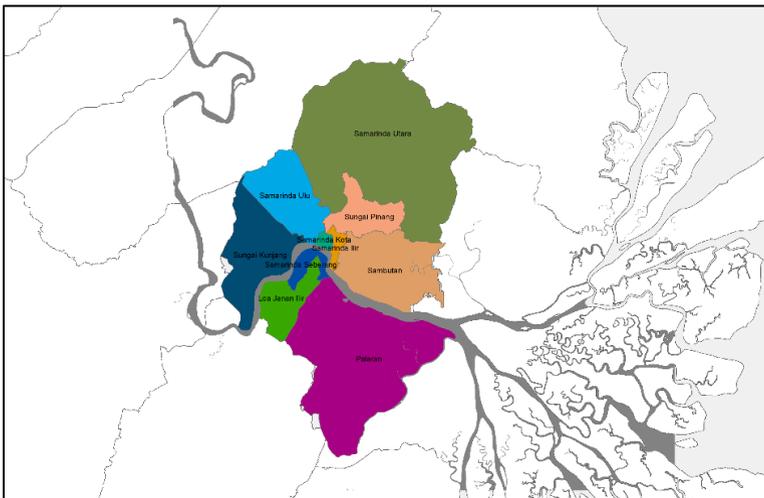

Fig. 1. Administrative Area Samarinda City

According to data from the DLH of Samarinda in 2023, there are 83 Temporary Disposal Sites (TPS) in the city, with the highest number located in Samarinda Ulu, totalling 18 TPS. Meanwhile, the waste transport collection in Samarinda consists of dump trucks (DT) and arm roll trucks, with 58 and 24 units, respectively. Samarinda waste collection operates in four different periods daily: from 06:00-12:00, 12:00-18:00, 18:00-24:00, and 24:00-06:00 WITA. Waste is sourced from local communities, and there are two ways to dispose of it at the TPS: directly and indirectly. Direct disposal means residents take their waste directly to the TPS.

In contrast, indirect disposal involves hiring a third party to transport the waste using carts, with an additional fee for waste collection services. Once the waste is collected, a team of 3-4 sanitation workers from the DLH. will collect the waste according to the set sch edule. The waste is transported using trucks or arm roll vehicles to the next TPS (if incomplete) or directly to the Final Processing Site (TPA).

2.2 Determination of Efficient Routes

Sallem et al. and Das et al. conducted studies on determining the shortest or most efficient routes using the GIS-based network analyst method [1, 6]. This research utilized ArcGIS version 10.8 software to assist in identifying the shortest and most optimal routes to the TPS. According to Adilang et al., in applying the network analyst method in ArcGIS, three main aspects are considered: route distance, nearest facility, and service area [7]. The results of this method include the calculation of the shortest route, the identification of the nearest facility, and the assessment and evaluation of the existing service area. Therefore, determining efficient routes requires comprehensive data, consisting of both primary and secondary data. Primary data is obtained through field surveys to collect the coordinates of the 83 TPS in Samarinda. Additionally, secondary data includes information such as the existing waste bin volume and details on the vehicles used, as shown in the following table:

Table 1. TPS Location and Cubication

Point	TPS	TPS Cubication (m³)
Sungai Kunjang		
SK01	TPS Perum Pemda (MT Haryono)	4
SK02	TPS depan DPRD Provinsi	54
SK03	TPS Pasar Kedondong	29
SK04	TPS Adam Malik	40
SK05	TPS Jalan Ir. Sutami	40
SK06	TPS Teuku Umar	34
SK07	TPS Perum Daksa	18
SK08	TPS Loa Bakung	72
SK09	TPS Jalan Ekonomi	16
Samarinda Seberang		
SS01	TPS bawah Jembatan Mahakam	34
SS02	TPS La Madu Kaleng (Jl. Hasanuddin)	20
SS03	TPS HOS Cokroaminoto	9
SS04	TPS TK Rajawali	12
SS05	TPS Daeng Mangkona	12
SS06	TPS Pasar Komura	20
Loa Janan Ilir		
LJ01	TPS SMAN 4 Seberang	20
LJ02	TPS Harapan Baru	19
LJ03	TPS Perum BPK	11
LJ04	TPS Kolong Mahulu	21
LJ05	TPS Perum H. Saleh	33
LJ06	TPS Tani Aman	8
Samarinda Ulu		
SU01	TPS samping DLH	16
SU02	TPS MAN 1	15
SU03	TPS Perumahan Graha Indah	12
SU04	TPS Jl. Ring Road II	17
SU05	TPS Bukit Pinang	9
SU06	TPS Pemancingan	9
SU07	TPS Jl. Samarinda-Tenggarong	12
SU08	TPS Folder	39
SU09	TPS Rujab Wawali	2
SU10	TPS Taman Cerdas	4
SU11	TPS Tri Sari	45

