Predicting of The Transportation Solid Waste Cost in the Alang-alang Lebar Sub-District, Palembang City

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ABSTRACT

The transportation subsystem of the MSW management system is responsible for collecting and transporting waste. Waste transportation costs are a significant factor for urban waste management systems. Therefore, research will be carried out regarding the study of waste transportation costs. This paper aims to look at transportation costs, daily travel times, and routes in the Alang-alang Lebar environment. The methodology used in this research is a survey and observation that refers to SNI 19-3964-1994, SNI 19-2454-2002, and SNI 03-3243-2008. The research variables reviewed were the volume of waste and the transportation time carried out by dump trucks for 7 consecutive days. The total transportation time by dump truck in Alang-alang Lebar District ranges from 5.45 - 10.27 hours/day with total transportation costs per day ranging from IDR 3,618.0 - IDR 3,751.7/km. The total cost of transporting waste by dump truck in Alang-alang Lebar District daily is IDR 576,904.8 or IDR 49,372.1/m^3.

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1. INTRODUCTION

Rising levels of solid waste generated in cities as a result of population increase, urbanization, and economic expansion raise severe concerns about public health, environmental degradation, and shortages of resources. Due to the inherent contaminants which represent a major threat to human health, ecosystems, soil, water, and the atmosphere, efficient and prompt management of solid waste throughout cities is essential [1]. In order to manage municipal solid waste (MSWM), waste must be produced, separated, stored, collected, transferred, and transported. Providing citizens with an effective system that takes into account factors like route design, collection schedules, infrastructure, bad roads, and the amount of waste collection vehicles is a difficulty. [2- 4]. The cost of collection and transportation for low-income and middle-income countries amounted to 50-90% of the MSWM budget, which makes it difficult to develop an integrated waste management system [5, 6]. Ineffective solid waste collection and transportation will have a significant negative impact on management organizations by raising operating costs and subsequently lowering profit. If developing countries are to achieve sustainable solid waste management, waste collection and transportation costs must be reduced. Other researchers agree with this claim and assert that the lack of funding, resource

constraints, users' unwillingness to pay, and improper use of economic instruments all make it more difficult to provide proper solid waste collection and disposal services [7,8].

Due to a lack of land in metropolitan centers and growing public concern about potential human health risks that from these facilities, remote regional treatment plants and sanitary landfills have arisen in MSWM systems in recent years. As a result, the traditional MSWM system structure has changed as a result of the development of longer transit routes between already-existing and newly-added facilities. As a result, the relevance of transportation, a key component of MSWM systems, has increased. This is because vehicle trips are becoming longer and more frequent [9,10]

The technical aspects of MSWM disposal are further complicated by the complexity of the transportation network, growing awareness of the environmental costs, and practical restrictions that frequently govern where processing facilities should be located, where waste streams come from, what can be recycled, and how difficult it is to manage transportation. The transport methods system's primary source of pollution and environmental issues, transportation management presents a considerable optimization challenge in and of itself [10]. Transportation is a sub-system in a MSWM management system for collecting and transporting waste from the source to the temporary collection point, to waste treatment facilities or to the final disposal or landfill directly [11,12]. When a waste collection and disposal transportation system is modeled, numerous realistic restrictions are frequently overlooked due to the increasing complexity of MSW management. For instance, heterogeneous fleets of waste transportation trucks are prevalent, but few studies take into account the fleet's fluctuating capacity, speed, fuel consumption, cost, emissions, and other aspects. By optimizing the transportation travel distances, transport costs, fuel consumption and time could be saved, thus ensuring a safe and economically sustainable MSWM [10, 13-17].

