Determination of minimum trucks and routes used in the case of municipal solid waste transportation in Bandung City with greedy algorithm

Nur Alim Habibi*, Ari Yanuar Ridwan, Erlangga Bayu Setyawan
Industrial Engineering Department, Faculty of Engineering
Universitas Telkom

*nuralimhabibi@student.telkomuniversity.ac.id
ariyanuar@telkomuniversity.ac.id
erlanggabs@telkomuniversity.ac.id

Abstract. This study discusses the determination of the minimum number of trucks and the route of transporting the municipal solid waste, where the trucks provided have the heterogeneous capacity, namely 2 trucks with a capacity of 6 m³, and 2 trucks with a capacity of 10 m³. In this study, the heuristic method uses the greedy algorithm because it is expected that the optimal local will produce a global solution so that the expected total cost can be optimal. Based on trials conducted, obtained 3 solutions that might be used, the solution chosen using 2 trucks with a capacity of 10 m³.

1. Introduction
This study aims to determine the minimum number of trucks and the best route for assignment vehicles in the transportation of solid waste with the consideration of heterogeneous trucks, and intermediate facilities. This problem is part of the vehicle routing problem by minimizing cost [1][2]. In carrying out the solid waste transportation, Based of Figure 1. the truck starts the route from the depot, then the truck picks up the solid waste, which in Indonesia it is called a Tempat Pembuangan Sementara (TPS), then goes to an intermediate facility, which is a facility used to empty the load of truck, which in Indonesia it is called a Tempat Pembuangan Akhir (TPA), before the truck serves TPS again, and terminate route at the depot [3][4][5].

![Figure 1. Flow of Municipal Waste Transportation](image)

Determination of this route is very useful for related agencies for solid urban transportation to minimize the operational costs because every day the amount of waste is fluctuating, so we need the right approach to determine the route for vehicles every day, so it can also be determined the minimum number of trucks that need to be provided [6]. If this approach is implemented, it will be very good for related agencies to minimize operational costs.

2. Method and Data
2.1. Data
The sample data used in this study came from the cleanliness department of the city of Bandung, here are the data data used in this study.
2.1.1 Data Demand of TPS

Table 1. Demand of TPS

| Code of TPS | Name of TPS   | Demand ($\rho_i^T$) |
|-------------|---------------|---------------------|
| TPS01       | Bintara       | 6 m$^3$             |
| TPS02       | Pemkot        | 5 m$^3$             |
| TPS03       | Patrakomala   | 7 m$^3$             |
| TPS04       | Binongjati    | 5 m$^3$             |
| TPS05       | Batununggal Indah | 6 m$^3$   |
| TPS06       | Cidurian      | 10 m$^3$            |

2.1.2 Data Capacity Truck

Table 2. Capacity of Truck

| Code of Truck Existing (k) | Capacity ($\Omega_i^T$) | Maximal Waste Transported (if maximal trip = 2) |
|----------------------------|------------------------|-----------------------------------------------|
| Truck A01                  | 6 m$^3$                | 12 m$^3$                                      |
| Truck A02                  | 6 m$^3$                | 12 m$^3$                                      |
| Truck B01                  | 10 m$^3$               | 20 m$^3$                                      |
| Truck B02                  | 10 m$^3$               | 20 m$^3$                                      |

2.1.3 Data Cost

Table 3. Variant of Cost

| Code of Truck Existing (k) | Fix Cost ($\phi_k$)  | Fuel Cost ($\beta_k$) | Labor Cost ($\theta_k$) |
|----------------------------|----------------------|-----------------------|-------------------------|
| Truck A01                  | Rp 67.000            | Rp 858 / km           | Rp 13.900 / Hour        |
| Truck A02                  | Rp 67.000            | Rp 858 / km           | Rp 13.900 / Hour        |
| Truck B01                  | Rp 80.000            | Rp 1.030 / km         | Rp 15.100 / Hour        |
| Truck B02                  | Rp 80.000            | Rp 1.030 / km         | Rp 15.100 / Hour        |

