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Route analysis of waste transportation vehicles in urban areas using the saving matrix method

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Abstract: The increase in population in Indonesia, particularly in the city of Makassar, will be followed by an increase in the volume of waste generated. Tamalate District, as part of Makassar City, has a waste generation volume of 583 m^3/day, requiring waste management to be addressed through waste collection services to handle the amount of waste produced. This study identifies the existing conditions of tangkasaki truck service routes to obtain data on service locations, number of vehicles, travel distance, travel time, and operational costs. The identification shows that there are 37 waste disposal sites served by 11 trucks at night, but the waste transportation is considered inefficient due to the underutilization of vehicle capacity. This study aims to optimize waste transportation routes with using the saving matrix method by maximizing vehicle capacity. The saving matrix method is used to evaluate fleet requirements on existing routes by considering vehicle capacity, working time, and predetermined fuel consumption. The research results show that proposed routes with the implementation of the saving matrix method can reduce the number of tanker truck fleets from 11 units to 9 units. The efficiency of travel distance is 21.7%, previously 294.4 km/day reduced to 230.4 km/day. The efficiency of travel time is 8.9%, previously 2,063 minutes/day reduced to 1,880 minutes/day by maximizing the working time of each service route and operational cost efficiency within one month of service is 22.6%, previously IDR 99,330,000.00 reduced to IDR 76,900,320.00.

1 Introduction

The swift expansion of urbanization and population, coupled with industrial and material transformations, has led to a crisis in urban solid waste management, particularly in developing countries, as a major challenge to sustainable developmen [1]. South Sulawesi Province is ranked 9th as the province with the largest population in Indonesia. Tamalate District is one of the sub-districts in Makassar City [2]. According to data from the Makassar City Environmental Service, Tamalate District is the sub-district with the second highest volume of waste generation (583 m3/day). In implementing the waste problem, the number of facilities and infrastructure for transporting waste in Tamalate District can be said to be sufficient to overcome the volume of waste generated every day. From the results of observations, the number of waste transportation fleets in Tamalate District is divided into several types of vehicles and different service assignment routes. Tamalate District has a fleet of 99 VIARs, 15 tangkasaki trucks, 10 barge trucks and 11 waste container units. This research focuses on the Tangkasaki truck .

Planning efficient waste transportation routes and schedules is the most important thing in improving the waste transportation system. Selecting a vehicle route will determine the total distance traveled by the fleet. So, the optimal route is the goal of determining the waste collection route by getting the shortest possible route from WDS (Waste Disposal Site) to FDS (Final Disposal Site) with as few obstacles as possible. In its implementation, considering the real conditions in the field, there are many factors that can influence the waste transportation process so that it is not optimal [3]. Several factors that influence the waste transportation process include inefficient use of working time, inappropriate use of vehicle load capacity, inefficient transportation routes, the volume of waste piled up at each WDS, the behavior of officers , and poor accessibility [4].

Waste collection heavily relies on route optimization, which demands substantial investments in capital, labor, and variable operational expenses. As collection routes become more efficient, both costs and environmental impacts decrease [5]. Traditional waste management systems, which typically follow fixed schedules and predetermined routes, often suffer from inefficiencies. This method may cause collection vehicles to make unnecessary trips to bins that are not yet full, leading to increased traffic congestion and higher operational expenses. Moreover, these inefficiencies contribute to greater fuel consumption and higher greenhouse gas emissions [6].

One method to obtain the shortest route with maximum waste the capacity is determined using the saving matrix method combined with the nearest neighbor approach. This method involves identifying the sequence of distribution routes to be followed and determining the number of transport vehicles required based on their capacity. A key feature of the saving matrix method is its ability to schedule a limited number of vehicles while considering the maximum capacity of both similar and different types of vehicles. Additionally, this method applies merging points in a single step and takes vehicle capacity into account throughout the process [7].

This research focuses on determining the existing condition of the waste transportation service route in Tamalate District based on vehicle capacity and the number of tangkasaki truck fleets as well as determining the optimal transportation route and number of fleets on the waste transportation service route in the Tamalate District area based on route determination using the method of saving matrix.

2 Literature review

2.1 *Route optimization*

Traditional methods for optimizing freight delivery routes mainly focus on minimizing costs based on distance. Newer approaches, however, also aim to minimize time as an objective. Despite this, the relationship between time and distance is not always straightforward, and the trade-off between the two can be complex [8]. Waste transportation is one of the several benefits of optimal routes, which is why they are necessary. Waste collection is an essential part of the waste management system, and the costs involved in this procedure account for a large amount of the total cost of disposing of waste [9]. The primary goals of optimizing waste collection routes are to minimize the total route length by selecting the shortest path that covers all destinations, reduce travel time to visit all locations, and keep costs as low as possible to maximize overall benefits [10]. Many site selection techniques have evolved alongside research on waste collection routes and solution algorithms. To maximize the efficiency of the waste collecting operation, an algorithm is needed rather than following a predetermined path [11].

