Municipal solid waste transportation optimisation with vehicle routing approach: case study of Pontianak City, West Kalimantan

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Abstract. Municipal solid waste (MSW) transportation in Pontianak City becomes an issue that need to be tackled by the relevant agencies. The MSW transportation service in Pontianak City currently requires very high resources especially in vehicle usage. Increasing the number of fleets has not been able to increase service levels while garbage volume is growing every year along with population growth. In this research, vehicle routing optimization approach was used to find optimal and efficient routes of vehicle cost in transporting garbage from several Temporary Garbage Dump (TGD) to Final Garbage Dump (FGD). One of the problems of MSW transportation is that there is a TGD which exceed the the vehicle capacity and must be visited more than once. The optimal computation results suggest that the municipal authorities only use 3 vehicles from 5 vehicles provided with the total minimum cost of IDR. 778,870. The computation time to search optimal route and minimal cost is very time consuming. This problem is influenced by the number of constraints and decision variables that have are integer value.

1. Introduction

The volume of waste generated from household waste, offices, markets and public facilities in Pontianak reaches 1,807 m³ of waste per day [1]. Pontianak City has 114 temporary garbage dumps (TGD) located at 58 points and spread in 6 Sub-districts [1]. The volume of waste that can be accommodated at all pooling stations in Pontianak city is 655,525 m³ of waste consisting of 493.03 m³ at market GD, 122 m³ at office GD, 26 m³ of garbage at public facility and 14.50 m³ at industrial area GD. These conditions forced Pontianak City Sanitation Office to impose three categories of transportation, namely regular transportation, overtime transportation and transportation by involving the cooperation with the third party. On regular garbage transportation, the total volume of waste that can be transported is 972 m³ per day. The garbage transportation with the total amount of waste that can be transported is 394 m³ of garbage every day. Transportation of waste with the cooperation of the third party is able to transport the waste as much as 120 m³.

High waste volume requires vehicle and greater freight frequency. These resulted in high costs and vehicle operating expenses, particulary if there are damaged or repaired vehicles. As a result, the level
of waste transportation services in Pontianak city can only reach its maximum service level is 85% and tends to decrease along with the increase of population every year resulting in an increase in the volume of waste. Pontianak City Government still has to work hard to improve the service and of course it needs to spend very big cost for garbage transportation. The cost of MSW transportation in this city is still very high. Thus, the MSW transportation study by considering vehicle routing is necessary. Therefore, this study is intended to minimise the number of vehicles, lower operational costs and vehicle maintenance, maximise vehicle utility, and maximise waste hauling at TGD.

2. Materials and Methods
The method of MSW transport optimisation in Pontianak City in this study uses the vehicle routing approach or often called as vehicle routing problem (VRP) method. In this method, it is assumed that the vehicle capacity is the same and each node is visited only once. The demand for each node is assumed not to exceed the vehicle's capacity. The vehicle journey begins from the vehicle depot then proceeds at each point to meet the demand per vehicle load limit and ends back at the vehicle depot [2]. The assumption used in the method makes the VRP approach still very common to be applied in the case of MSW transportation. Therefore it is necessary to add decision variables and constraint to see the actual conditions closer.

Transportation of MSW from one or more TGD to final garbage dump (FGD) needs to take into consideration the following aspect: the number and capacity of the fleet used, the operational cost of each vehicle, the volume of waste from each TGD, the distance from the TGD to the FGD and the distance between one TGD and another TGD. Each assigned vehicle transports the garbage from the Depo of the vehicle to a TGD or more to the FGD and return to the Depo vehicle when there is no garbage in the TGD to be transported. One vehicle can transport more garbage than one TGD if the garbage volume at the previous TGD is less than the capacity of the vehicle [3,4].

Vehicles that have reached maximum capacity move towards the TGD to clear the load. The vehicle returns to the Depo vehicle if there is no garbage in the TGD to be transported. If there is still waste left in GD that cannot be transported in advance because it exceeds the maximum capacity of the vehicle, the vehicle must return to the TGD to pick the remaining waste or be transported by another vehicle. Therefore, a TGD can be visited more than once by the same carrier or other vehicles. The approach used for transporting waste is commonly known the vehicle routing with split-deliveries [3]. Another combination approach is called the mix-vehicle capacities, used when the vehicle capacity for transporting the garbage is not identical [5].