2.1.4 Data Time Window

Table 4. Time Window

| Time Window | Open ($\lambda_i$) | Closed ($\pi_i$) |
|-------------|--------------------|------------------|
| TPS01       | 06:00:00           | 15:00:00         |
| TPS02       | 06:00:00           | 15:00:00         |
| TPS03       | 06:00:00           | 15:00:00         |
| TPS04       | 06:00:00           | 15:00:00         |
| TPS05       | 06:00:00           | 15:00:00         |
| TPS06       | 06:00:00           | 15:00:00         |
| TPA         | 06:00:00           | 17:00:00         |
2.1.5 **Data Maximum Tour Truck**

**Table 5. Maximum Tour Duration of Truck**

| Code | Maximal Tour Truck |
|------|-------------------|
| H    | 11 Hours          |

2.1.6 **Data Loading/Unloading**

**Table 6. Time of Loading/Unloading**

| Code | Time of Loading/Unloading |
|------|---------------------------|
| ε<sub>i</sub> | 2.5 Minutes / m<sup>3</sup> | 0.0417 Hour / m<sup>3</sup> |

2.1.7 **Data Velocity of Truck**

**Table 7. Velocity Of Each Truck**

| Name of Truck | Velocity (<i>R</i><sub>k</sub>) |
|---------------|-------------------------------|
| Truck A01     | 40 km / hour                  |
| Truck A02     | 40 km / hour                  |
| Truck B01     | 35 km / hour                  |
| Truck B02     | 35 km / hour                  |

2.1.8 **Data Distance from i to j**

**Table 8. Distance Matrix from i to j**

| i/j | TPS01 | TPS02 | TPS03 | TPS04 | TPS05 | TPS06 | Depo | TPA |
|-----|-------|-------|-------|-------|-------|-------|------|-----|
| TPS01 | 1.59  | 4.01  | 3.32  | 5.48  | 4.39  | 4.64  | 48.7 |
| TPS02  | 3.3   | 4.17  | 4.81  | 5.64  | 4.55  | 4.8   | 47.8 |
| TPS03  | 2.46  | 2.47  | 1.9   | 2.73  | 1.64  | 1.89  | 50.2 |
| TPS04  | 3.52  | 3.75  | 1.27  | 2.73  | 2.91  | 3.16  | 49.1 |
| TPS05  | 5.03  | 5.05  | 2.57  | 2.36  | 3.57  | 3.81  | 50.7 |
| TPS06  | 2.55  | 1.94  | 1.85  | 2.49  | 3.32  | 0.244 | 50.8 |
| Depo   | 2.8   | 2.19  | 2.09  | 2.73  | 3.56  | 0.244 | 51   |
| TPA    | 51.4  | 47.2  | 49    | 48.5  | 50.4  | 50.6  | 50.9 |

2.2. **Method**

The method used in this research is the heuristic approach using the greedy algorithm. The greedy algorithm was chosen because it is based on the greedy assumption that the local optimum will produce a global optimum, so it is expected to reach the minimum total cost [7]. The following are sets, indexes, parameters, decision variables, and objective functions of the solution that will be used in this study.

**Set**

- <i>O</i>' = Starting Location (Depo)
- <i>O</i>'' = Final Location (Depo)
- <i>D</i> = Tempat Pembuangan Akhir (TPA)
- <i>P</i> = Tempat Pembuangan Sampah (TPS01, TPS02, ..., TPS05)
- <i>K</i> = Number of Truck Available (A01, A02, B01, B02)
- <i>N</i> = <i>O</i>' ∪ <i>O</i>'' ∪ <i>D</i> ∪ <i>P</i>
Index

\[ i = \text{Index TPS, TPA, or Depo for starting point} \]
\[ j = \text{Index TPS, TPA, or Depo for final location} \]
\[ k = \text{Index of truck} \]