The optimal route is closely linked to vehicle routing problems. The Vehicle Routing Problem (VRP) is a crucial problem in combinatorial optimization that entails determining the optimal set of routes a fleet of vehicles should travel in order to serve a particular customer group [12]. Significant advancements have been made in the techniques used to model and solve both standard and capacity VRPs, as well as their various variants. Researchers and practitioners have developed more efficient and precise solution algorithms, along with improved models, enabling them to address large-scale problems more effectively [13].

The relationship between time and distance is not always straightforward. It's evident that relying solely on distance or time functions doesn't yield the most realistic or optimal outcomes. When there is no traffic congestion, distance and time are perfectly correlated. In such cases, the route optimized for distance will also be the same as the one optimized for time, and both will match the route where all costs are minimized. However, when factors like congestion, fluctuating demand, accidents, or road repairs come into play, the results from these different optimization methods will diverge [8]. This limited coordination has been a factor for inefficient planning of services and infrastructure which includes facility location, allocation of communities, medical referrals, and land transportation [14].

2.2 *Nearest neighbour*

Using a random example, the performance of the Variable Neighbourhood Search (VNS) method is assessed in relation to our problem [15]. Neighbor set models are designed to handle incomplete, imprecise, and uncertain data. These models have found applications in various fields, including anomaly detection and data classification. However, many existing neighbor models struggle with inappropriate neighborhood radius selection and lack of adaptability. To address this, an improved k-nearest neighbor model is proposed, where the distance serves as the k-nearest neighborhood radius, leading to more accurate granulation results and a more effective anomaly detection model [16].

Nearest neighbor-based approaches are well-established strategies that continue to be used because of their effectiveness [17]. The customer nearest to the first one visited is the next one on the route, and so on, until every customer is on the path [18]. The following steps are involved in applying the Nearest Neighbour algorithm: To ensure that the total number of requests in the current route does not exceed the vehicle's capacity (Q), we start at the depot and visit exactly one client (vertex) from each cluster. The procedure is repeated from the depot and the closest unvisited client from any unvisited cluster is selected next if the total number of requests in the current route above the vehicle capacity. This keeps going until every cluster has been visited; after then, the algorithm stops. The end result is a collection of routes, each of which has precisely one client from every cluster in the order that they were accessed [19]. The Nearest Neighbor algorithms are straightforward to implement and fast to execute, but their greedy approach can sometimes result in missing shorter, more optimal routes. The specific steps of the Nearest Neighbor algorithm are detailed in [20]:

1. A starting vertex will be selected at random.
2. The edge that joins the current vertex to an unvisited vertex with the smallest weight will be chosen.
3. Vertex V represents the current vertex V.
4. Vertex V has a visited mark.
5. After visiting every vertex in the domain, the procedure will end.

2.3 Saving Matrix

One method for determining the best paths for product delivery to marketing regions is the Saving Matrix. In order to ensure the shortest routes and reduce transportation costs, it entails figuring out the necessary routes and the number of vehicles based on their capacity. The deployment of vehicles from facilities with different maximum capacity is also planned using the Saving Matrix approach [21]. Steps for using the saving matrix method:

1. Constructing the distance matrix can be done using Google Earth application, Google Maps, or manual calculations with a speedometer.
2. Creating the savings matrix involves merging two potential WDS into a single truck to optimize distance, time, and transportation costs. If S(x,y) represents the distance saved—such as in a route from the central starting point → point x → 14 point y → back to the center—then the equation to determine the savings amount is:

$$S(x,y) = Dist(Pusat,x) + Dist(Pusat,y) - Dist(x,y) \qquad (1)$$

3. Allocate WDS to a transportation route. The first step is that each WDS is allocated to a different truck or route. The second step is to combine the two routes based on the largest distance savings obtained using equation (1) and checking whether the combination is feasible or not. It is said to be feasible if the total shipments that must be passed via that route do not exceed the capacity of the transport equipment. Route combinations are focused on saving the greatest distance in order to obtain distance efficiency, so that the time traveled will be faster. Checking the total amount of shipments via a route is done by looking at the distance between the largest savings. What is done after selecting the distance with the greatest savings is to add up the WDS pairs that have the greatest savings so that it can be seen that the route is less than or equal to the capacity of the transport equipment.
4. Sorts WDS on a route, at this stage the aim is to minimize the travel distance that each means of transport must travel. To obtain optimal transportation routes, two stages can be carried out, namely determining the initial delivery route for each vehicle using the Nearest Neighbor procedure and making improvements to routes that are not feasible.