Point	TPS	TPS Cubication (m³)
SU12	TPS Anggur	28
SU13	TPS Batu Lumpang	6
SU14	TPS Juanda 2	25
SU15	TPS Siradj Salman	16
SU16	TPS Kuburan Pasundan	2
SU17	TPS Wahidin Sudirohusodo	8
SU18	TPS Kuburan Cina	8
Samarinda Kota		
SK01	TPS samping Balai Kota	4
SK02	TPS Jl. Dahlia (Lapangan tenis Balaik Kota)	4
SK03	TPS Jl. Milono	17
SK04	TPS Jl. Harmonika	40
SK05	TPS Perum TNI	2
SK06	TPS Jembatan Arief Rahman Hakim	29
SK07	TPS Jembatan Tempekong	16
SK08	TPS Jl. Pelabuhan	40
Samarinda Ilir		
SI01	TPS Kehewanan Gang I	24
SI02	TPS Jelawat	22
SI03	TPS Pasar Sungai Dama	25
SI04	TPS RS Islam (Jl. Kakap)	3
SI05	TPS Selili (Jl. Lumba-Lumba)	20
SI06	TPS Puskesmas GP (Jl. S. Alimmudin)	5
Sambutan		
SA01	TPS Gunung Manggah	9
SA02	TPS Pelita 4 Sambutan	26
SA03	TPS Arisco	
SA04	TPS Jl. Kapten Soedjono	8
SA05	TPS Pelita 7 (Perum Idaman Permai)	29
SA06	TPS Jl. Telkom	14
SA07	TPS Pelita 8	8
SA08	TPS Makroman	8
SA09	TPS Sindang Sari	9
SA10	TPS Jembatan Mahkota	16
Palaran		
PA01	TPS Gotong Royong	2
PA02	TPS Segara	19
PA03	TPS Pasar Palaran	12
PA04	TPS Samping Kel. Handil Bakti	2
PA05	TPS Peti Kemas	17
PA06	TPS Stadion Palaran	12
Sungai Pinang		
SP01	TPS Jalan Rajawali	48
SP02	TPS Jalan Pelita	65
SP03	TPS Jalan Gerilya	50
Samarinda Utara		
SUT01	TPS Kandang Sapi Jl. AWS	20
SUT02	TPS Jalan Batu Cermin	25
SUT03	TPS Jalan Padat Karya	18
SUT04	TPS Jalan Bayam 3	16
SUT05	TPS Jalan Pinang Seribu	9
SUT06	TPS PM Noor	65
SUT07	TPS Panjaitan II	45
SUT08	TPS Gunung Tangga	10
SUT09	TPS Gunung Kapur	20
SUT10	TPS Pasar Hewan	5
SUT11	TPS SMPN 19	3

The road network database is sourced from OpenStreetMap, which includes six different categories of traffic roads: arterial roads, collector roads, local roads, other roads, footpaths, and levees. It is important to note that this study focuses only on vehicle movement, so pathways like footpaths and levees are excluded. The results of the road network analysis used in this study need to be adjusted based on the findings of existing road conditions from field surveys. This adjustment is intended to ensure that optimizing waste transportation routes becomes more effective and that the proposed routes can be used without any obstacles.