Parameter

\[ \pi_{ij} = \text{arc distance from i to j (km)} \]
\[ \tau_{ijk} = \frac{\pi_{ij}}{R_k}, \text{is travel time from i to j (hour)} \]
\[ \varepsilon_i = \text{loading/unloading time at point i (hour)} \]
\[ [\lambda_i, \pi_i] = \text{Time Window in i, from open to closed (hour)} \]
\[ H = \text{Maximal operational time (hour)} \]
\[ \rho_i^v = \text{Waste demand in } i \text{ (m}^3\text{)} \]
\[ \Omega_k^v = \text{Maximal capacity of truck } k \text{ (m}^3\text{)} \]
\[ \phi_k = \text{Fixed cost truck } k \text{ (Rp)} \]
\[ \beta_k = \text{Fuel cost truck } k \text{ (Rp } / \text{km)} \]
\[ \theta_k = \text{Labor cost (Rp } / \text{hour)} \]

Decision Variable

\[ x_{ijk} = \begin{cases} 
1 & \text{if use truck } k \text{ with arc (i,j)} \\
0 & \text{if another} 
\end{cases} \]
\[ y_k = \begin{cases} 
1 & \text{if use truck } k \\
0 & \text{if another} 
\end{cases} \]
\[ Q_{ik}^p = \text{Cumulative waste transported by truck } k \text{ at point } i \text{ (continuously)} \]
\[ S_{ik}^p = \text{Cumulative time use of truck } k \text{ at point } i \text{ (continuously)} \]

Objective Function (Minimize)

\[ f = \sum_{k \in K} (\phi_k y_k + \beta_k \sum_{i \in N} \pi_{ij} x_{ijk} + \theta_k (\sum_{j \in O'} S_{jk} - \sum_{i \in O'} S_{ik})) \]

Constrain,

1. Ensure that each route i to j is visited by exactly one truck k
\[ \sum_{k \in K} \sum_{j \in D \cup P} x_{ijk} = 1, \quad \forall i \in P \] (2)

2. Ensuring that the truck starts the tour from Depo, and then visit to the TPS, then visits the TPA before the truck back to depo
\[ \sum_{i \in O'} \sum_{j \in N} x_{ijk} = y_k, \quad \forall k \in K \] (3)
\[ \sum_{i \in D} \sum_{j \in O'} x_{ijk} = y_k, \quad \forall k \in K \] (4)

3. Make sure the truck ends the trip at the depo
\[ \sum_{i \in N} x_{ijk} = 0, \quad \forall k \in K, j \in O' \] (5)
\[ \sum_{j \in N} x_{ijk} = 0, \quad \forall k \in K, i \in O'' \] (6)

4. Ensure that the truck will visit point j, and leave point j to point i
\[ \sum_{i \in N \setminus O''} x_{ijk} = \sum_{i \in N \setminus O'} x_{ijk}, \quad \forall k \in K, j \in D \cup P \] (7)

Figure 2. Constrain
5. Ensure that the cumulative volume of the load must not exceed the truck’s load capacity

\[ Q_{ik}^v \leq \Omega_{ik}^v, \quad \forall k \in K, i \in P \]  \hspace{1cm} (8)

6. Ensure that the truck will unloading of load in TPA

\[ Q_{ik}^u = 0, \quad \forall k \in K, i \in N \setminus P \]  \hspace{1cm} (9)

7. Ensure all demands are transported by the truck

\[ Q_{ik}^u + \rho_j^i \leq Q_{ik}^v + (1 - x_{ijk})M, \quad \forall k \in K, i \in N \setminus O', j \in P \]  \hspace{1cm} (10)

8. Ensure that the cumulative time of the vehicle at point i, plus the loading / unloading time of waste at point i, plus the travel time from point i to point j must be less than or equal to the cumulative time of the truck up to point j

\[ S_{ik} + \varepsilon_i + \tau_{ijk} \leq S_{jk} + (1 - x_{ijk})M, \quad \forall k \in K, i \in N \setminus O', j \in N \setminus O' \]  \hspace{1cm} (11)

9. Ensure that the cumulative time of the truck at point i, does not exceed time window in i

\[ \lambda_i \sum_{j \in O'} x_{ijk} \leq S_{ik} \leq \mu_i \sum_{j \in N \setminus O'} x_{ijk}, \quad \forall k \in K, i \in N \setminus O' \]  \hspace{1cm} (11)

