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EQUATION MODEL FOR MUNICIPAL SOLID WASTE COLLECTION AND TRANSPORTATION IN MANADO CITY

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ABSTRACT: This study aimed to obtain an equation model of the collection and transportation of Municipal Solid Waste (MSW) in Manado City, North Sulawesi. Common problems typically encountered in a system of waste management are, in particular, the vehicle routing, the loading capacity of the vehicle, travel time, the working time per day, and high operational costs. The methodology used in data retrieval is direct observation. Meanwhile, to create MSW collection and transportation equation model, drawing logical paths and pathways are made. After that, continue by defining the problem, setting goals, assigning functions as influential factors, making notations. To apply the equations, C ++ is used with a Codeblock editor. Three scenarios were developed in which scenario 1 uses an individual pattern directly, scenario 2 uses a pattern combination between individual directly with the communal directly, and scenario 3 uses a communal pattern directly. The analysis results show that scenario 3 produces a smaller value than scenarios 1 and 2. The number of vehicles required for scenario 3 is 45, and the number of routes per year is as high as 45,000. The distance is 674,172 km/year and the travel time is 120,242 hours/year. The conclusion is that optimization of travel time is proportional to the distance and operating costs as well as environmental costs. The operation of TPS3R, which facilitated by the government and managed by the community, requires active community involvement. Waste is reduced significantly, and the use of waste carrier vehicles is also reduced because the travel time and mileage decrease. The operational costs of waste management also decrease.

Keywords: Equation model, Collection and transportation lines, Route time, Travel time

1. INTRODUCTION

The waste management system condition in Indonesia with total population increases and the level of public consumption increased, resulting in increases in waste volume. This condition means that garbage must be managed well so that it does not cause problems. Basically, everyone wants a place to live with surroundings in clean condition, so did the scope of the broader every city or district. Waste management in Indonesia is the responsibility of each local government. Each city or district manages the problem of waste by establishing a separate sanitation office. In big cities, waste management is provided partially to third parties. Many problems faced in waste management will result in negative consequences for the surrounding environment. This condition has led to the idea of creating regional waste management. Urban waste management has been conducted in the UK, as proposed by [1], for example, where regional landfills are made using all assets (human resources, equipment, and depots) together. In relation to the duties and responsibilities of local governments, according to [2], waste issues are the responsibility of districts and are required to carry out waste handling, including proper sanitation processing, and under certain conditions it is necessary to implement regional final waste processing sites. With regard to garbage management, according to [3], especially Chapter VIII concerning cooperation and partnership, Article 26 about regional cooperation between verse 1 and verse 2 mentions that “the local government can do cooperation between the local government in performing garbage management”. The research that will be done is related to the research that has been done previously. According to [4]–[6], research has been done with route network planning using GIS for trash. Use of treatment plants for integrated waste management and collection and transport of waste [7], [8]. Optimizing the route of MSW collection and transportation systems using GIS [9] - [12]. Path optimization, municipal solid waste collection to minimize fuel using GIS [13], [14], route calculations by algorithm have also been performed [15]. From the results of earlier research, this research is done by system optimization, and transportation of waste is integrated with the final regional disposal (landfills).

The operational system of the collection and transportation of the MSW.

In the waste system, especially, collection and transportation are the most important things. Selection of the correct route will result in short distance and travel time so that the efficiency and effectiveness of collection and transportation activities will be achieved.

In the selection of appropriate routes, factors that must be considered include traffic, productive waste sources, and placement of polling stations (TPS).

The most influential main factors are travel time, travel time value and travel cost [16]. With regard to operational costs, the influencing factor is the number of workers. The use of fuel in a year can be calculated from the distance traveled per cycle route (km/route) and the vehicle's fuel consumption (km/L). Vehicle maintenance costs can vary depending on the age and type of vehicle [17].

In planning the operation of an efficient and effective transportation system [18], the following limitations should be considered:

- Use the shortest possible transport routes and with the smallest possible obstacles.
- Using a transport vehicle with the maximum capacity / carrying capacity.
- Using fuel-efficient transport vehicles.
- Can utilize the maximum work time by increasing the number of workload as much as possible by increasing the number of workloads / ritations of transportation.

Direct Individual System

For direct individual systems or door-to-door systems, ie collection and transport of waste, the garbage transport system may use the following transport patterns:

- Vehicle out of the pool and go straight to the garbage collection path.
- The garbage truck stops by the roadside in every house to be serviced, and the workers pick up the trash and fill the trash can full.
- Once fully charged, the truck goes directly to the Final Processing Place (TPA).
- From the final processing site, the vehicle returns to the next service line until the last shift, then returns to the pool.