Trip Calculation. In waste transportation management, one of the performance indicators is trip, which refers to the number of trips a waste collection truck makes to transfer waste from a TPS to a TPA. The trip is crucial for measuring operational efficiency and optimizing the use of the transportation fleet. The formula for calculating the trip is based on the ratio between the volume of waste at the TPS. and the capacity of the collection truck. Mathematically, the formula can be expressed as follows:

$$\text{Rit} = \frac{\text{Qw}}{\text{Qtr}} \tag{1}$$

where Rit is the number of the trip(s), Q_w is the waste cubication in Temporary Disposal (m^3), and Q_{tr} is the truck capacity (estimated about 8 m^3)

The formula above represents the equation to calculate the number of "trips" or repeated trips a waste collection vehicle makes in transporting waste. "Qw" refers to the volume of waste that needs to be transported from the TPS, while "Qtr" represents the maximum volume of waste that can be carried by truck in a single trip, which in this case has a maximum capacity of 8 m^3. Adjustments need to be made to account for the capacity of the waste collection truck and the waste volume at each TPS. The higher the waste volume at each TPS, the more required trips. This needs careful consideration due to the limited number of vehicles in Samarinda's fleet, which often results in the exact vehicle being operated on multiple routes. To overcome this limitation, ensure all routes are serviced.

Fuel Consumption. Fuel consumption is essential when managing waste transportation vehicle fleets to optimize operational costs. To determine how much fuel a vehicle uses on a given trip, a fuel consumption calculation formula can be applied, which takes into account the travel distance, average speed, and fuel consumption per hour.

$$F_{co} = \frac{s}{v} \times C_h \tag{2}$$

where F_{co} is the fuel consumption needed (L), v is the truck's velocity (km/h), s is the length of the distance (km), and C_h is the fuel consumption per hour (L/h)

The higher the speed of a dump truck or arm roll, the greater the fuel consumption. However, in other contexts, factors such as low speed also influence fuel consumption. At low speeds, fuel consumption tends to be high if the vehicle experiences friction resistance and inertia forces, such as in traffic where frequent stops occur but the engine remains running, and the vehicle is not moving efficiently (idle). Considering these factors, according to a study by Muqoddas et al., it can be assumed that a truck-type

vehicle consumes approximately 5.305 litres of fuel per hour when loaded (Ch) [8]. Additionally, it is assumed that the average speed of a medium-capacity truck (<10 m³) is around 24.26 km/h when loaded in urban areas [6].

Fuel Cost on Trip. In transportation operations, one significant component of costs is fuel expenses. To calculate the total fuel cost in one trip cycle, we must consider the fuel consumption per trip and the current fuel price. The following formula can be used to calculate the fuel cost:

$$Cost = F_{co} \times Rit \times F_{Cost} \tag{3}$$

where F_{co} is the fuel Consumption (L), Rit is the number of the trip by truck, and F_{cost} is the Fuel Cost Existing (Price = IDR 6.800,00).

The formula presented is the equation that calculates the fuel cost for each trip or trip of the waste collection vehicle. This formula calculates the fuel cost by multiplying the fuel consumption per trip by the number of trips and the fuel price per litre. The fuel cost represents the total fuel expense for each trip. Fuel consumption (L) refers to the fuel used in each trip. The fuel price (IDR/L) indicates the fuel per litre, which is IDR 6,800.00 (Pertamina price).

CO2 Emission Estimate. One of the critical components that must be calculated in calculating carbon emissions from fuel usage is Activity Data, which shows the total energy produced by fuel consumption, measured in terajoules (TJ). This calculation is necessary to assess the environmental impact, particularly the carbon dioxide (CO_2) emissions from fuel consumption. The formula for calculating the Activity Data from fuel consumption is as follows:

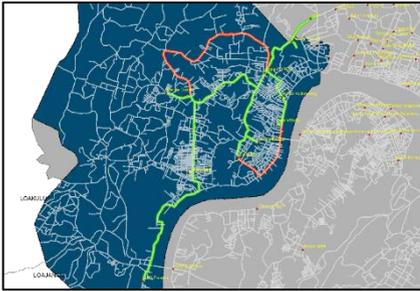$$DA_{Fuel} = F_{co} \times NCV \times \rho \times 10^{-6} \tag{4}$$

$$Emission\ CO_2 = DA_{Fuel} \times EF \tag{5}$$

where DA_{Fuel} is the data of truck's activity (TJ), F_{co} is the fuel consumption (kilo liter), NCV is the Net Calor Value (TJ/Gg Fuel) = 27 TJ/Gg, ρ is the fuel density (kg Fuel/m³) = 910 kg/m³, and EF   is the emission factor = 70.800 KgCO₂/TJ.