Palembang is a developing city with a variety of low- and middle-income residents, as well as varying levels of solid waste generation. The majority of the waste produced in Palembang City is made up of organic materials. To determine the types of waste and rubbish generation at the household scale, numerous research on waste management in Palembang City has been conducted. Waste trucks with schedules and routes to serve collecting points are used in this city's waste collection system [18-20]. In earlier studies, Sarino et al. [22] and Putri et al. [21] investigated the movement of solid waste in Palembang's Seberang Ulu sub-district. Transportation time was defined by Sarino et al. [22] as the sum of the pickup time, travel time, and number of trips made within a given day. Hauled Container Systems (HCS) and Stationary Container Systems (SCS) are used by the specified transport systems. According to the study's findings, an armroll truck requires an average of 2.88 hours per day to transport waste through one cycle, and 2.28 cycles on a daily average. In contrast, the average number of trips made by dump trucks each day is 1,475 trips, taking an average of 4.77 hours to complete each trip. Using samples collected from the 4 sub-district sites under consideration, Putri et al.'s [21] study of waste transportation estimates in the Seberang Ulu Area of Palembang City. Armroll trucks and dump trucks, each with seven and nineteen units, were among the waste transportation methods examined. According to the investigation's findings, Armroll truck activity analysis determined that one ritation typically lasts 2.72 hours and that an average of 3 ritations occur each day. IDR 13,433.68 per m^3 per day is the needed operating expense for the armroll truck. As a result of analyzing the activities of dump trucks, it was discovered that one ritation lasts, on average, 4.77 hours and that there are 2 ritations every day with operating cost is IDR 25,400.1 per m^3 per day.

To promote the sustainability of MSWM, it is crucial to analyze the cost components of the waste transportation system, taking into account the descriptions and literature studies from earlier researchers. Only the Seberang Ulu area of Palembang City has been the subject of research on waste transportation costs analysis; Seberang Ilir has not been included. Seberang Ilir is at the core of Palembang City, making it possible to conduct more waste management operations there. The

investigation of solid waste transporting costs in the Alang-alang Lebar sub-district will be done in order to complete the information regarding waste transportation costs. With a population of 126,207, the Alang-alang Lebar sub-district is a development area of Palembang City, making understanding of the waste transportation system in this area important.

2. METHODS

The research location is in Alang-alang Lebar sub-district of Palembang city and can be seen in Figure 1. The transportation waste was focused only on 3 unit dump trucks that serve the temporary collecting point (TCP) in Alang-alang Lebar sub-district. The survey and observation methods were used in this study to get the actual data for 7 consecutive days.

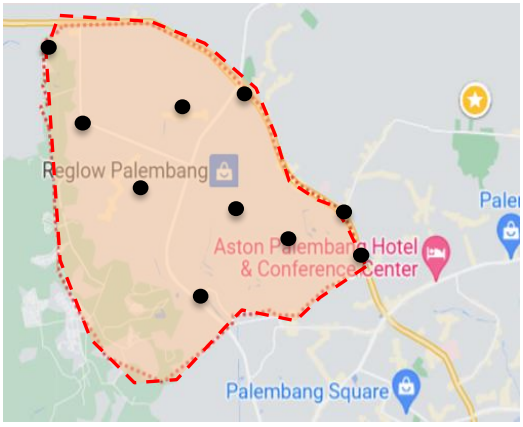

Figure 1. Alang-alang Lebar sub-district location

The data taken is the transport time, distance traveled and volume of solid waste at each TCP [4, 17]. The distance measurement uses GPS while the measurement of solid waste volume uses the SNI 19-3964-1994 method. Calculation of total transport time (Ttotal) using the reference SNI 19-2454-2002 and SNI 03-3243-2008 by modifying some of the formulas that presented in the equation below:

$$T_{total} = t_1 + (Ct \times uc) + dbc + h + s + t_2 \quad (1)$$

$$T_{distance} = T_{total} - s - (Ct \times uc) \quad (2)$$

Where:

t_1 = the average time from pool to TCP (hour)
t_2 = the average time from landfill to pool (hour)
h = the average time from TCP to landfill and from landfill to TCP (hour)
Ct = the number of containers that take out the trash (unit)
uc = the average time of emptying containers (hour)
dbc = the average time between TCP locations (hour)
s = the average time in landfill (hour)
T_{total} = total transport time (hour)
$T_{distance}$ = the average time when truck is moving (hour)

The solid waste transportation costs can be calculated using a regression equation that has been developed by Pacific Consultants International (PCI). The equation depends on the average speed of the vehicle which is calculated per 1000 km. The PCI regression equation can be seen in the equation below:

Cost1 : Fuel consumption

$$Y = (0.0627\ V^2 - 7.06130\ V + 318.3326) \text{ x fuel prices /liter} \quad (3)$$

Cost2 : engine oil consumption

$$Y = (0.00048\ V^2 - 0.05608\ V + 3.07383) \text{ x price of lubricant /liter} \quad (4)$$

Cost3 : tire usage

$$Y = (0.0011553\ V - 0.0059333) \text{ x tire prices /unit} \quad (5)$$

Cost4 : parts maintenance costs

$$Y = (0.0000191\ V + 0.0015400) \text{ x truck prices} \quad (6)$$

Cost5 : mechanical costs

$$Y = (0.01511\ V + 1.2120\ V) \text{ x cost/hour} \quad (7)$$

Cost6 : overhead costs

$$\text{overhead costs} = 10\% \text{ from sub total} \quad (8)$$

Figure 2 illustrates the data processing steps used to determine the cost of transportation. The process of computation begins by determining the truck's distance traveled before calculating the total time (Ttotal) needed for the truck to travel from the pool to its starting location. To calculate the truck's velocity while transporting trash, use the results of this calculation.

