Minimization of municipal solid waste transportation route in West Jakarta using Tabu Search method

M Chaerul1 and A M Mulananda1

1Department of Environmental Engineering, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia

chaerul_2000@yahoo.com

Abstract. Indonesia still adopts the concept of collect-haul-dispose for municipal solid waste handling and it leads to the queue of the waste trucks at final disposal site (TPA). The study aims to minimize the total distance of waste transportation system by applying a Transshipment model. In this case, analogous of transshipment point is a compaction facility (SPA). Small capacity of trucks collects the waste from waste temporary collection points (TPS) to the compaction facility which located near the waste generator. After compacted, the waste is transported using big capacity of trucks to the final disposal site which is located far away from city. Problem related with the waste transportation can be solved using Vehicle Routing Problem (VRP). In this study, the shortest distance of route from truck pool to TPS, TPS to SPA, and SPA to TPA was determined by using meta-heuristic methods, namely Tabu Search 2 Phases. TPS studied is the container type with total 43 units throughout the West Jakarta City with 38 units of Armroll truck with capacity of 10 m$^3$ each. The result determines the assignment of each truck from the pool to the selected TPS, SPA and TPA with the total minimum distance of 2,675.3 KM. The minimum distance causing the total cost for waste transportation to be spent by the government also becomes minimal.

1. Introduction
The rapid development of Jakarta City causes changes including the alteration of environmental quality. These developments include the growth of population, social, economic and cultural. With population of more than 10 Million inhabitants, Jakarta generates 6,595 tons of waste daily [1]. These development implicates for the increasing amount of municipal solid waste (MSW) that should be transported to final disposal site (TPA). Indonesia still adopts the concept of collect-haul-dispose for MSW handling system. The concept has consequences for the high operational costs of waste management. Cost for the waste transportation contributes dominantly to total cost of MSW management [2] [3]. The high cost of management will require an increase in fees to be paid by the generator. Higher fees will encourage generator to reduce waste generation rate [4].

Transportation is a sub-system in a MSW Management system to collects and transports the waste from the generator to temporary collection point, to waste treatment facilities, or directly to the final disposal site/landfill (TPA). By optimizing the assignment of trucks, the sub-system is expected to transporting waste easier, faster, and lower the cost. Another objective of the waste transportation is to minimize of vehicles used, the distance, and travel time [5]. These waste transportation route must be effective and efficient and so that it results to the optimum route of waste transportation and the minimal adverse effects on the environment [6].

Jakarta has a landfill that located outside the city, namely TPA Bantar Gebang in Bekasi City. The location of the landfill outside the city would be required the most cost if all trucks directly entering to TPA Bantar Gebang. Moreover, it will cause the queue at the entrance of the landfill site. The study
aims to find the shortest route as the proposed route of the existing route by utilizing the compaction facility as a transshipment point as part of Vehicle Routing Problem (VRP).

2. Research Methodology

Transshipment Model is a transportation mode that enables the delivery of goods (commodities) indirectly, where goods from one source can be transported to another source or another destination before reaching its final destination. In this study, transshipment point is a compaction facility (SPA) that located in Sunter, Jakarta. The waste coming from temporary collection points may or may not transit to SPA before transported to TPA Bantar Gebang. Other constraints that should be achieved in this study include:

- All truck coming from a pool should go to a TPS to transport the waste in these TPS;
- All waste generated and stored in all TPS should be transported using a particular truck to SPA or TPA;
- All waste accepted at SPA and TPA cannot exceed the respective capacity. SPA Sunter will only accept waste from West Jakarta at a maximum 200 m³. While, there is no limitation for TPA capacity;
- A truck may transport waste generated in TPS in a maximum 3 times of return a day.

The algorithm to find the solution is divided into two, namely the construction algorithm and improved algorithm. Construction algorithm performed by sequential insertion, while the improvement using the Tabu Search Algorithm. Sequential insertion algorithm is one of the algorithms for generating the initial solution. The algorithm is easily extended to accommodate hard constraints such as time windows, heterogeneous fleet, and pick up delivery [7]. The principle of sequential insertion is to insert the component solutions (in the VRP problem is the customer, in this study refers to TPS) one by one according to certain criteria.