3 Methodology

This research is a quantitative research utilizing historical data. The time of the research was carried out in October - November 2023 and the object of this research was the waste transportation service route in Tamalate sub-district, Makassar City. The data sources consist of both primary and secondary data.. Primary data is data obtained directly from observations and interviews with parties involved in waste transportation service activities in Tamalate District, Makassar City to formulate research problems. In contrast, secondary data refers to information not directly collected by the researchers but obtained through intermediaries or documentation related to waste transportation service activities in the Tamalate District, Makassar City.

3.1 Service route tangkasaki truck

The problems that exist in transporting waste in the Tamalate District area, especially on the Tangkasaki truck service route. The main cause of determining existing service routes that are not optimal is due to the large number of service location points and not maximizing vehicle capacity on each route based on the transport volume of each truck. This causes the total distance traveled, total travel time and operational costs to be high. So we will determine the optimal route and evaluate the needs of the Tangkasaki truck fleet using a combination of saving matrix and nearest neighbor methods. The use of the saving matrix method begins by determining the distance matrix that connects the FDS and each WDS. Next, the largest savings value is calculated and it will be allocated to a new route taking into account vehicle capacity. Allocation into a route will be combined with the nearest neighbor procedure to get a more optimal solution from the previously formed route by prioritizing the closest neighbors on the route to be visited. The proposed route using the saving matrix method is known to provide work and service efficiency in the waste transportation process in the Tamalate District area. The first step is determine the location of WDS use the coordinates of the existing Tangkasaki truck route as in Table 1.

Table 1 The coordinates of the existing Tangkasaki truck route

Truck number	Route	WDS Code	Coordinate		Volume WDS (m^3/day)	Total (m^3/day)
			Latitude	*Longitude*		
011	I	A1	5°10'21.51"S	119°25'54.86"E	3.04	8.10
		A2	5°10'4.09"S	119°25'54.46"E	1.89	
		A3	5°10'6.56"S	119°25'46.70"E	1.49	
		A4	5°10'18.93"S	119°25'43.63"E	0.96	
		A5	5°10'24.20"S	119°25'47.37"E	0.72	
023	II	B1	5°10'19.63"S	119°25'38.21"E	1.02	10.04
		B2	5°10'21.86"S	119°25'14.37"E	2.77	
		B3	5°10'14.54"S	119°25'7.57"E	3.18	
		B4	5°10'5.90"S	119°25'15.84"E	3.07	
148	III	C1	5°10'2.73"S	119°25'11.11"E	2.06	10.95
		C2	5°10'1.11"S	119°25'7.60"E	0.78	
		C3	5°10'10.80"S	119°25'2.91"E	2.89	
		C4	5°10'15.55"S	119°24'50.35"E	1.59	
		C5	5°10'9.92"S	119°24'48.39"E	1.56	
		C6	5°10'6.27"S	119°24'59.90"E	2.07	
047	IV	D1	5°10'24.81"S	119°24'56.82"E	3.67	8.51
		D2	5°10'39.06"S	119°24'49.65"E	1.32	
		D3	5°10'30.74"S	119°25'0.08"E	3.52	
012	V	E1	5°10'52.51"S	119°24'57.47"E	1.96	12.22
		E2	5°10'52.33"S	119°24'46.55"E	2.47	
		E3	5°10'54.41"S	119°24'34.00"E	1.77	
		E4	5°10'43.86"S	119°24'44.40"E	2.56	
		E5	5°10'48.91"S	119°25'0.79"E	2.51	
		E6	5°10'54.84"S	119°25'7.85"E	0.95	
156	VI	F1	5°10'42.41"S	119°24'24.42"E	3.39	8.24
		F2	5°10'39.85"S	119°24'19.15"E	2.85	
		F3	5°10'46.74"S	119°24'21.53"E	2.00	
167	VII	G1	5°10'7.38"S	119°24'5.00"E	3.78	6.77
		G2	5° 9'59.14"S	119°24'17.04"E	2.99	
021	VIII	H1	5°10'58.15"S	119°26'25.20"E	5.98	5.98
		X1	5°10'57.72"S	119°25'57.82"E	10.5	10.50
166	IX	I1	5°11'13.85"S	119°25'52.26"E	5.74	5.74
		X1	5°10'57.72"S	119°25'57.82"E	10.5	10.50
074	X	J1	5°11'11.98"S	119°25'32.28"E	1.74	8.70
		J2	5°11'24.14"S	119°24'51.06"E	3.56	
		J3	5°11'5.50"S	119°24'51.27"E	3.40	
054	XI	K1	5°11'4.33"S	119°25'21.17"E	3.18	8.07
		K2	5°10'41.91"S	119°25'35.03"E	4.89	