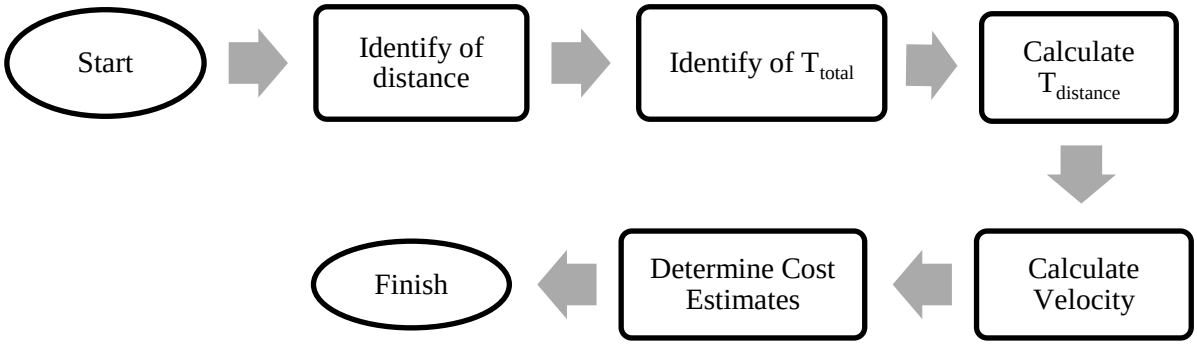

Figure 2. Data processing and analysis

3. RESULTS AND DISCUSSION

At the location of the study, solid waste transportation activities were carried out starting at 06.00 AM where the officers headed to the temporary collection point location with their respective duties (Figure 3). Figure 3 illustrates the collection operation performed on one of the TCPs using the

supplied basket. Waste officers require time to transfer waste from the trash container to the trash truck.


Figure 3. Collecting of waste in the location

Table 1. Temporary Collection Point (TCP)

Code	Location of TCP	Vol. (m^3)	Quantity (unit)	Distance to Landfill (km)
C1	Jln. Kol Burlian	6	1	9.4
C2	Km5 pos 6	6	1	8
C3	Terminal AAL	6	1	10.8
C4	Griya Hero	6	1	8.8
C5	SMP N 54	6	1	7.9
C6	Talang Kelapo	6	1	14
C7	Jln. Sultan Mahmud Badarudin	6	1	7.9
C8	Hero	6	1	10.6
C9	Jl. Soekarno Hatta	6	1	13.5
C10	Grand City	6	1	13.7
	Average			10.46

Table 1 shows the number of temporary collection points served are 10 units with a capacity of 6 m^3. The average distance to landfill is 10.64 km with the farthest distance of 13.7 km and the closest distance is 7.9 km. Table 2 shows the routes on each truck where TrukA has the longest route than the other trucks with a total distance of 58.76 km, while TrukB has the shortest route than the other trucks with a total distance of 47.75 km. The total distance is calculated from the poll to the temporary collection point to the landfill and back to the poll.

Table 2. The truck transportation routes

Truck Name	Route	Total Distance (km)
TrukA	X – C1 – C2 – Y – C3 – C4 –C5 – Y – X	58.76
TrukB	X – C6 – C7 – Y – X	47.75
TrukC	X – C8 – C9 – C10 – Y – X	50.63
	Average	52.38

Note: X= poll, Y = landfill

The quantities of waste in the solid waste collected at the temporary collection station has been measured. The volume of waste in each TCP varies significantly every day, with an average volume of waste of 3.59 m^3 per day, as shown in Table 3's analysis of solid waste volume over an average of

seven days. C7 has the highest average waste volume at the temporary collection site, 4.74 m^3, while C3 has the lowest average waste volume, 3.04 m^3. TrukA, TrukB, and TrukC each handle an average volume of waste of 16.29 m^3, 9.27 m^3, and 10.37 m^3, respectively.