Table 1. Algorithm developed for the research.

| ALGORITHM 1 | TOUR ALGORITHM |
|-------------|----------------|
| Step 1: Construct a giant tour T, where T = {v_1, v_2, ..., v_n} |
| Step 2: for each arc (i,j) \( \in \) G, do |
| (a) Calculate \( c_{ij} \) and \( d_i \) the travel cost and demand associated to the route. |
| (b) Calculate \( F_k \), the fixed cost of vehicle \( k \). |
| end do |
| Step 3: Calculate the shortest path from node \( v_i \) to node \( v_n \) of graph \( G \). |
| Step 4: Repeat steps 2-3 for other possible tours. |

| ALGORITHM 2 | TABU SEARCH ALGORITHM |
|-------------|----------------------|
| Step 1: (Initialization) |
| Calculate an initial solution using the Tour Algorithm |
| Step 2: (Search Procedure) |
| (a) Begin with \( \lambda = 1 \) and define \( \lambda_{max} \) |
| (b) Select best non-tabu feasible solution \( \epsilon' \in N(\epsilon) \) |
| (c) Keep tabu elements of the movement |
| (d) Keep the new solution cost \( f(\epsilon') \) in array |
| (e) Do \( \epsilon \rightleftharpoons \epsilon' \) and \( \lambda = \lambda + 1 \) |
| Step 3: (Swapping Procedure) |
| (a) Calculate \( \epsilon' \) from \( \epsilon \) applying the swap procedure at each route \( \epsilon \) |
| (b) Update \( \epsilon \rightleftharpoons \epsilon' \) and \( \lambda = \lambda + 1 \) |
| (c) If \( f(\epsilon') < f(\epsilon_{BEST}) \) then \( \epsilon_{BEST} = \epsilon' \), \( \lambda_{BEST} = \lambda \) and \( over = 0 \) else |
| \( over = over + 1 \) |
| Step 4: (Diversification/Intensification Mechanism) |
| (a) Split each route of \( \epsilon \) |
| (b) Allocate the cheapest vehicles to satisfy demand |
| (c) Define the new solution cost \( f(\epsilon') \) |
| Step 5: (Stopping Rule) |
| if \( \lambda > \lambda_{max} \) then stop |
Tabu Search is a meta-heuristic algorithm that is designed to escape from a local optimum [8]. Tabu Search has taboo restriction to limit the search space and aspiration criteria to be separated from the barrier that had been determined previously using restriction taboo. Tabu Search also has a memory function with different timescales in the form of short-term memory and long-term memory to run the intensification and diversification strategy in the process of finding solutions. Intensification strategy is a strategy centering on local search solutions that are considered "promising". Meanwhile, diversification strategy is the search strategy by directing the search in a new area.

Tabu Search has been applied for several studies related with various areas [9] [10] [11]. In general, there are two algorithms developed for the research, namely Tour and Tabu Search algorithms (See table 1) [12]. In our study, node, travel cost, demand, and the cheapest vehicles in the algorithms below refers to TPS, distance of transportation, waste generated at TPS, and the shortest distance of transportation, respectively.

3. Result and discussion

West Jakarta is located at 106°22′42″ E - 106°58′18″ E and 5°19′12″ S - 6°23′54″ S with an area of 126.15 km². The area of West Jakarta is divided into 8 districts including 56 urban villages, with a total population of 2,427,414 people [13]. The amount of waste generated from various sources amounted to 1,528.03 tons per day [14].

West Jakarta has 264 locations of TPS where 190 locations of TPS are handled by West Jakarta Sub-dept., and the rests are handled by the private sector. In this study, Tabu Search methods are used as a tool to formulate the problems of transporting waste in West Jakarta City. There are 43 locations of TPS with container type for storing the waste throughout the city (figure 1). Vehicle considered in this study is Armroll truck with total amount of 38 locations with capacity of 10 m³ each. Total waste generated at each TPS can be found in table 2. The waste coming from TPS may or may not transit to SPA Sunter located in North Jakarta City, about 60 km from center city of West Jakarta. SPA Sunter serves also other 4 cities in Jakarta Province namely East Jakarta, South Jakarta, East Jakarta, and Central Jakarta, while TPA Bantar Gebang located in Bekasi City, about 60 km from West Jakarta.