The volume of waste generated at the WDS in each Tangkasaki truck service route is based on the results of observations of the average waste generation per service route. So it can be assumed that the volume of waste generated every day at each WDS is the same. Meanwhile, determining the size of the waste volume from each waste source at the WDS is the result of brainstorming between the author and the head of the cleanliness section of Tamalate District as in table 1. Based on the coordinate data of 37 WDS points shown in table 1, it will be visualized into 11 service routes marked with different colors using Google Maps. The existing route of the Tangkasaki truck in Tamalate District is shown in Figure 1.

Figure 1 Existing Route of Tangkasaki Truck

Mileage is calculated based on the total distance from the depot (FDS) to each service route (WDS) and back to the depot (FDS). Calculation of distance traveled using the get directions feature on Google Earth. Based on the results of the interview, the route that must be taken from the FDS back to the FDS must be within the Makassar City area. Data on the distance traveled from the existing Tangkasaki truck route in Tamalate District is shown in the Table 2. The fuel consumption of Tangkasaki trucks can also be seen in Table 2 with the assumption that the average fuel consumption of each truck can reach 5 km/liter. The fuel allowance is given because the average actual fuel consumption per truck is 7.5 liters/day. In providing services, each Tangkasaki truck is given a fuel allowance of 7.5 liters/day. So, in one day of service the total fuel consumption of all Tangkasaki trucks in Tamalate District is 82.5 liters/day. If it is assumed that the price of diesel is IDR 6,800.00 per liter, then the fuel costs are IDR 561,000.00 per day or IDR 16,830,000.00 per month assuming 1 month, namely 30 days.

3.2 Distance traveled and fuel consumption on existing route

Mileage is calculated based on the total distance from the depot (FDS) to each service route (WDS) and back to the depot (FDS). Calculation of mileage using the get directions feature on Google Earth. Based on the results of the interview, the route that must be taken from the FDS back to the FDS must be within the Makassar City area. Data on the distance traveled from the routes of Tangkasaki trucks in Tamalate District is shown in Table 2.

Fuel consumption on the existing Tangkasaki truck route in Tamalate District is known based on the results of interviews with truck drivers. The average fuel consumption of each truck can reach 5-6 km/liter, which is because during service the truck engine must remain idling or in conditions such as stop and go and is also influenced by the weight of the waste load. So, it can be assumed that the fuel consumption of a Tangkasaki truck is 5 km/liter. Actual fuel consumption is obtained from the total distance traveled by each truck divided by fuel consumption per liter. This has absolutely no effect on the fuel allowance given because the average actual fuel consumption per truck is <7.5 liters/day and it shown in Table 2.

Table 2 Distance traveled and fuel consuption on the existing Tangkasaki truck route

Truck Code	Route	Route Flow	Mileage (km/day)	Fuel Consumption (liters/day)
011	I	FDS -A1-A2-A3-A4-A5-FDS	24.8	4.96
023	II	FDS -B1-B2-B3-B4- FDS	22.2	4.44
148	III	FDS -C1-C2-C3-C4-C5-C6- FDS	25.4	5.08
047	IV	FDS -D1-D2-D3- FDS	24.3	4.86
012	V	FDS -E1-E2-E3-E4-E5-E6- FDS	27.0	5.4
156	VI	FDS -F1-F2-F3- FDS	27.9	5.58
167	VII	FDS -G1-G2- FDS	30.7	6.14
021	VIII	FDS -H1-X1- FDS	28.2	5.64
166	IX	FDS -I1-X1- FDS	27.2	5.44
074	X	FDS -J1-J2-J3- FDS	28.7	5.74
054	XI	FDS -K1-K2- FDS	28.0	5.6
Total			**294,4**	**58.88**

Travel time is calculated based on two aspects, namely the total time during the journey from and back to the landfill and the time required for loading and unloading the waste from the landfill into the truck. Travel time greatly influences the working time of workers (drivers and maids) which has been set at 4 hours (240 minutes). Working hours are determined outside of the time for waste disposal at the landfill due to the large queue of rubbish trucks so it takes a long and uncertain time. Travel time data from the existing route for each tangkasaki truck in Tamalate District is shown in the Table 3.