The formula estimates the CO_2 emissions from waste collection trucks' fuel consumption. This process involves converting fuel consumption into energy activity data, which is then multiplied by an emission factor to calculate the amount of CO_2 emissions produced. The formula is based on the 2006 IPCC standards, which focus on using biodiesel as an energy source.
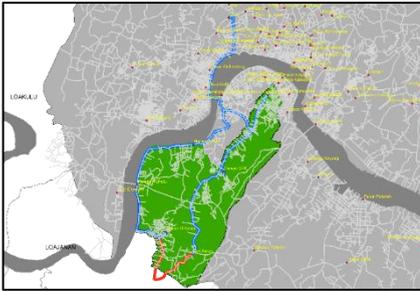
3   Results

The GIS network analyst analysis shows a significant difference between the existing travel distance and the analysis results. Overall, the analysis shows a reduction in waste transportation distance of 12.99 km compared to the existing conditions, equivalent to a 3.1% decrease.
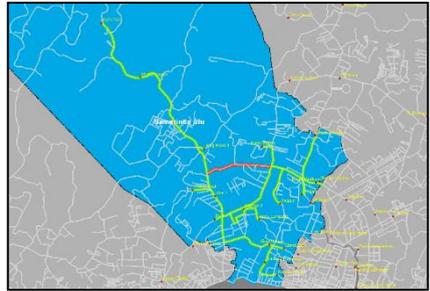
Existing Route : 24,5 km, Optimed Route :
23,3 km, distance reduced 1,2 km

(a)

Existing Route : 35,8 km, Optimed Route :
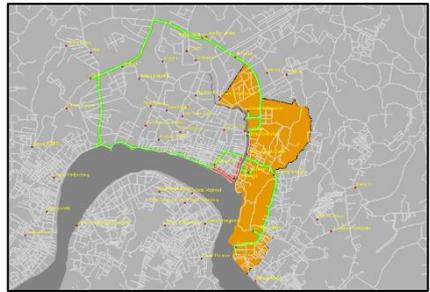32,1 km, distance reduced 3,7 km

(b)

Existing Route : 53,7 km, Optimed Route :
51,7 km, distance reduced -2 km

(c)

Existing Route : 35,9 km, Optimed Route :
4,5 km, distance reduced -1,4 km

(d)

Existing Route : 23,4 km, Optimed Route :
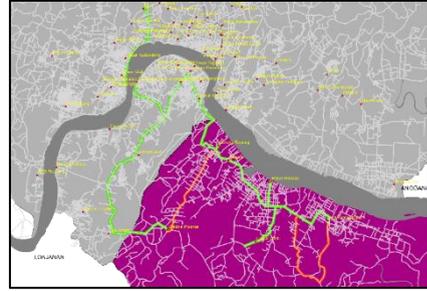20,9 km, distance reduced 2,6 km

(e)

Existing Route : 25 km, Optimed Route :
23,9 km, distance reduced 1,1 km

(f)

Existing Route : 55,6 km, Optimed Route : 50,9 km, distance reduced 4,7 km
(g)

Existing Route : 70,8 km, Optimed Route : 67,2 km, distance reduced 3,6 km
(h)

Existing Route : 73 km, Optimed Route : 73,5 km, distance reduced -0,5 km
(i)

Existing Route : 16,4 km, Optimed Route : 16,4 km, distance reduced 0 km
(j)

Fig. 2. (a) Sungai Kunjang; (b) Samarinda Seberang; (c) Loa Janan Ilir; (d) Samarinda Ulu; (e) Samarinda Kota; (f) Samarinda Ilir; (g) Sambutan; (h) Palaran; (i) Samarinda Utara; (j) Sungai Pinang