![Figure 1. Distribution of TPS in West Jakarta.](image-url)
In total, waste generated in West Jakarta City is 548 m$^3$/day. It can be found also from Table 1 that TPS#27 contributes waste generation dominantly (30 m$^3$/day), while TPS#12 stores the minimum waste generation (1.5 m$^3$/day). The difference of amount stored at each TPS is affected significantly by inhabitants living at the surrounding of the TPS site.

The distance from pool of trucks to each TPS, each TPS to SPA, and each TPS to TPA was generated using Google maps and the range data is presented in Table 3. In addition, the distance between SPA and TPA is 40.8 km.

Table 2. Amount of waste generated in TPS.

| Code | Capacity (m$^3$) | Code | Capacity (m$^3$) | Code | Capacity (m$^3$) |
|------|-----------------|------|-----------------|------|-----------------|
| TPS1 | 10              | TPS16| 20              | TPS31| 16              |
| TPS2 | 10              | TPS17| 16              | TPS32| 20              |
| TPS3 | 12              | TPS18| 10              | TPS33| 16              |
| TPS4 | 16              | TPS19| 8               | TPS34| 15              |
| TPS5 | 10              | TPS20| 11              | TPS35| 15              |
| TPS6 | 7               | TPS21| 11              | TPS36| 11              |
| TPS7 | 7               | TPS22| 11              | TPS37| 14              |
| TPS8 | 12              | TPS23| 12              | TPS38| 13              |
| TPS9 | 9               | TPS24| 11              | TPS39| 5               |
| TPS10| 13              | TPS25| 10              | TPS40| 10              |
| TPS11| 12              | TPS26| 26              | TPS41| 9               |
| TPS12| 1.5             | TPS27| 30              | TPS42| 8               |
| TPS13| 10              | TPS28| 16              | TPS43| 8               |
| TPS14| 17              | TPS29| 20              |      |                 |
| TPS15| 17              | TPS30| 14              |      |                 |

Table 3. Vehicle mileage.

| TPS     | Distance (Km) | TPS     | Distance (Km) |
|---------|---------------|---------|---------------|
|         | Pool of truck | SPA     | TPA           |
| TPS1    | 6.5           | 22.3    | 45.6          |
| TPS2    | 7.4           | 15.9    | 46.8          |
| TPS3    | 7.6           | 19      | 47.1          |
| TPS4    | 5.5           | 20.1    | 51.1          |
| TPS5    | 8.3           | 17.7    | 44.8          |
| TPS6    | 5.9           | 20.4    | 55.1          |
| TPS7    | 5.5           | 21.4    | 55.4          |
| TPS8    | 6.6           | 20.2    | 55.2          |
| TPS9    | 1.5           | 19.1    | 56.2          |
| TPS10   | 15.2          | 23.3    | 40.2          |
| TPS11   | 12.5          | 15.6    | 42.7          |
| TPS12   | 12.8          | 18.2    | 44.5          |
| TPS13   | 12.6          | 15.6    | 44.9          |
| TPS14   | 11.6          | 14      | 42.8          |
| TPS15   | 13.1          | 21.2    | 41            |
| TPS16   | 12.5          | 15.6    | 44.9          |
| TPS17   | 10.4          | 16.5    | 44.9          |
| TPS18   | 12.5          | 15.6    | 42.7          |
| TPS19   | 13.2          | 21.5    | 46.5          |
| TPS20   | 11.5          | 24.6    | 48.3          |
| TPS21   | 10.7          | 24.8    | 43.6          |
| TPS22   | 10.2          | 24.3    | 43.2          |
From table 2 it can be seen that TPS#9 is the closest from the pool, which as far as 1.5 km and TPS#28 is the farthest from the pool as far as 15.5 km. For a distance from TPS to SPA, TPS#35 is the closest (10.3 km) and TPS#24 is farthest (25 km). For a distance from TPS to TPA, TPS#29 is the closest (37.4 km) and TPS#9 is the farthest (56.2 km).

