Metropolitan Cities’s Waste Transportation Model

Asrul. H. Ismail, Yulita V. Usman, Nur Y. Hidayah, Laela Chairani*

Industrial Engineering Department, Pancasila University, Srengseng Sawah, Jakarta 12640, Indonesia

Abstract

Metropolitan cities have the many problem to manage their waste, particularly in transportation management. One of the critical factors to be considered at the time of transporting waste is traffic jam. It means using more resources and high cost. Through system engineering process approach as research methodology, the optimization model is developed using linear programming method to assign specific type of fleet in the right time and destination based on the best route to meet maximum saving of cost where traffic jam factor is inserted as an independent variable.

Key words: linear programming; optimization; transportation model; waste management; travelling salesman problem

1. Introduction

Characteristics of transporting waste in an urban and rural areas have different characters. Mainly the metropolitan cities, especially the chaotic metropolis like Jakarta, have higher traffic jam rates than rural ones. Considering the traffic jam rates factor in managing waste, particularly in the areas of transportation management, will meet the optimal solution. In a fleet assignment plan of urban waste districts hygiene section doesn’t into currently consideration this jam factor. In waste management in Jakarta every transporting waste from landfill (original) to the transfer stations or the final disposal site (destination) managed by each district under hygiene section. Each section has their own fleets that are managed independently. The problem today is the hygiene section do not have decision making model to configure...
the assignment of fleet that led to low productivity. This research will answer how configuration
assignment each fleet from the original to the destination will meet the maximum saving of cost.

2. Binary Integer Programming Theory

Numbers 0 and 1, or more commonly known as a binary, it can be used in linear programming. This
binary numbers with such characteristics as a decision variable will create a linear programming model
that can be used to solve various problems. 0-1 variable characteristics allow us to pour into the causality
constraint functions. If the positive decision value is 1, then the negative decision value is 0. The simplest
way to do this is to assume \(0 \leq x \leq n\) is an integer variable where \(n\) is an integer limit. Then with a note
that \(y_1, y_2, ..., y_n\) are binary variables 0-1.

\[
x = y_1 + y_2 + ... + y_n
\]

(1)

The equation is an exact binary representation of all feasible values of \(x\). A representation of a more
economical where the number of binary variables is usually smaller than \(n\) are known.

\[
x = y_0 + 2^1 y_1 + 2^2 y_2 + ... + 2^k y_k
\]

(2)

Where \(k\) is the smallest integer that satisfies \(2^k - 1 \geq n\)

The fact that every problem can be a binary integer along with the simplicity of calculations in dealing
with variable 0-1 (each variable has only two values) have directed attention to the use of these properties
to develop an effective algorithm (Taha. 2006, Siswanto 2007).

Nomenclature

\(i\) Original points = Landfills in a village = 1, 2, ..., \(m\).

\(j\) Destination points = Transfer stations or the final disposal site = 1, 2, ..., \(n\).

\(k\) Vehicle type.

\(r\) Trip scheduled.

\(X_{ij}\) The distances between the original \(i\) and destination \(j\).

\(Y_k\) Average vehicle Speed by vehicle type \(k\).

\(tj\) Traffic jam rates (\%).

\(Z_{ijr}\) 1 - \(tj\) is levels of smooth traffic from \(i\) to \(j\) on trip \(r\).

\(C_k\) Costs per hour using the vehicle type \(k\).

\(H_{ijkr}\) Binary decision variables, it would be worth 1 for assignment of a vehicle type \(k\) to transport
waste from the original \(i\) towards destination \(j\) on the trip \(r\).

\(U_{ijkr}\) Integer decision variables, it would be representing the number of units fleet that assigned from
the original \(i\) towards destination \(j\) using \(k\) type on the trip \(r\).

\(M\) Huge number.
$J_k$  The number of vehicles type $k$.

$Cap_k$  The amount of capacities of vehicle type $k$.

$Un_i$  The minimum amount of undistributed waste.

3. State of The art

State of the art this research when we compare with other researches of the waste management system in metropolitan city, see table 1.