Table 3 Travel time on the existing Tangkasaki truck route

Truck Code	Route	t_{bm}	$t_{FDS-WDSa}$	$t_{WDSt-FDS}$	t_{total}
011	I	98	26	31	155
023	II	127	27	25	179
148	III	186	29	29	244
047	IV	115	29	28	172
012	V	149	32	30	211
156	VI	126	34	34	194
167	VII	63	38	36	137
021	VIII	153	32	29	214
166	IX	95	32	29	156
074	X	175	35	35	245
054	XI	93	32	31	156
Total					**2063**

t_{bm} : Loading and unloading time (minutes/day)
$t_{FDS-WDSa}$: Travel time from FDS /landfills to WDS /temporary shelter (minutes/day)
$t_{WDSt-FDS}$: Travel time from WDS /temporary shelter to FDS /landfills (minutes/day)
t_{total} : total time (minutes/day)

Based on the travel time data for the existing route shown in table 3, it is known that the Tangkasaki trucks with codes 148 and 074 exceeded the specified working time limit. This is because the condition of WDS C4 and C6 on the route served by the Tangkasaki 148 truck has to reach the last road section that borders Mamajang District, so the truck has to turn around and continue to WDS C5.

3.3 Operational costs of existing route

The operational costs of Tangkasaki trucks in Tamalate District are divided into fuel costs (diesel) and workers' salaries (drivers and maids). From the results of the interview, each truck received a fuel allowance of 15 liters for two days of transportation service. So it is assumed that one day each truck gets 7.5 liters of fuel. Meanwhile, workers' salaries are divided into basic salary and daily wages for the driver and two garbage collector. The calculation of the total costs incurred in one month for workers' salaries is an assumption if in one full month (30 days) all workers have carried out their duties and obligations Salary data for Tangkasaki truck workers in Tamalate District is shown in table 4. One truck have one driver and 2 garbage collector.

Table 4 Salaries of existing route

Type of Worker	Amount	Basic salary (per month)	Daily salary (per month)	Total (per month)
Truck Driver	11	IDR1,000,000.00	IDR 50,000.00	IDR 82,500,000.00
Garbage collector	22			

From the calculation results between worker salaries and fuel costs incurred, the expenditure for operational costs in one month can be seen in Table 5, which shows a total cost of IDR 99,330,000.00 per month.

Table 5 Total cost

Cost	Total Cost (per month)
Salaries	IDR 82,500,000.00
Fuel	IDR 16,830,000.00
Operasional Cost	**IDR 99,330,000.00**

4 Results and discussion

4.1 Savings matrix proposed route

Data processing is carried out using the saving matrix method and combined with the nearest neighbor algorithm to obtain a more optimal solution from the existing route as in Table 6. The result of using a saving matrix is to combine two routes based on saving the distance from the largest until all points have been combined. It can be calculated using equation (1) and checking the feasibility of the combination so that it does not exceed the truck capacity.

Table 6 Allocation of WDS to truck routes

Truck	Route Combine	*Saving*
1	A1B2	19.1
1	A1A5	18.8
1	A1B1	18.1
1	A1A2	18
1	A1A3	18
1	A1A4	18
2	H1I1	8.8
3	G1G2	4.6
4	C1C2	3.9
5	F1F2	3.7
5	F1F3	3.7
4	C1C3	3.3
6	J2J3	3
4	B3B4	2
7	D1D2	1.7
7	D1E4	1.6
7	D1E1	1.6
7	D1E2	1.5
8	E5E6	1.5
8	J1K1	1.5
6	J3K2	1.2
3	C4C5	1.1
3	C4C6	1.1
5	E3F1	1
8	D3J1	0.5

The final step is to sort the WDS that have been combined on a route. In ordering WDS hat have been merged, you can use the nearest neighbor procedure to determine the initial transportation route at each WDS. Apart from considering vehicle capacity, when sorting routes, travel time (<=240 minutes) and fuel usage (<=7.5 liters) will also be considered. The following is a proposed route for a combination of saving matrix and nearest neighbor which is shown in Table 7.

Table 7 The proposed route is a combination of saving matrix and nearest neighbor

Rute	Alur Rute	WS	DT	TT	FC
I	FDS-A1-A2-A3-A4-A5-B1-B2- FDS	11.89	24.4	216	4.88
II	FDS -I1-H1- FDS	11.72	24.0	235	4.80
III	FDS -C4-C5-C6-G2-G1 - FDS	11.99	30.4	197	6.08
IV	FDS -C1-C2-C3-B3-B4- FDS	11.98	23.0	229	4.60
V	FDS -E3-F1-F2-F3- FDS	10.01	27.1	207	5.42
VI	FDS -K2-J2-J3- FDS	11.85	26.5	237	5.30
VII	FDS -D1-D2-E1-E2-E4- FDS	11.98	25.5	207	5.10
VIII	FDS -D3-E5-E6-K1-J1- FDS	11.90	26.3	238	5.26
IX	FDS -X1- FDS	10.50	23.2	114	4.64
Total		**103.82**	**230.4**	**1880**	**46.08**

WS = Waste volume (m3/day),
DT = Distance traveled (km/day),
TT = Travel time (minutes/day),
FC = Fuel consumption (liters/day).