Before running the model, the study simulates 2 scenarios: (1) all waste from TPS transported directly to TPA; and (2) all waste from TPS transported to SPA before transported to TPA. From 1st and 2nd scenarios, it results to the total distance of trucks will be 5,238 Km and 2,194 Km, respectively. Result of the model obtained by processing the waste transportation route optimization is presented in Table 4.

| Truck No. | Route | Truck No. | Route |
|-----------|-------|-----------|-------|
| 1         | 0-1   | 0-2       | 21    |
|           | 45-0  | 10-45     | 36-45 |
| 2         | 6-4   | 5-46      | 37-46 |
|           | 4-04  | 10-44     | 38-46 |
| 3         | 5-4   | 0-54      | 39-49 |
|           | 4-47  | 10-47     | 40-49 |
| 4         | 8-4   | 0-84      | 41-49 |
|           | 4-34  | 10-43     | 42-49 |
| 5         | 9-4   | 0-94      | 43-49 |
|           | 11-44 | 14-11     | 44-49 |
| 6         | 11-4  | 0-114     | 45-49 |
|           | 12-44 | 14-12     |       |
| 7         | 14-4  | 0-144     | 46-49 |
|           | 15-44 | 16-15     |       |
| 8         | 15-4  | 0-154     | 47-49 |
|           | 16-44 | 16-16     |       |
| 9         | 18-4  | 0-184     | 48-49 |
|           | 17-44 | 17-17     |       |
| 10        | 19-4  | 0-194     | 49-49 |
|           | 20-44 | 20-20     |       |
| 11        | 2-1   | 21-42     | 50-49 |
|           | 4-42  | 22-42     |       |
| 12        | 2-2   | 4-23      | 51-49 |
|           | 3-23  | 4-23      |       |
| 13        | 2-4   | 4-24      | 52-49 |
|           | 5-24  | 4-24      |       |
| 14        | 2-6   | 4-26      | 53-49 |
|           | 6-26  | 4-26      |       |
| 15        | 2-7   | 4-27      | 54-49 |
|           | 7-27  | 4-27      |       |
| 16        | 2-8   | 4-28      | 55-49 |
|           | 8-28  | 4-28      |       |
| 17        | 2-9   | 4-30      | 56-49 |
|           | 9-30  | 4-30      |       |
| 18        | 3-1   | 4-31      | 57-49 |
|           | 1-31  | 4-31      |       |
| 19        | 3-2   | 4-32      | 58-49 |
|           | 2-32  | 4-32      |       |

This algorithm defines that (0) is the notation for pool of truck, (44) for SPA and (45) for TPA. From these results, it can be seen that Truck#1 transport waste at TPS1 and subsequently go to the TPA. Truck#1 only has to transport waste at TPS#1, while another truck may have different number of rotations. For instance, Truck#36 transport wastes at TPS#3 and TPS#2. Almost trucks transport the waste from 3 locations of TPS. It can be seen also that from total 38 trucks owned by the city, it is only 26 trucks necessary used to transport the waste from 43 locations of TPS. It means that 12 trucks can be used to transport the waste from other type of TPS in the city. Another result of the program using Visual Basic can generate solution by minimizing the distance. Total minimum distance by considering a set of constraints mentioned above is 2,673 Km.

4. Conclusion
Waste management is an issue that is still frequently occurring in environmental management. The present study focuses to transport all waste generated at 43 locations of TPS using container to store the waste throughout the city of West Jakarta. The trucks may or may not transit to SPA as a transshipment point before finally dispose the waste at TPA as a final destination. The Visual Basic model can generate solutions by minimizing the distance that should be traveled by the trucks is 2,673 Km. Second result from the model is that the number of trucks required to transport all waste generated at all TPS are 26 trucks. Minimum distance will generate minimum cost for operational of the transportation. Thus, the model helps the municipality having lack of financial to increase the service level of waste management.
5. References

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