3.1   Efficiency of Distance

The green or blue road routes represent the routes from GIS. analysis, while the red road routes indicate the existing routes frequently taken by waste collection trucks. From the displayed image, the total waste transportation distance from the analysis is 397.73 km, which is more efficient than the existing transportation distance of 410.72 km.
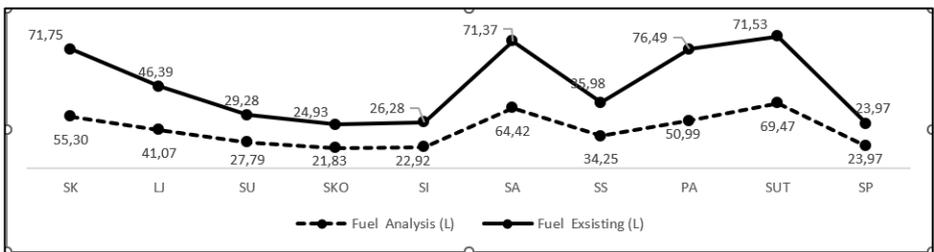
In Sungai Kunjang sub-District, the current waste transportation distance is 24.5 km, with the route passing through Jl. M.T. Haryono and Jl. Teuku Umar. However, the analysis results show a more efficient route with a distance of 23.3 km, reducing the distance by 1.2 km. There is a significant distance reduction in Samarinda Kota sub-District from the existing 23.44 km, which passes through Jl. Aminah Syukur, Jl. Pangeran Hidayatullah, and Jl. Pulau Flores, to 20.85 km, reducing the distance by 2.59 km. Sambutan sub-District's most considerable distance reduction is from 55.6 km via Jl. Sultan Sulaiman to 50.9 km via Jl. Lumba-Lumba, a reduction of 4.7 km. However, this route is only accessible in one direction. In Samarinda Seberang sub-District, the distance is reduced from 35.78 km to 32.08 km, a reduction of 3.7 km, with the route

passing through Jl. Bung Tomo and Jl. Sultan Hasanuddin. In Samarinda Ilir sub-District, the transportation distance was originally 25 km via Jl. Muso Salim and Jl. Jelawat, which can be shortened to 23.9 km, resulting in a 1.1 km reduction. Meanwhile, the waste transportation distance was 70.8 km via Jl in Palawan sub-District. Simpang Pasir, Jl. Ampera, and Jl. Peti Kemas is reduced to 67.2 km, saving 3.6 km.
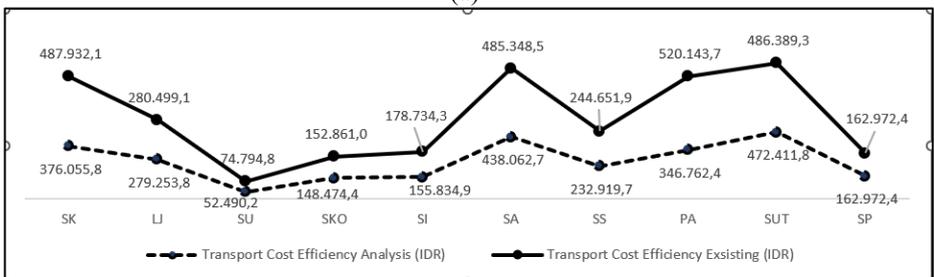
In contrast, in Loa Janan Ilir sub-District, the analysis shows that the transportation distance is longer than the existing route through Jl. Cipto Mangunkusumo and Jl. H.A.M.M Rifaddin. In Samarinda Ulu sub-District, the existing route via Jl. Suryanata and Jl. Juanda, which is 34.5 km, increases to 35.9 km, adding 1.4 km. In Samarinda Utara sub-District, the distance increases from 73 km to 73.5 km, although this 0.5 km increase is relatively small, possibly due to improved accessibility on routes like Jl. Pangeran Suryanata and Jl. Poros Samarinda-Bontang. Meanwhile, in Sungai Pinang sub-District, the distance between the existing and analyzed conditions remains the same, with the distance remaining at 16.4 km via Jl. D.I. Panjaitan and Jl. Gerilya, indicating that the current route is already efficient.