The calculation results show that the waste transportation service routes in Tamalate District can be eliminated into 9 routes. Each route will be served by one truck, so there is a reduction of 2 trucks from the existing route of 11 trucks to 9 trucks on the proposed route. This of course takes into account the volume of waste transportation which must not exceed the capacity of the vehicle, the travel time which must not exceed the specified working hours of 4 hours (240 minutes) and the fuel consumption which must not exceed the daily allowance (<7.5 liters/ day).

4.2 Distance traveled and fuel consumption on route saving matrix

Based on the results of data processing, a proposed route is obtained with a total distance that can be reduced linearly with a reduction in fuel consumption. The following is a table of distance traveled and reduction in fuel consumption for the proposed route using the saving matrix shown in Table 8.

Table 8 Distance traveled and fuel consumption

Truck Code	Route	Mileage (km/day)	Fuel Consumption (liters/day)
I	FDS -A1-A2-A3-A4-A5-B1-B2- FDS	24.4	4.88
II	FDS -I1-H1- FDS	24.0	4.80
III	FDS -C4-C5-C6-G2-G1- FDS	30.4	6.08
IV	FDS -C1-C2-C3-B3-B4- FDS	23.0	4.60
V	FDS -E3-F1-F2-F3- FDS	27.1	5.42
VI	FDS -K2-J2-J3- FDS	26.5	5.30
VII	FDS -D1-D2-E1-E2-E4- FDS	25.5	5.10
VIII	FDS -D3-E5-E6-K1-J1- FDS	26.3	5.26
IX	FDS -X1- FDS	23.2	4.64
Distance Total		**230.4**	**46.08**

Actual fuel consumption for the route proposed by the saving matrix method is 46.08 liters/day. This shows that the average truck fuel consumption does not exceed the allotted allowance of 7.5 liters/day. So, fuel costs can follow the proposed actual fuel consumption. If it is assumed that the price of diesel is IDR 6,800.00 per liter, then the fuel costs are IDR 313,344.00 per day or IDR 9,400,320.00 per month assuming 1 month, namely 30 days.

Table 9 Travel time on the existing Tangkasaki truck route

Route	t_{bm}	$t_{FDS-WDSa}$	$t_{WDSt-FDS}$	t_{total}
I	164	22	30	216
II	186	27	22	235
III	132	28	37	197
IV	178	27	24	229
V	146	30	31	207
VI	182	25	30	237
VII	151	27	29	207
VIII	179	28	31	238
IX	62	26	26	114
Total				**1,880**

t_{bm} : Loading and unloading time (minutes/day).
$t_{FDS-WDSa}$: Travel time from FDS / landfills to WDS /temporary shelter (minutes/day).
$t_{WDSt-FDS}$: Travel time from WDS /temporary shelter to FDS /landfills (minutes/day).
t_{total} : total time (minutes/day).

4.3 *Operational costs of route saving matrix*

The reduction in the number of trucks also has a positive impact on operators and drivers, thereby reducing costs. Previously, 11 trucks were used and the final result of the proposed route was 9 units. This is linear with the number of workers and fuel consumption. The fewer vehicles used, the less labor costs must be paid, and the fewer waste transport vehicles used, the less fuel used. Salaries and total cost can be seen in Table 10 and Table 11, which show the total operational costs consisting of salary costs and fuel costs. The total operational cost for the optimized 9-truck route is IDR 76,900,320.00 per month, which is a reduction from the previous operational costs.

Table 10 Salaries of existing route

Type of Worker	Amount	Basic salary (per month)	Daily salary (per month)	Total (per month)
Truck Driver	9	IDR1,000,000.00	IDR 50,000.00	IDR 67,500,000.00
Garbage collector	18			

Table 11 Total cost

Cost	Total Cost (per month)
Salaries	IDR 67,500,000.00
Fuel	IDR 9,400,320.00
Operasional Cost	**IDR 76,900,320.00**

4.4 *Comparison of existing routes and proposed saving matrix routes*

The proposed route using the saving matrix method will compare the existing route with the proposed route in terms of fleet number, distance traveled, travel time and operational costs. The following is a comparison table of the total distance traveled by Tangkasaki truck waste transportation services from the existing route and the proposed route using the saving matrix method. Comparison of existing routes and proposed saving matrix routes in terms of fleet number, distance traveled, travel time and operational costs is shown in table 12 below.