Table 3. The result of solid waste volume measurement for 7 days

Truck name	TCP	Volume (m^3) Day							Average (m^3)	Total (m^3)
		1	2	3	4	5	6	7		
TrukA	C1	2.3	3.1	2.2	5	2.8	4.5	4	3.41	16.29
	C2	2.1	2	2.4	2	3.2	5.4	6	3.30	
	C3	1.8	1.7	4.2	3.1	3	2	5.5	3.04	
	C4	2	2	3.4	4.2	6	2	4	3.37	
	C5	2.6	1.5	2.2	3	2.5	6	4.3	3.16	
TrukB	C6	5.1	3.2	5.4	3	3	6	6	4.53	9.27
	C7	4.5	6	2.3	6	6	3.4	5	4.74	
TrukC	C8	2.1	4.1	3.5	1.5	4.1	5.1	6	3.77	10.37
	C9	1.8	1.8	6	1.8	3.2	3	6	3.37	
	C10	2	2.5	2.6	3.1	2.2	4.7	5.5	3.23	
Average									3.59	

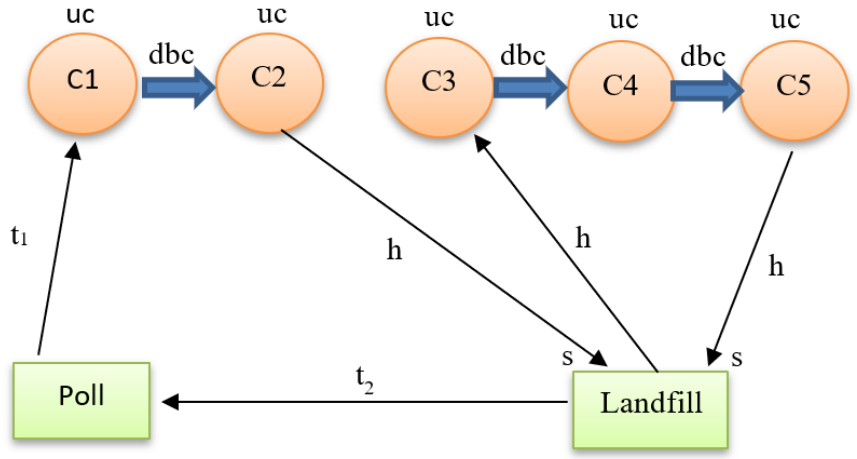

Figure 4. An example of how to calculate the overall transport time for TrukA

Figure 4 shows how the overall travel time in TrukA was calculated. TrukA collects waste from C1 and C2, transports it to a landfill, then travels to C3, C4, and C5 before returning to the landfill. The vehicle returns to the poll after removing the solid waste from the dump. According to Figure 4, the following formula represents the overall travel time for TrukA, TrukB, and TrukC:

T_{total} of TrukA = t_1 + (Ct x uc) + (3 x dbc) + (3 x h) + (2 x s) +t_2

T_{total} of TrukB = t_1+ (Ct x uc) + (1 x dbc) + h + s +t_2

T_{total} of TrukC = t_1 + (Ct x uc) + (2 x dbc) + h + s + t_2

Table 4 shows the results of the calculation of the total transport time for each truck. In Table 4 it can be seen that the largest total transport time is TrukA of 4.18 hours because the truck has a very long transport route. Whereas TrukB has a total transport time of 2.74 hours because the truck has a very short route. Time at landfill (s) is the longest time than at other times, this is caused by waiting for loading and unloading of waste at landfills.

Table 4. The result of solid waste transport time (hour)

Truck name	t_1	t_2	h	Ct	uc	dbc	s	T_{total}	$T_{distance}$
TrukA	0.51	0.7	0.84	5	0.55	0.15	1.67	10.27	4.18
TrukB	0.67	0.41	1.44	2	0.47	0.22	1.77	5.45	2.74
TrukC	0.85	0.55	1.32	3	0.67	0.3	1.45	6.78	3.32

The truck's travelling time is computed by combining the time spent at the landfill (s) and the time required for waste collection (Ct x uc), places where the truck is stationary. Calculating the truck's average velocity is important in order to determine the cost using the PCI approach. Table 5 shows the results of dividing the distance traveled by the truck by its travel time to determine its average velocity.