Direct Communal System

In a direct communal system; garbage collected in a communal container (garbage bin, container, collection point without construction) which is then transported by garbage truck. The garbage transport system may use the following transportation patterns:

- Vehicles come out of the pool and go straight to the point of collection
- The garbage truck stops at the collection point to be served, and the worker picks up the trash and fills the trash can full.
- Once fully charged, the truck goes directly to the Final Processing Place (TPA).
- From the final processing site, the vehicle returns to the next service line until the last shift, then returns to the pool.

2. MODEL AND METHODOLOGY

The research location is Manado city. The city of Manado is located on the tip of the island of Sulawesi and is the largest city among several cities in the region of North Sulawesi and is the capital of North Sulawesi province. Geographically, Manado City lies between 1 ° 25 '88 "and 1 ° 39 '50" north latitude and 124 ° 47' 0 0 "and 124 ° 56" 00 "east lo ngitude [2.17].

The model of collection and transportation in this study will be integrated with the final regional disposal.

The collection and transport model is designed by creating a travel path from the starting point of the movement to the location of the garbage collection to the point where the vehicle's capacity is full, and back to the starting point, hereinafter referred to as one route cycle (see Figure 1). This model consists of several parameters, namely distance, vehicle speed, and time required to disassemble the load at each collection/transfer point and landfill.

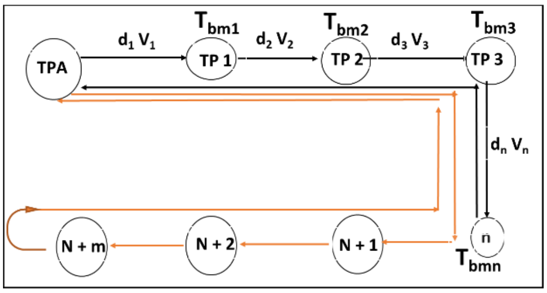

Figure 1. Model of cycle route

Where:

- The collecting and transporting vehicles move from the starting point or Point 0 (TPA) and then head to the collection point 1 (TP1).
- Vehicle speed (V_1) in empty condition $\pm$ 40 km/h, with a certain distance (d_1). In TP1, the time required to load the waste (t_{bm1}) is calculated.
- After hauling all the waste in TP1, the vehicle moves towards TP2. The speed of vehicle (V2) moving towards TP2 is 10 km / h, with distance (d2). Load load time (tbm2) is calculated.
- All waste in the TP1, TP2, TP3…TPn is transported by garbage transport vehicle.
- If the volume of waste collected and transported is the same as the capacity of the transport vehicles, then the transport vehicles go back to the TPA to be emptied.
- The speed of garbage collection and transport vehicle (V3) to TPA (in full condition) is 40 km/hour.

- The next route can be done if the work time still available.

The distance between the points and the speed of the vehicles are measured directly in the field. The time of waste loading at the points of collection and that of unloading at the landfill site are based on the results of the movement study, and attention is paid to the number of working hours per day and the capacity of the vehicle. The modeling is continued by determining the objective function that will be the main objective, then determining the notation of influencing factors and building the following equation:

The objective function in this modeling is determined to minimize the time traveled, namely:

$$\text{Min } Wt = \text{Min } [T_1 + T_i + T_n] \quad (1)$$

Description:

- T_1 [the time required to travel from Point 0 (landfill/TPA) toward P1 (TP1)]

$$T_1 = \frac{d\,[0.1]}{V1} \quad (2)$$

where:

$d_{[0.1]}$ = distance from Point 0 (TPA) to Point 1 (TP1)

V_1 = vehicle speed

- T_i (time required to travel from point 1 (TP1) to the next point (TPn) added to the time required for loading/unloading at each point of the collection)

$$T_i = \sum_{i=1}^{n} \frac{d[i,i+1]}{V2} + Tbm_i \quad (3)$$

where:

$d_{[i,\,i+1]}$ = Distance between collection point *i* and *i+1*, for *i = 1, . . . , n – 1*

V_2 = vehicle speed

$Tbmi_i$ = time taken to load/unload at the collection point *i*

- T_n [the time it takes to travel from Point n (end point) to Point 0 (TPA)]

$$T_n = \frac{d\,[n.0]}{V3} + Tbm_0 \quad (4)$$

where:

$d_{(n,0)}$ = distance from Point n (end point) to Point 0 (TPA)

V_3 = vehicle speed

Tbm_0 = Time required to load/unload at TPA

Constraints

To optimize the path of the vehicle and waste collection transporters, then determined the variables in the modeling of Distance, where the distance that has been determined divided by the speed of the vehicle will result in the travel time of the vehicle.