Table 12 Comparison of existing routes and proposed saving matrix routes

	Existing Route	Proposed Route	Difference	Efficiency
Number of truck (unit)	11	9	2	18.0%
Distance Traveled (km/days)	294.4	230.4	64	21.7%
Travel time (menit/days)	2063	1880	183	8.9%
Operasional Cost (per month)	IDR 99,330,000.00	IDR 76,900,320.00	IDR 22,429,680.00	22.6%

The comparison between the existing route and the proposed route showcases the efficiency gains achieved through route optimization. As shown in the Table 12, the number of trucks required is reduced from 11 to 9, representing an 18.0% efficiency improvement. The distance traveled per day also decreased by 64 km, a 21.7% reduction, while the travel time decreased by 183 minutes per day, an 8.9% improvement.

The most significant impact is seen in the operational cost, which decreased from IDR 99,330,000.00 per month for the existing route to IDR 76,900,320.00 per month for the proposed route, a 22.6% reduction. This cost savings can be attributed to the decreased number of trucks, reduced fuel consumption, and lower labor costs associated with the optimized route.

The findings from this analysis demonstrate the substantial benefits that can be achieved through the implementation of the saving matrix method for optimizing waste transportation routes in urban areas. Management should consider adopting this approach to enhance the efficiency and cost-effectiveness of their waste management operations. By reducing the number of trucks, distance traveled, and travel time, companies can not only achieve significant cost savings but also contribute to reduced environmental impact and improved resource utilization. The insights gained from this study can guide managers in making informed decisions about fleet management, route planning, and resource allocation to drive operational excellence and maximize the overall performance of their waste transportation systems

5 Conclusions

Comparison of existing routes and proposed routes using the saving matrix method. The number of Tangkasaki truck fleets was successfully reduced by maximizing vehicle capacity from 11 trucks to 9 trucks. The total distance travelled for the proposed route using the saving matrix method produces an efficiency of 21.7%. The total travel time results in an efficiency of 8.9%. The results of the proposed route using the saving matrix succeeded in reducing travel time disparities and maximizing the working time set by the sub-district, namely 4 hours (240 minutes). The operational costs of the proposed route using the saving matrix method produce an efficiency of 22.6%. Operational costs can be streamlined due to a reduction in the truck fleet which has an impact on reducing the workforce, namely 2 drivers and 4 maids. Apart from that, fuel costs were successfully reduced because the actual fuel consumption of each Tangkasaki truck was obtained.

Future research potential can be concentrated on developing predictive models to optimize waste transportation routes by considering variables such as varying waste volumes and external factors such as traffic congestion. In addition, the application of big data and artificial intelligence technologies can be explored to improve operational efficiency in predicting fleet needs and vehicle capacity utilization in real-time. Research can also include environmental impact analysis of optimized routes, including the potential for carbon emission reduction in waste management in urban areas.

References

[1] MOJTAHEDI, M., FATHOLLAHI-FARD, A.M., TAVAKKOLI-MOGHADDAM, R., NEWTON, S.: Sustainable vehicle routing problem for coordinated solid waste management, *Journal of Industrial Information Integration*, Vol. 23, No. 10, pp. 1-44, 2021.

[2] BADAN PUSAT STATISTIK (BPS RI): *Sulawesi Selatan Dalam Angka Tahun* 2023, BPS Provinsi Sulawesi Selatan, Makassar, 2024. (Original in Indonesian)

[3] SLAMET, R.: Perbaikan Pengelolaan Sampah di Indonesia, *Inovasi*, Vol. 21, No. 14, pp. 19-22, 2009. (Original in Indonesian)

[4] RIDHA, M.R., ABDI, C., MAHYUDIN, R.P.: Studi Optimasi Rute Pengangkutan Sampah Kota Marabahan dengan Sistem Informasi Geografis, *Jukung Jurnal Teknik Lingkungan*, Vol. 2, No. 2, 2016. (Original in Indonesian) https://dx.doi.org/10.20527/jukung.v2i2.2310

[5] HANNAN, M.A., AKHTAR, M., BEGUM, R.A., BASRI, H., HUSSAIN, A., SCAVINO, E.: Capacitated

vehicle-routing problem model for scheduled solid waste collection and route optimization using PSO algorithm, *Waste Management*, Vol. 71, pp. 31-41, 2018. https://doi.org/10.1016/j.wasman.2017.10.019

[6] NEMATOLLAHI, H., GITIPOUR, S., MEHRDADI, N.: Comparative life cycle assessment and route optimization modeling of smart versus conventional municipal waste collection: Environmental impact analysis in an urban context, *Results in Engineering*, Vol. 24, No. 11, pp. 1-14, 2024. https://doi.org/10.1016/j.rineng.2024.103408