<table>
<thead>
<tr>
<th>Authors, Year</th>
<th>Location</th>
<th>Output</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lisye Fitria, Susy Susanty, Suprayogi, 2009</td>
<td>Bandung, Indonesia</td>
<td>Transportation route optimization</td>
<td>Vehicle Routing Problem with Multiple Trips and Intermediate Facility</td>
</tr>
<tr>
<td>This Research, 2012</td>
<td>DKI Jakarta, Indonesia</td>
<td>Model of assignment of waste transportation’s fleet</td>
<td>Linear Programming, Transportation Model, Travelling Salesman Problem</td>
</tr>
</tbody>
</table>

4. Methodology

The system engineering process approach is used in this research. After defining the objective, documenting the requirement from stakeholder by collecting and analyzing them will lead to the model requirement list needed, then analyzing the existing process using Functional Flow Block Diagram (FFBD) to design the optimization model. The model requirement list states that the model has to be configured the capacities, based on fleet type, and 1st and 2nd arrival-departure schedule, and the cost that can be reduced (System engineering fundamental, 2001). The flow process illustrated in figure 1.
5. Developing Optimization Model

In this research a model has been developed to solve the waste distribution problem using the approach of a binary system with integer linear programming. As it has been noted above that the main objective of this study was to determine the lowest cost of transportation fleet assignment. This assignment includes the type and departure schedule based on any of its trip.

5.1. Decision variables

The values of these variables provide the solution to the problem. This paper’s answer to this question should be fleet type assigned to a specific trip scheduled (Hijk).

5.2. The data needed

Data needed to build the model:

- The amount of distances from original to destination point.
- The amount of costs from transporting using each type of fleets.
- The number of percentages of traffic jam rates.
- The amount of average speeds of each type of fleets.
The amount of capacities of each type of fleets.

The demand to assign resources from landfills to final disposal site is assumed to depend on transportation fleet, the amount vehicle type, trip scheduled, traffic jam rates, the distance between landfills to final disposal site, average vehicle speed and costs per hour using the vehicle type. Waste transportation access affects to reduce the amount of household waste in each house. In this case assignment resources will be focused on the fleet (tool carrier) used by each district to transport waste from landfills in each village to the best of final disposal site. Purpose of this assignment models is assumed to maximize transportation cost savings with number and capacity of fleet, capacity of final disposal per day and capacity of landfills per day as constraint. Variables were defined to represent distance from landfills to final disposal, average vehicle speed by vehicle type, levels of smooth traffic from landfills to final disposal site on trip scheduled, and costs per hour using the vehicle type. This research using mathematical model with binary integer programming approach to assign fleet, based on the purpose and constraint.

5.3. Objective function

Initially the objective function was designed to minimize the total transportation cost stated below.

Verbal form:
Transportation cost is the number of hours of transporting waste from original to destination point using certain vehicle type on trip schedule multiple by costs per hour.

Decomposition:
Transportation cost = \[(The \ distances \ between \ i \ and \ j) \times \{(Average \ speed \ of \ k) \times (Levels \ of \ smooth \ traffic \ i-j \ on \ r)\}^{-1} \times (Costs \ per \ hour \ using \ k)\] \hspace{1cm} (3)

Since binary integer programming could not minimize it, so the objective function is modified as to maximize the transportation cost savings. Transportation Cost Saving is an initial transportation cost (initial assignment) reduced by transportation costs minimal (new assignment). Assume that initial transportation costs are a huge number represented by M number.

Verbal form:
Transportation cost saving is transportation cost before optimizing minus transportation cost after optimizing

Decomposition:
Transportation cost saving = Huge number – \[(The \ distances \ between \ i \ and \ j) \times \{(Average \ speed \ of \ k) \times (Levels \ of \ smooth \ traffic \ i-j \ on \ r)\}^{-1} \times (Costs \ per \ hour \ using \ k)\] \hspace{1cm} (4)

5.4. Mathematical model and its constraints

There is only one destination for every original landfill using certain vehicle. The total number of assignment cannot exceed the number of owned fleets. The total amount of unloading waste capacities cannot exceed the amount of the transfer stations or the final disposal site capacities. The constraints are
the decision variable have to be binary number and all of the variables must be non-negative number. Mathematical formulation for the problem in this paper shows in equation 5-9.