Volume of trash transported

After the travel time has been obtained, the modeling is limited by restrictions (constraints), which are specified as follows:

- The number of working hours cannot exceed the maximum work schedule.
- The volume of waste transported cannot exceed the capacity of the vehicle.
- The whole of the volume of waste from every collection point must be transported.

Limitation I: The travel time should not be greater than maximum working hours.

Based on the above variables and constraints, the time logic traveled based on the distance and speed of the vehicle are:

$$[T_1 + T_i + T_n] < JK \quad (5)$$

where JK is the working time.

Equation (2), (3), and (4) are substituted into Eq.(1), so the resulting equation is:

$$\frac{d(0,1)}{v1} + \sum_{i=1}^{n} \frac{d[i,i+1]}{v2} + Tbm_i + \frac{d(n,0)}{v3} + Tbm_0 \leq JK \quad (6)$$

Limitations II: The volume of waste transported cannot exceed the capacity of the waste transport vehicles.

The amount of waste transported is the accumulation of each collection point, which is limited by the capacity of the garbage transport vehicle. If Vk is the volume of waste transported on route k and $V_{vehicle}$ is the capacity of the vehicle, then the following conditions must be met for each route:

$$V_{Vehicle} \ \forall \geqslant V_k, \ k = \{1.2,...,n\} \quad (7)$$

The above condition states that the accumulation of waste transported must be less than or equal to the capacity of the vehicle, where n is the number of routes.

Limitation III: The whole of the volume at each waste collection point must be transported.

Assuming that we have *m* garbage collection points and that Vi is the volume of trash at each garbage collection point in- *i*, then

$$Vk = \sum_{i=1}^{m} Vi \quad (8)$$

So

$$\sum_{k=1}^{n} Vk - \sum_{i=1}^{m} Vi = 0 \quad (9)$$

Equations (8) and (9) state that at each point of collection, all waste has been transported.

After generating a mathematical model, an algorithm is generated to obtain a sequence in coding by using a "code block" with C ++ language.

Its algorithmic form is as follows:

1) Specify all nodes with the status has not been assigned; 2) start with the first route r = 1; and the first route begins; 3) if all nodes have been assigned, then stop; 4) for each assigned node, limited by the capacity of the vehicle; 5) if the accumulation of volume (qi) at each collection point is equal to the capacity of the vehicle; 6) the vehicle must return to Final Processing Place to be emptied;7) If travel time is less than working hours, then create a new additional route; 8) go back to step 3; 9) if travel time is less than working hours, then go to step 10; 10) form a new additional route, R = r + 1; go back to step 1; 11) stop.

3. RESULTS AND DISCUSSION

The latest data on the condition of the collection system of municipal solid waste in the city of Manado indicated that the number of TPSs in Manado City is 575 units. The types of waste transfer and containers used over the whole of Manado were as follows:

- 349 collection points with a capacity of 15-20 L
- 21 points with a capacity of 2 m^3
- 37 units of 2 m^3 trash bins
- 40 units of 1 m^3 waste carriages.
- 17 units of 40 L trash cans
- 76 units of 20 L trash bins, and
- 35 units of 6 m^3 containers

From the data that have been obtained, three scenarios for the waste transportation system were developed.

Scenario I: Using individual patterns directly (existing conditions)

Scenario II: using individual and communal patterns directly (Placement of TPS and set the vehicle path)

Scenario III: Using the communal pattern directly (TPS) and using TPS3R. (Placement of TPS and addition of TPS3R, and find the shortest path of vehicle).

3R is a waste treatment process.

3R means reducing, recycling, and reusing.

So TPS3R is a TPS that has facilities for 3R. Analysis and calculation is done by using equation model whose objective function minimizes travel time. The result is:

3.1 Travel time/year

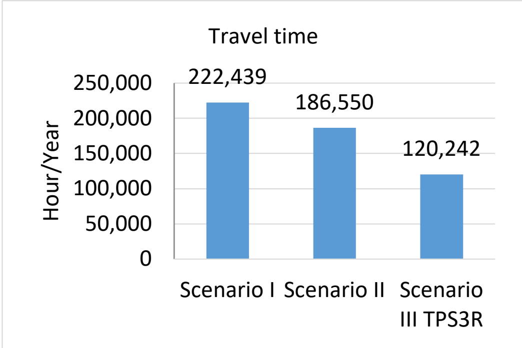

Figure 3. Travel time vs. scenario

By arranging the garbage collection system using the communal pattern directly, it can be seen that the travel time is less than the scenario I and II (Figure 3). By minimizing the travel time, so the number of routes, the mileage in scenario III shows fewer numbers than in the other two scenarios, as shown in Figure 4, 5, and 6.