3.2 Fuel Consumption Efficiency, Operating Costs and CO_2 Emission Reduction

Based on the analysis of waste transportation's distance efficiency in several sub districts of Samarinda, there is potential for fuel savings that can contribute to operational efficiency and reduced carbon emissions. The reduction in distance indicates that the analysis results can provide greater efficiency in terms of time and operational costs for waste transportation and lower environmental impact due to the reduction in emissions.
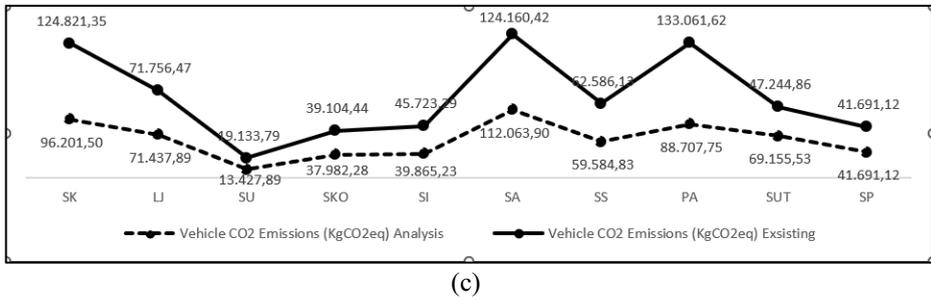
(a)

(b)

124.821,35

71.756,47

124.160,42

133.061,62

2.586,1

7.244,86

39.104,44   45.723

41.691,12

96.201,50   9.133,79   112.063,90

71.437,89

88.707,75

69.155,53

13.427,89   37.982,28   39.865,23   59.584,83

41.691,12

| SK | LJ | SU | SKO | SI | SA | SS | PA | SUT | SP |

- - ● - - Vehicle CO2 Emissions (KgCO2eq) Analysis   — ● — Vehicle CO2 Emissions (KgCO2eq) Exsisting

(c)

Fig. 3. (a) Fuel efficiency; (b) Transport cost efficiency; (c) Vehicle emmission per year

This study conducted a fuel efficiency analysis to optimize waste transportation in Samarinda City by comparing the existing conditions with the optimization results. The findings show that most sub districts experienced a reduction in fuel consumption after optimization, such as in Sungai Kunjang sub-District, where it decreased from 71.75 L to 55.30 L. In Palaran, from 76.49 L to 50.99 L. Overall, fuel consumption decreased from 477.98 L in the existing conditions to 412.02 L, resulting in savings of 13.8%. The sub district with the highest fuel consumption was Samarinda Utara, while the lowest was Samarinda Kota.

The data in the table presents the results of an analysis related to transportation cost efficiency and annual CO_2 emissions in several sub districts of Samarinda. In the analysis scenario, transportation costs and annual CO_2 emissions significantly reduce compared to existing conditions. Overall, total transportation costs in the existing conditions reach IDR 1,122,129,390 per year, while the analysis results indicate that these costs can be optimized to IDR 972,811,915. This reflects a transportation cost efficiency of 13.31%. This reduction suggests that the optimization, primarily through selecting more efficient transportation routes, has successfully reduced transportation expenses in the area.

In addition to cost efficiency, reducing carbon dioxide emissions is also a key focus. Based on the estimated CO_2 emissions data, the existing conditions generate 258,888,473.52 KgCO2eq annually. However, with the analysis and optimization, emissions can be reduced to 229,993,037.40 KgCO2eq per year, representing an 11.14% reduction. This decline in emissions demonstrates that environmental impact reduction strategies have been implemented, such as using more eco-friendly modes of transportation or reducing travel frequency. Overall, this data shows a significant improvement in transportation cost efficiency and carbon dioxide emission reduction. The optimization measures taken have successfully reduced operational costs and environmental impact.