[7] INDRAWATI, N., ELIYATI, N., LUKOWI, A.: Penentuan Rute Optimal pada Pengangkutan Sampah di Kota Palembang dengan Menggunakan Metode Saving Matrix, *Jurnal Penelitian Sains*, Vol. 18, No. 3, pp. 105-110, 2016. (Original in Indonesian)

[8] ÁLVAREZ, P., SERRANO-HERNANDEZ, A., LERGA, I., FAULIN, J.: Optimizing freight delivery routes: The time-distance dilemma, *Transportation Research Part A: Policy and Practice*, Vol. 190, No. 10, 104283, pp. 1-12, 2024. https://doi.org/10.1016/j.tra.2024.104283

[9] ABDALLAH, M., ADGHIM, M., MARAQA, M., ALDAHAB, E.: Simulation and optimization of dynamic waste collection routes, *Waste Management & Research*, Vol. 37, No. 8, pp. 793-802, 2019.

[10] CHENG, X., et al.: Optimizing rural waste management: Leveraging high-resolution remote sensing and GIS for efficient collection and routing, *International Journal of Applied Earth Observation and Geoinformation*, Vol. 135, No. 10, 104219, pp. 1-13, 2024. https://doi.org/10.1016/j.jag.2024.104219

[11] ISLAM, R., RAHMAN, M.S.: *An ant colony optimization algorithm for waste collection vehicle routing with time windows, driver rest period and multiple disposal facilities*, 2012 International Conference on Informatics, Electronics & Vision (ICIEV), pp. 774-779, 2012. https://doi.org/10.1109/ICIEV.2012.6317421

[12] TOTH, P., VIGO, D.: *Vehicle Routing: Problems, Methods, and Applications*, 2nd Edition, Philadelphia: SIAM, 2014.

[13] GOLDEN, B.L., RAGHAVAN, S., WASIL, E.A.: *The Vehicle Routing Problem: Latest Advances and New Challenges*, Springer, New York, 2008. https://doi.org/10.1007/978-0-387-77778-8

[14] PEREZ-BALBOA, I.C., CABALLERO-MORALES, S.O., SANCHEZ-PARTIDA, D., CANO-OLIVOS, P.: Design of logistic criteria to establish healthcare facilities in vulnerable regions in Mexico, *Acta logistica*, Vol. 10, No. 2, pp. 251-265, 2023. https://doi.org/10.22306/al.v10i2.457

[15] PAK, Y.J., MUN, K.H.: A practical vehicle routing problem in small and medium cities for fuel consumption minimization, *Cleaner Logistics and Supply Chain*, Vol. 12, No. 7, 100164, pp. 1-11, 2024. https://doi.org/10.1016/j.clscn.2024.100164

[16] CHEN, X., YUAN, Z., FENG, S.: Anomaly detection based on improved k-nearest neighbor rough sets, *International Journal of Approximate Reasoning*, Vol. 176, No. 11, 109323, pp. 1-19, 2025. https://doi.org/10.1016/j.ijar.2024.109323

[17] ZAFRA, A., GIBAJA, E.: Nearest neighbor-based approaches for multi-instance multi-label classification, *Expert Systems with Applications*, Vol. 232, No. 6, 120876, pp. 1-14, 2023. https://doi.org/10.1016/j.eswa.2023.120876

[18] FITRIANI, N.A., PRATAMA, R.A., ZAHRO, S., UTOMO, P.H., MARTINI, T.S.: *Solving capacitated vehicle routing problem using saving matrix, sequential insertion, and nearest neighbor of product 'X' in Grobogan district*, AIP Conference Proceedings, Vol. 2326, 2021. https://doi.org/10.1063/5.0039295

[19] RAND, G.: The life and times of the Savings Method for Vehicle Routing Problems, *ORiON*, Vol. 25, No. 2, pp. 125-145, 2009. https://doi.org/10.5784/25-2-78

[20] ALSALIBI, B.A., JELODAR, M.B., VENKAT, I.: A Comparative Study between the Nearest Neighbor and Genetic Algorithms: A revisit to the Traveling Salesman Problem, *International Journal of Computer Science and Electronics Engineering*, Vol. 1, No. 1, pp. 34-38, 2013.

[21] POP, P.C., ZELINA, I., LUPSE, V., SITAR, C.P., CHIRA, C.: Heuristic algorithms for solving the generalized vehicle routing problem, *International Journal of Computers, Communications & Control*, Vol. 6, No. 1, pp. 158-165, 2011. https://doi.org/10.15837/ijccc.2011.1.2104

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