

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

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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 m³ 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 $T = \{v_1, v_2, \dots, v_n\}$
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 λ_{\max}
(b) Select best non-tabu feasible solution $\varepsilon' \in N(\varepsilon)$
(c) Keep tabu elements of the movement
(d) Keep the new solution cost $f(\varepsilon')$ in array
(e) Do $\varepsilon = \varepsilon'$ and $\lambda = \lambda + 1$
Step 3: (Swapping Procedure)
(a) Calculate ε' from ε applying the swap procedure at each route ε
(b) Update $\varepsilon = \varepsilon'$ and $\lambda = \lambda + 1$
(c) If $f(\varepsilon') < f(\varepsilon^{BEST})$ then $\varepsilon^{BEST} = \varepsilon'$, $\lambda_{BEST} = \lambda$ and $over = 0$
else
$over = over + 1$
Step 4: (Diversification/Intensification Mechanism)
(a) Split each route of ε
(b) Allocate the cheapest vehicles to satisfy demand
(c) Define the new solution cost $f(\varepsilon')$
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 $106^{\circ}22'42''$ E - $106^{\circ}58'18''$ E and $5^{\circ}19'12''$ S - $6^{\circ}23'54''$ S with an area of 126.15 km^2 . 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 m^3 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.

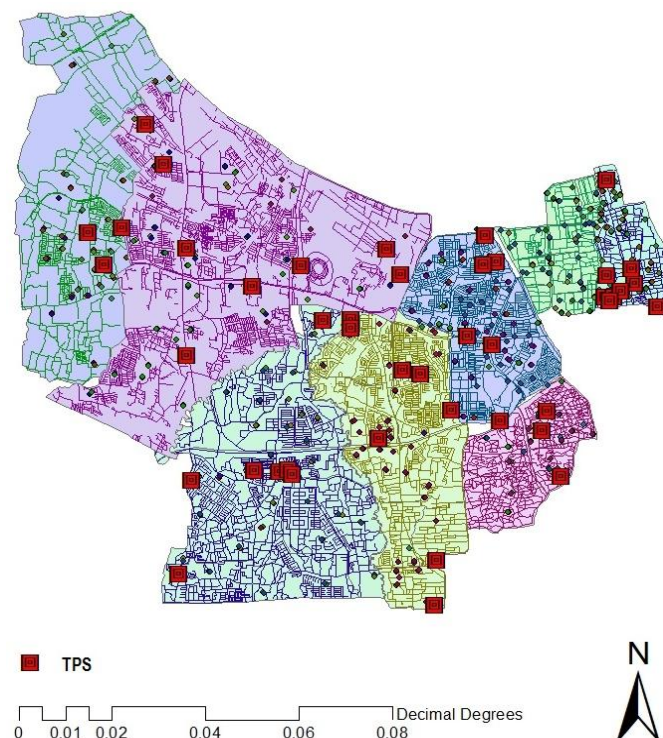


Figure 1. Distribution of *TPS* in West Jakarta.

In total, waste generated in West Jakarta City is 548 m³/day. It can be found also from table 1 that TPS#27 contributes waste generation dominantly (30 m³/day), while TPS#12 stores the minimum waste generation (1.5 m³/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 (m3)	Code	Capacity (m3)	Code	Capacity (m3)
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 to (Km)		
	Pool of truck	SPA	TPA		Pool of truck	SPA	TPA
TPS1	6.5	22.3	45.6	TPS23	13.6	22.7	48.5
TPS2	7.4	15.9	46.8	TPS24	11.3	25	45.7
TPS3	7.6	19	47.1	TPS25	14.4	23.3	44.6
TPS4	5.5	20.1	51.1	TPS26	14.6	12.7	38.7
TPS5	8.3	17.7	44.8	TPS27	13.2	12.4	38.6
TPS6	5.9	20.4	55.1	TPS28	15.5	13	40.1
TPS7	5.5	21.4	55.4	TPS29	13.2	12.9	37.4
TPS8	6.6	20.2	55.2	TPS30	12.4	11.7	43
TPS9	1.5	19.1	56.2	TPS31	11.5	10.4	44.2
TPS10	15.2	23.3	40.2	TPS32	12.6	11.8	43.1
TPS11	12.5	15.6	42.7	TPS33	12	12.1	40.2
TPS12	12.8	18.2	44.5	TPS34	14.5	12.5	50.3
TPS13	12.6	15.6	44.9	TPS35	12.2	10.3	47.3
TPS14	11.6	14	42.8	TPS36	11.8	13.4	48.5
TPS15	13.1	21.2	41	TPS37	13.1	13.5	46.9
TPS16	12.5	15.6	44.9	TPS38	15.2	15.6	47.8
TPS17	10.4	16.5	44.9	TPS39	14.5	14.3	51.3
TPS18	12.5	15.6	42.7	TPS40	13.7	16.5	48.5
TPS19	13.2	21.5	46.5	TPS41	12.8	12.1	49.1
TPS20	11.5	24.6	48.3	TPS42	12.8	12.1	49.1
TPS21	10.7	24.8	43.6	TPS43	12.2	14.7	50.8
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.