10. Ensure that the cumulative time of the truck does not exceed the maximum duration of the maximum operational time of the truck

\[ \sum_{j \in O'} S_{jk} - \sum_{i \in O'} S_{ik} \leq H, \quad \forall k \in K \]  \hspace{1cm} (12)

11. The decision variable \( x_{ijk}, y_{ik} \) is a binary value

\[ x_{ijk}, y_{ik} \in \{0, 1\}, \quad \forall k \in K, i, j \in N \]  \hspace{1cm} (13)

12. Ensure that cumulative volume, and time service at point i is more than or equal to 0

\[ Q_{ik}^u, S_{ik} \geq 0, \quad \forall k \in K, i \in N \]  \hspace{1cm} (14)

**Figure 3. Constrain (continuous)**

Based on Figure 2, and Figure 3, Determination of the solution using the greedy algorithm is based on a mathematical model that has been developed, assuming that the maximum number of trips is 2 to match the problems that exist in Indonesia [8]. Step 1, choose truck with the smallest fix cost. Step 2, start the truck from the depo, then visit the TPS with the most optimum distance, and make sure it is in the TPS time window range, if not, then visit the next TPS. Step 3, check the truck capacity is still sufficient, if it is still enough, then visit the next TPS. Step 4, visit the TPA if the truck capacity is full. Step 5, visit the depo when the truck operational time is up or reach the maximum trip. Step 6, if the operational time, or vehicle trip reaches a maximum, then assign the next available truck. The process will end when all TPS are served, or the number of truck is insufficient. After the above steps are carried out, the total costs will be incurred by the distance, time, and the number of vehicles.

3. Results and Discussion

3.1. Result of Total Distance, and Total Time From Route

Based on the amount of solid waste that needs to be transported, 3 combinations need to be checked, this combination is done by changing the truck used. The following is the route that results from 3 possible combinations.

**Table 9. Result of Total Distance and Total Time**

| Code of Truck Use | Route | Route Sequence (with demand transported) | Total Distance | Total Time \((S_j - S_i)\) |
|-------------------|-------|----------------------------------------|---------------|------------------|
| A01               | Route 1 | Depo - TPS06 (6) - TPA - TPS03(6) - TPA - Depo | 201,044    | 6,027           |


3.2. Result of Total Cost

The following table is the result of a comparison of each combination used, where the smallest total cost is a route with combination 3, which is Rp 816,461.

| Route Combination | Total Cost |
|--------------------|------------|
| Combination 1      | Rp 1,051,002 |
| Combination 2      | Rp 1,121,094 |
| Combination 3      | Rp 816,461  |

4. Conclusion

Research has been conducted to produce the best route for the city of Bandung cleanliness department. Based on the comparison that has been done, the best solution is obtained by assigning trucks with a capacity of 10 m$^3$, with the sequence of routes by route combination 3, because route combination 3 has the total cost generated at the lowest value compared to the other two combinations, which is Rp 816,461. Based on these results also, it appears that operating a truck with a large capacity will be able to save total costs.

5. References

[1] A Desiana, AY Ridwan, R Aurachman, in *Jurnal Rekayasa Sistem & Industri*, 2016
[2] AF Abdurrahman, AY Ridwan, B Santos, *Jurnal Rekayasa Sistem & Industri*, 2019
[3] R. A. Putra, in *Proceeding Universitas Negeri Yogyakarta*, Yogyakarta, 2014.
[4] M. N. Ramdhani, I. Baihaqi and N. Siswanto, in *International Conference on Industrial and System Engineering (IConISE) 2017*, 2017.
[5] L. Fitria, S. Susanty, and Suprayogi, in Jurnal Teknik Industri ITB 2009, 2009.
[6] M. N. Ramdhani, I. Baihaqi and N. Siswanto, "Master Theses," Institute Technology Surabaya, Surabaya, 2017.
[7] E. N. Hayati and A. Yohanes, in *Seminar Nasional IENACO*, 2014.
[8] I. Markova, S. Varoneb and M. Bierlaire, *Elsevier: Transportation Research Part B*, pp. 1-18, 2015.