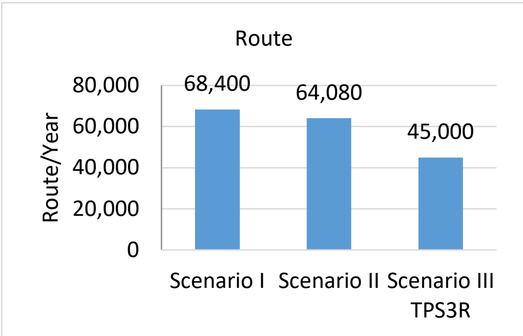

Figure 4. Number of routes vs. scenario

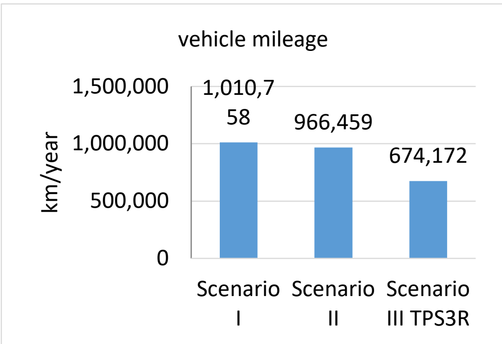

Figure 5. Vehicle mileage vs. scenario

With the amount of waste of 1149.36 m^3 / day, the number of garbage transport vehicles required in each scenario is as follows:

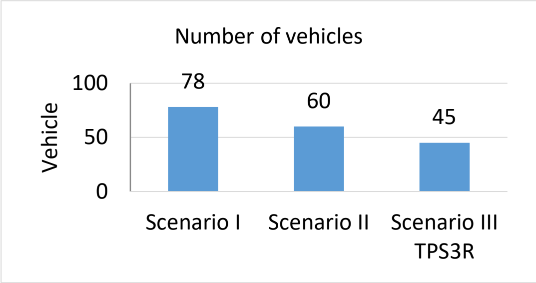

Figure 6. Number of vehicles vs. scenario

3.2 Vehicle Costs

The results of the calculation of the travel time and the distance traveled show that the third scenario has the lowest value. This will affect the financing. The operational costs and the cost to the environment are strongly influenced by the distance traveled by the vehicles. The operational cost of scenario 1 is Rp 7,714,200,000, that of scenario 2 is Rp 5,934,000,000, and that of scenario 3 is Rp 4,423,500,000. The cost scenario can be seen in Figure 7:

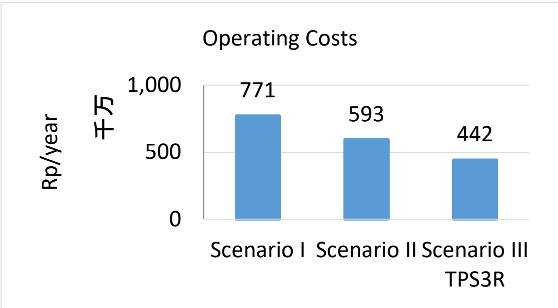

Figure 7. Operating Costs vs. scenario

Environmental costs are calculated using "carbon footprint". Carbon emissions will be converted into currency values. The minimum mileage will affect the use of fuel oil. The use of fuel is one factor that is very influential in the calculation of environmental costs. Figure 8 shows the environmental costs for each scenario. Scenario III has the least value of Rp 1,434,638.

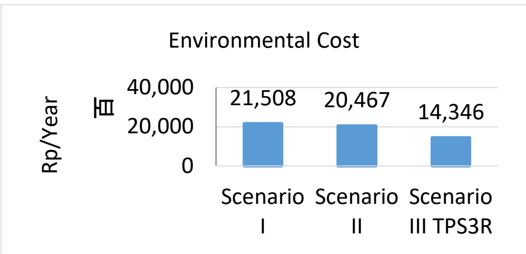

Figure 8. Environmental costs vs. scenario

4. CONCLUSION

From the results of the analysis and evaluation that have been done, it can be concluded that:

1. The equation was created not for optimization, but to find the optimal choice among several scenarios**.**
2. Minimization of travel time produces a minimal value also for mileage, operational costs, and environmental costs.
3. Reduction of waste through the 3R program showed significant results, so the number of garbage transport vehicles is also less because of the travel time, the mileage decreases.

5. ACKNOWLEDGMENTS

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