Waste Transportation Route Optimization in Malang using Network Analysis

A.H Putra1*, A. Amalia1, R.K.H Putro1, L.F Darmayani2

1Universitas Pembangunan Nasional “Veteran” Jawa Timur
2Department of Public Work and Spatial Planning West Lombok Regency

*Corresponding author’s e-mail: agil.harnowo@gmail.com

Abstract. Malang has a projection population of 861,414 people in 2018. This big population would cause waste generation that is increasing every day. Waste generation was recorded at the amount of up to 646.07 tonnes/day just from Malang in 2018. However, waste transported to landfill was only 516.84 tonnes/day. It means that the load factor was only 84.73%. Waste transportation problems come from various factor. Malang had only 68 temporary waste storage (TPS) that were spread in the city. This number of TPS was not commensurate with waste generation that was generated every day. The limited number of trucks was another issue considering Malang only had 35 trucks capable of making three trips per day. Limited number of trucks and TPS has led to a bad situation for transporting waste. As a result, many wastes were left behind in TPS. Therefore, it is necessary to analyze the best route for the trucks so that the waste route can be optimized using network analysis in ArcGIS. This study assessed one route of a truck which had the longest distance (TPS Tunggul Wulung) with a total of 60.2 km at a time that it reached in 113.8 minutes. The result of the network analysis method with ArcGIS showed that the total distance declined to 36.2 km. This indicates that the alternative route shown by the shortest distance method has been able to reduce the existing distance for waste transportation route by 24 km. This certainly resulted in the decline in travel time for ± 39 minutes/day. This indicates that the existing routes can be optimized by alternative route network analysis in ArcGIS.

Keywords: Waste Transportation, Network Analysis, GIS

1. Introduction

The environment currently has potential risk due to the management and unsustainability of waste disposal. Sustainable waste disposal is a sensitive issue that concerns about environmental problems in the world. The disposal of waste without pretreatment such as proper separation can lead to serious consequences in environmental pollution [2]. The problem of waste management is commonly found in large cities, one of them being Malang. Malang is a city located in the province of East Java, with a population of 861,414 in 2015 [1].

2. Material and Methods

2.1 Waste Transportation routes and patterns

Waste transportation is an activity to bring garbage that has accumulated at a certain point to a landfill (TPST). The transportation stage is a stage which requires the highest cost compared with other...
stages of waste management, due to the cost of investment, operation and maintenance required. Therefore, it is very important to determine an alternative route for waste transportation to be of shorter distances. Shorter distance will result in the decrease in time and fuel consumption. Transporting pattern for waste transportation is divided into two types, i.e. direct transport and indirect transport[8].

2.2 TPS Types
According to ISO 3242-2008, a temporary waste storage (TPS) is a place for transferring waste from a garbage collector to a landfill. TPS are classified into 3 types[9], with characteristic shown in Table 1.

| Type   | Characteristic                                                                 |
|--------|-------------------------------------------------------------------------------|
| Type 1 | Sorting room, Warehouse, Ground for waste removal container, Total area ± 10 - 50 m² |
| Type 2 | Sorting room (10 m²), Room for organic waste composting (200 m²), Warehouse (50 m²), Ground for waste removal container, Total area ± 60 - 200 m² |
| Type 3 | Sorting room (30 m²), Room for organic waste composting (800 m²), Warehouse (100 m²), Ground for waste removal container (60 m²), Total area > 200 m² |

2.3 Descriptive Analysis of Waste Management
Descriptive analysis of waste management explains non-technical, operational and technical operations. Non-technical operational aspects discussed in this research include retribution and financing [3], accountable institutions in waste management and regulation [4] as well as community participation [6]. As for the technical aspects of waste management operation, this research focuses on and discusses about the existing sources, collection and TPS [9] as well as the transportation route of solid waste.

2.4 Network Analysis (Shortest Distance)
The study was conducted in Malang which has five subdistricts and 68 TPS. The study used one sample from a number of garbage trucks in Malang that has the longest driving distance for waste transportation. Network analysis method was used to determine an alternative route for waste transportation in Malang to run an efficient, effective and environmentally friendly route. The key point of this network analysis technology is using Geographic Information System (GIS). Three stages were needed to determine the alternative route, i.e. gathering data, geo-spatial database development and analysis of the current condition of garbage collection [7]. In addition to the general criteria used in this study, two main criteria were included, i.e. distance and time [2].
2.5 GIS Analysis and Constraints
GIS software has some advantages compared to other software because it can mark barriers so that vehicles are not recommended to use routes that have been marked with a barrier. This study signed a barrier to a waste transportation route if the route has the following road criteria (Chalkias, 2009):
a. The road is a one-way type of road.
b. The type of road is narrow and dense so it would be difficult for garbage trucks to traverse (assuming the width of the road cannot be passed by 2 garbage trucks simultaneously).
c. Small type of road (village road that can only be passed by a medium-sized car, or motorcycle).
d. U-turn access, GIS cannot calculate roads that have a U-turn access because all roads are connected.
e. Residential road, a special road for residents who live in a residential area so that the access road is closed to the public.
f. Public Road, access road that cannot be passed by garbage trucks (schools, military roads, education, public facilities, government, hospitals).
To do a network analysis, it takes the right route selection so that the results generated can be read and easily understood.