Table 5. Average velocity of truck

Truck name	Total distance (km)	$T_{distance}$ (hour)	Average velocity (km/hour)
TrukA	58.76	4.18	14.06
TrukB	47.75	2.74	17.43
TrukC	50.63	3.32	15.25

Table 6. The total cost of solid waste transportation (/km/day)

Truck name	Average velocity (km/hour)	Cost1 (IDR)	Cost2 (IDR)	Cost3 (IDR)	Cost4 (IDR)	Cost5 (IDR)	Cost6 (IDR)	Total cost (IDR/km/day)
TrukA	14.06	2,268.3	513.6	16.5	296.6	194.1	328.9	3,618.0
TrukB	17.43	2,100.3	739.8	22.7	307.1	240.6	341.1	3,751.7
TrukC	15.25	2,207.2	588.0	18.7	300.3	210.5	332.5	3,657.3

After getting an average velocity in accordance with the total transport time, then the transportation costs of using the PCI method could be estimated. Table 6 shows the calculation of the total cost for each section which starting from Cost1 to Cost6. TrukB has the largest total cost than the others truck which has IDR 3,751.7/km/day, while TrukA has the minimum total cost. Table 7 shows the results of the calculation of transport costs associated with the volume of waste transported. TrukB has the largest transportation cost per m^3 of IDR19,493.2/day while TrukA has the smallest transportation cost per m^3 of IDR12,557.2/day. This is influenced by the amount of waste and also the distance traveled by each truck, thus resulting in different costs. The average daily transportation cost for each truck is IDR192,301.6 while the average cost per m^3 is IDR16,457.4/day. So that the total cost of transporting solid waste in the Alang-alang Lebar sub-district especially dump trucks is IDR576,904.8/day or IDR49,372.1 /m^3/day.

Table 7. The total cost of solid waste transportation (/m^3/day)

Truck	Total distance (km)	Waste Volume (m^3)	Total cost (IDR/km/day)	Total cost (IDR/km/m^3/day)	Total cost (IDR/day)	Total cost (IDR/m^3/day)
TrukA	58.76	16.93	3,618.0	213.7	212,594.1	12,557.2
TrukB	47.75	9.19	3,751.7	408.2	179,142.1	19,493.2
TrukC	50.63	10.69	3,657.3	342.1	185,168.6	17,321.7
			Average		192,301.6	16,457.4
			Total		576,904.8	49,372.1

A comparison between the estimated waste transportation costs and the findings from previous research is shown in Table 8. The analysis carried out for the current study is different from previous research in that it calculates travel time, which influences the estimated transportation costs. Analysis of cost estimate results for other types of trucks may vary according to this table. The estimated number of daily trips and the average daily distance determine the final cost. This differs from the Alang-Alang Lebar District area where Putri et al. [21] conducted their research, Seberang Ulu District area is much further from the landfill. However, the route is shorter because more trucks are serving Seberang Ulu. On the other hand, because fewer vehicles are in the Alang-alang Lebar area, the distance traveled by trucks is greater, thus expanding the service area for one truck.

Table 8. Comparison of the results of waste transportation cost estimates

No.	Comparison	Putri et al. [21]	Current Study
1	Year of study	2018	2023
2	Cost calculation method	PCI	PCI
3	Calculation travel time method	SNI 03-3243-2008	Observation of overall transport time
4	Type of Transportation	Dump truck and Armroll truck	Dump truck
5	Number of truck	Dump truk = 19 unit Armroll truck = 7 unit	Dump truk = 3 unit
6	Ritations per day	Dump truck = 2 Armroll truck = 3	Dump truck = 2
7	Average distance	Dump truck = 42.79 km Armroll truck = 105.7 km	Dump truck = 52.38 km
8	Cost calculation results	Dump truck = IDR 25,400.1 per m^3 per day Armroll truck = IDR 13,433.68 per m^3 per day	Dump truck = IDR 16,457.4 per m^3 per day

4. CONCLUSION

The transportation of solid waste has been successfully studied in the Alang-alang Lebar subdistrict. The Alang-alang Lebar sub-district's solid waste transportation infrastructure, in particular the three dump trucks that serve 10 temporary collection stations with an average waste volume of 3.59 m^3/day. Dump truck travel duration varies from 5.45 to 10.27 hours per day, while daily travel costs range from IDR 3,618.0 to IDR 3,751.7/km. In the Alang-alang Lebar District, the daily cost of moving solid waste by dump trucks is IDR 576,904.8, or IDR 49,372.1/m^3.

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