4   Discussion

This research successfully optimized the waste collection route from the existing condition by minimizing the travel distance by 3.1%. The route optimization was carried out in six sub districts of Samarinda City, namely Sungai Kunjang, Samarinda Kota,

Sambutan, Samarinda Seberang, Samarinda Ilir, and Palaran, all of which experienced a reduction in travel distance. However, in three other sub districts, the optimization results showed an increase in travel distance compared to the initial condition.

The increase in distance is due to the limitations of the network analyst method used. This method must account for traffic obstacles such as congestion and road width, so a shorter route is not necessarily efficient in natural conditions. Therefore, route selection must consider traffic flow and road access width, supported by field reviews, to achieve optimal results. In this context, the shortest route is sometimes the best, primarily if on-site conditions do not support smooth travel. In Sungai Pinang sub district, there was no change in distance because the existing route was already efficient, indicating that the current route may be optimal in some cases and does not require adjustments.

The optimization of waste collection routes not only reduces travel distance but also directly impacts the reduction of the waste management budget. With more efficient routes, fuel consumption decreases, contributing to significant savings in operational costs and thus reducing the budget burden allocated by the local Government for waste management programs.

According to the 2023 Regional Government Work Plan (RKPD) the budget for Samarinda City's waste management program, managed by the DLH, reached IDR 5.1 billion. The most significant waste collection cost is attributed to vehicle fuel, accounting for 27.45% [9]. In this study, route optimization can reduce fuel consumption by 13.8%, equivalent to saving 65.96 L of fuel. This fuel savings translates to a 13.31% reduction in fuel costs, or approximately IDR 149,317,476, significantly lowering operational expenses and positively impacting the local Government's budget.

Meanwhile, the savings from the budget can be allocated to other sectors to enhance waste management efficiency in Samarinda City. One option is to invest in additional assets, such as containers. The higher operational costs of dump trucks compared to armroll trucks make this an important consideration in future waste collection system planning [10]. The selection of containers is considered due to the high frequency of trips required at each TPS, driven by the large volume of waste. The larger the waste volume at the TPS, the more trips are needed. This makes waste collection with dump trucks less effective, requiring more trucks for each round.

From an environmental perspective, the results of this study show that route optimization positively impacts reducing GHG emissions. According to Wati et al., a comparison of waste collection using diesel fuel, CNG, biomethane, and pneumatic systems shows that diesel-fueled waste collection trucks have the most significant environmental impact, particularly in terms of CO_2 emissions, which significantly contribute to GHG emissions [11]. Considering that the transportation sector consumes around 42% of global energy, it is a significant contributor to GHG emissions, accounting for one-third of the total emissions in the energy sector [12, 13].

The impact of air pollution caused by GHG emissions is severe for human health. According to a study Greenstone & Fan, air pollution globally reduces Life Expectancy (LE) by an average of 2.2 years, with an increase of 3-4% in Southeast Asia, particularly in major cities [14]. The decrease in LE due to air pollution is more significant than the adverse effects of smoking, alcohol consumption, contaminated water, HIV/AIDS, and malaria. Therefore, efforts to reduce fuel consumption and cut GHG emissions by up

to 11.14% through route optimization lower operational costs and environmental impacts and improve public health and quality of life. If this route optimization is fully implemented, it will provide long-term economic, health, and environmental benefits. This will create multiplier effects, including significant budget savings and improved environmental quality through the sustainable reduction of GHG emissions.

5   Conclusions

This study successfully optimized waste collection routes, leading to a 3.1% reduction in travel distance across six sub districts in Samarinda City. This optimization resulted in a 13.8% decrease in fuel consumption, saving 65.96 liters, and a 13.31% reduction in budget costs, equivalent to approximately IDR 149,317,476. Additionally, the 11.14% reduction in GHG emissions supports ongoing environmental sustainability efforts in Samarinda. The operational cost savings can be reinvested in more effective measures, strengthening the waste management system to be more environmentally friendly and sustainable. This route optimization also has the potential to reduce GHG emissions that negatively impact human health, ultimately improving the overall quality of life. Hopefully, this solution can be widely adopted to enhance public welfare through more efficient and sustainable waste management practices.

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