3. Results and Conclusions

3.1 Waste Management System
Waste management includes two aspect, both in terms of operational technical and non-operational. Non-technical aspects address regulations, institutions, retributions and community participation. Waste management regulation in Malang is stated in its Regional Regulation No. 10 of 2010 on Waste Management, and regarding the institutional aspects of waste management, the institution responsible of trash in Malang is the Malang Environmental Services. Table 2 shows the number and types of waste points (TPS) in each subdistrict to accommodate waste management in Malang.

| No | Subdistrict   | TPS Total              |
|----|---------------|------------------------|
| 1  | Klojen        | 3 units of type II and 11 units of type I |
| 2  | Blimbing      | 1 units of type II and 20 units of type I |
| 3  | Kedungkandang | 11 units of type I     |
| 4  | Sukun         | 12 units of type I     |
| 5  | Lowokwaru     | 17 units of type I     |

Table 2 shows that Blimbing has the most TPS in Malang while Kedungkandang has the least with a total of 21 and 11 units respectively. There are some problems in the waste management system in Malang. These problems can be caused by several things, including hardware (infrastructure), lack of waste containers as well as a growing number of illegal uncontrolled TPS and inefficient patterns of waste transportation and mileage of these trucks either from the pool to get to waste containers and landfill.

3.2 Existing Waste Transportation Route
There are 35 units of vehicles transporting waste from TPS to landfill in Malang, consisting of 17 arm roll trucks and 18 dump trucks. Transportation facilities carry out waste transport operations for 365 days a year where operation begins from 04.00 am until 07.00 am.
### Table 3. Existing waste transport in Malang

| Trips (time) | Total trucks (Unit) | Total Distance (km) | Average Distance Trips (km/trip/truck) |
|-------------|---------------------|---------------------|----------------------------------------|
| 2           | 3                   | 125.2               | 20.86                                  |
| 3           | 32                  | 1.971.95            | 20.54                                  |

Table 3 shows that the traveling trucks with three trips a day have shorter distance to travel compared with trucks that travel 2 trips a day. This shows that the existing transport conditions in Malang can be maximized by adding the number of trips so that the vehicles can carry more waste and increase the waste service.

![Figure 1. Existing Route of Waste Transportation in Malang](image)

**3.3 Alternative waste transportation**

Alternative waste transportation analysis with shortest distance method is an analysis to predict routes that can be taken by trucks so they can travel with shorter distance, time and lower fuel consumption. Alternative routes do not only take into account the financial aspects such as the distance, time, and fuel consumption, but also public facility aspect. Table 4 shows the comparison sample of one dump truck in Malang between existing routes and alternative routes based on network analysis.
Based on Figure 2, the dump truck route started from the truck pool to Tunggulwulung TPS then to Landfill. The existing route is shown to cross several barriers of infrastructures such as schools and hospitals. Moreover, the existing route also passes roads with an average service level B and C and intersections of service level B and C. This route had a distance of 60.20 km in 1 trip, with a travel time of 113.48 minutes and gasoline consumption reaching 7.89 liters per trip.

**Figure 2.** Existing Route of Waste Transportation Pool-TPS Tunggulwulung-Landfill

**Figure 3.** Optimal/Shortest Route Waste Transportation Pool-TPS Tunggulwulung-Landfill
According to Figure 3, there are different routes that can be taken after a network analysis from GIS considering obstacles such as the road service levels, intersections and infrastructures. In Figure 3, the majority of the routes passed have minimum contact with infrastructures and only pass through roads with service level B. The majority of intersection are crossed with service level C, so that this is able to shorten the distance in one trip. The comparison of distance, time and fuel consumption between the existing route and the optimum route can be seen in Table 4.

Table 4. Comparison existing route and alternative route

| Information        | Distance (km) | Time (minute) | Fuel (l/day) |
|--------------------|---------------|---------------|--------------|
| Existing Route     | 60.20         | 113.48        | 7.89         |
| Shortest Route     | 36.27         | 74.28         | 4.59         |
| Difference         | 23.93         | 39.2          | 3.3          |

As shown in Table 4, the distance traveled between the existing route and alternative route was significantly decreased (±40%), this affects the distance of travel time and total fuel consumption. The sample showed that using a network analysis which considers alternative routes based on the shortest route and the level of road services affects the travel time of garbage trucks in the same origin.

4. Conclusions
The main conclusion obtained from this study is that the method of determining network analysis through GIS can help waste management, especially in the field of transportation so that route selection is effective. Shorter routes will have an impact on travel time and also fuel consumption. Determining the optimum route must also consider obstacles along the way including the presence of urban infrastructure, the level of road services and the level of intersection services.

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