Objective: \[
Z = \text{Max} \sum_{i} \sum_{j} \sum_{k} \sum_{r} [M - (X_{ij} \cdot (Y_{ik} \cdot Z_{jr}) \cdot C_{kr})] \cdot U_{ijk} \cdot H_{ijk}
\]  

(5)

\(st-1: \quad \sum_{j} H_{ijk} = 1, \quad \forall i, \forall r, \text{and} \ \forall k\)  

(6)

\(st-2: \quad \sum_{i} \sum_{j} H_{ijk} \leq J_k, \quad \forall k, \text{and} \ \forall r\)  

(7)

\(st-3: \quad \sum_{j} \sum_{k} \sum_{r} H_{ijk} \cdot U_{ijk} \cdot \text{Cap}_k \leq U_{nj}, \quad \forall i\)  

(8)

\(st-4: \quad H_{ijk} = \text{binary}\)  

(9)

6. Case Study

Fleet scheduling of transportation model was developed by considering the number of fleet owned by the City Cleansing Department of East Jakarta as a case study. The fleet that owned by East Jakarta City Cleansing Department consists of various types and loading capacity, such as: arm roll, dump truck, truck, etc., see table 2. The type and loading capacity of each fleet is one of the constrain that are used to model scheduling. Another constrain to consider is the distance, based on the best of waste transportation routes, from district location to integrated landfills location or selected location for final disposal sites, as well as assumption of the levels of traffic jam and operational costs of transporting waste for each type. Transportation schedule is currently divided into 2 (two) trip schedule (the maximum that can be allocated). The schedule for each trip presented in table 3 (City Cleansing Department of East Jakarta, 2012). Trip schedule which has been implemented is also used in model development.

Table 2. Type and capacity of fleet owned by City Cleansing Department of East Jakarta

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Various type of fleet</th>
<th>Capacity (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Small Arm Roll</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Small Conveyor</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Large Arm Roll</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Large Conveyor</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Arm Roll Mobile</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Waste transportation schedule of East Jakarta

<table>
<thead>
<tr>
<th>Trip schedule</th>
<th>Time schedule</th>
<th>Departure schedule to integrated landfills (final disposal sites)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt;</td>
<td>05.00 – 12.00</td>
<td>08.00</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt;</td>
<td>13.00 – 17.00</td>
<td>15.00</td>
</tr>
</tbody>
</table>

Table 4. Fleet scheduling of waste transportation in Matraman District

<table>
<thead>
<tr>
<th>Village</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Trip</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt; Trip</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fleet Type</td>
<td>Units</td>
</tr>
<tr>
<td>Kebon Manggis</td>
<td>Type 2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>1</td>
</tr>
<tr>
<td>Kayu Manis</td>
<td>Type 2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>1</td>
</tr>
<tr>
<td>Utan Kayu Selatan</td>
<td>Type 2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>2</td>
</tr>
<tr>
<td>Pisangan Baru</td>
<td>Type 2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Type 4</td>
<td>1</td>
</tr>
<tr>
<td>Utan Kayu Utara</td>
<td>Type 4</td>
<td>1</td>
</tr>
</tbody>
</table>

Transportation scheduling model is developed by using data from the Matraman District. Matraman District consists of 6 (six) villages, but it is used for modeling scheduling only 5 (five) villages because they are directly managed by the City Cleansing Department of East Jakarta, while 1 (one) village is managed by private company (excluding research scope). Matraman District has 3 (three) types of fleet, i.e.: 6 units of type 2, 6 units of type 4, and 1 unit of type 5. Based on the formulation of mathematical models, equation 5-9, obtained fleet scheduling of Matraman District, see Table 4.

7. Conclusion

The output of this research is optimization model to assign the fleet of waste transportations in metropolitan cities. The model has been developed and validated in Matraman District, East of Jakarta by considering the number of fleet that owned by the City Cleansing Department of East Jakarta and their trip schedules. The model’s constraints are the type and loading capacity of each fleet, the distance from original location to the transfer stations or the final disposal site based on the best waste transportation routes, the assumption of the level of traffic jam in Jakarta, and the operational costs of transporting waste for each type of fleet. After all the fleet scheduling of waste transportation for each type of fleet and its final disposal site has been determined at the maximum saving of cost. This model is also referred to actual condition at the time of research or as close as it is.
References