Table 4. Assignment and proposed route of trucks.

Truck No.	Route	Truck No.	Route
1	0-1-45-0-45-0-45	20	0-34-44-34-44-35-45
2	0-6-44-0-44-10-45	21	0-35-44-36-44-36-45
3	0-5-44-4-44-7-45	22	0-37-44-37-44-38-45
4	0-8-44-8-44-3-45	23	0-38-44-39-44-40-45
5	0-9-44-10-44-11-45	24	0-41-44-42-44-43-45
6	0-11-44-12-44-13-45	25	0-0-45-0-45-0-45
7	0-14-44-14-44-15-45	26	0-0-45-0-45-0-45
8	0-15-44-16-44-16-45	27	0-0-45-0-45-0-45
9	0-18-44-17-44-17-45	28	0-0-45-0-45-0-45
10	0-19-44-20-44-20-45	29	0-0-45-0-45-0-45
11	0-21-44-21-44-22-45	30	0-0-45-0-45-0-45
12	0-22-44-23-44-23-45	31	0-0-45-0-45-0-45
13	0-24-44-24-44-25-45	32	0-0-45-0-45-0-45
14	0-26-44-26-44-26-45	33	0-0-45-0-45-0-45
15	0-27-44-27-44-27-45	34	0-4-44-0-45-45
16	0-28-44-28-44-29-45	35	0-0-45-0-45-0-45
17	0-29-44-30-44-30-45	36	0-3-45-0-44-2-44
18	0-31-44-31-44-32-45	37	0-0-45-0-45-0-45
19	0-32-44-33-44-33-45	38	0-0-45-0-45-0-45

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

- [1] Wardhani I 2011 *Policy analysis of integrated waste management based on Zero Waste and Environment Management (ZWEM) System* (in Indonesian) Universitas Indonesia.
- [2] Tavares G Zsigraiova Z Semiao V and Carvalho M G 2009 Optimization of MSW collection routes for minimum fuel consumption using 3D GIS modelling *Waste Man.* 29 1176-1185.
- [3] Elmira S Nadi B and Mahmud AR 2011 *Optimization of municipal solid waste management* Int. Conf. on Biology, Environment and Chemistry. Singapore.
- [4] Widyarsana I M W Damanhuri T P and Tomo H S 2014 *Study of household waste handling scheme using dynamic modelling: A case study of Bandung City* (in Indonesian) Institut Teknologi Bandung.
- [5] Byung-In K Seongbae K and Surya S 2005 Waste collection vehicle routing problem with time windows *Comput. Oper. Res.* 33 3624-3642.
- [6] Clifford T 2008 *Waste collection optimization tools* Proc. on Waste and Climate Change. London.
- [7] Widagdo S J 2014 *Determination of Medical Waste Routing at PT. Jasa Medivest using Tabu Search* (in Indonesian) Institut Teknologi Bandung. Bandung, Indonesia.
- [8] Glover F 1999 Tabu Search: A Tutorial. *Interfaces* 20 74-94.
- [9] Fan W and Machemehl R B 2008 Tabu Search Strategies for the Public Transportation Network Optimizations with Variable Transit Demand. *Compt. Aided Civil Infrs. Eng.* 23 502-520.
- [10] Glover F Laguna M and Dowsland K A 1993 *Tabu Search-Modern heuristic techniques for combinatorial problems* Blackwell: London, UK.
- [11] Gómez J R Pacheco J and Gonzalo-Orden H 2015 A Tabu Search Method for a Bi-Objective Urban Waste Collection Problem *Compt. Aided Civil Infrs. Eng.* 30 36–53.
- [12] Cheeneebash J and Jugee S 2012 Applying Tabu Search Algorithm in Public Transport: A Case Study for University Students in Mauritius *Int. J. Transport. Vehicle Eng.* 6 1794-1797.
- [13] Statistic of West Jakarta 2013 *City Statistic year of 2014* (in Indonesian) West Jakarta City.
- [14] West Jakarta Cleanliness Sub-Department 2013 *Waste generation data: A yearly report* (in Indonesian) West Jakarta City.