The main purpose of the VRP method is to investigate the cost-effective routes for transporting the MSW [2]. The vehicle routing case, especially garbage hauling, is a linear integer programming problem, where the resulting decision variable must be in a rounded form. Therefore, the problem needs to be solved by integer programming. One of the reliable integer programming algorithms for the case is the Branch and Bound method. The Branch and Bound method divides each solution in linear programming into sub-solutions for rounding each sub-solution, the value of the continuous optimum solution of the purpose function is set as the upper limit. The best round solution becomes the lower limit. Sub-solution with a lower limit than the existing lower border is not included in the next analysis. A feasible integer solution is either as good as or better than the upper limit for each sub-solution sought. If such a solution occurs, a sub-issue with the best upper limit is selected for branching [6].

3. Modelling
3.1. Model restriction and assumption
The model of MSW transport in this study is formed using basic model of VRP by imposed some constraints. These constraints are used in order to relax the limitation of vehicle trip to the TGD. The TGD can be visited by more than one vehicle with the same vehicle or different vehicle. Vehicle operating costs are assumed to be part of transportation costs per vehicle for every kilometre travelled. The MSW volume from each TGD is assumed to be fixed in one day and does not increase during the
transportation time. All types of vehicles are assumed to pass the route from the TGD to the FGD without any obstacles. All vehicles are in good operation and are capable of transporting waste in accordance with their maximum capacity.

3.2. Model formulation

3.2.1. Sets

| Notation | Definition |
|----------|------------|
| $N$      | The set of TGD having a volume of less than or the same as the vehicle maximum capacity = $(2,3,\ldots,n)$, |
| $M$      | The set of TGD having a volume exceeding the vehicle maximum capacity = $(n+1,n+2,\ldots,n+m)$, |
| $S$      | The set of all node = $(1,2,\ldots,n,n+1,n+2,\ldots,n+m,n+m+1)$, as 1 states the depo and $n+m+1$ states the TGD |
| $V$      | The set of all vehicles = $(1,2,\ldots,v)$. |

3.2.2. Indexes

| Notation | Definition |
|----------|------------|
| $i,j,p$  | Indexes to state the node, |
| $k$      | Indexes to state the vehicle |

3.2.3. Parameters

| Notation | Definition |
|----------|------------|
| $S_i$    | The garbage volume on node $i$. |
| $w_k$    | Vehicle capacity $k$. |
| $c_k$    | The cost of transportation per km on the transportation of $k$. |
| $d_{ij}$ | the distance of node $i$ and node $j$ |
| $BigM$   | Positive constants having a relatively bigger value |

3.2.4. Decision Variables

| Notation | Definition |
|----------|------------|
| $f_{ik}$ | Part of garbage volume on node $i$ transported by vehicle $k$. |
| $Q_{ik}$ | The garbage cumulative volume on vehicle $k$ after leaving node $i$. |
| $N_k$    | The number of vehicle retaking to $k$. |
| $x_{ijk}$| It scores 1 if vehicle $K$ visits node $j$ after node $i$ and it scores 0 if it is on the contrary. |
| $y_k$    | It scores 1 if vehicle $k$ is used to transport garbage and it scores 0 if it is on the contrary |
3.2.5. **Objective Function**

Notation

\[ \sum_{k \in V} \sum_{j \in S} \sum_{i \in S} c_{kji} x_{ijk} \]

Definition

The objective function in this model aims to determine the garbage transportation route for the purpose of minimising the total transportation cost.

3.2.6. **Constraints**

Definition

Not every vehicle leaves the depot

\[ \sum_{j \in M \setminus N} x_{ijk} \leq 1, \forall k \in V \]

Vehicles leaving the depot will be used to transport garbage,

\[ \sum_{j \in M \setminus N} x_{ijk} = y_k, \forall k \in V \]

No node visited by unused vehicle,

\[ x_{ijk} \leq y_k, \forall i, j \in S, \forall k \in V \]

Vehicles visiting the node must leave the node

\[ \sum_{i \in S} x_{ipk} - \sum_{j \in S, p \neq j} x_{pkj} = 0, \forall p \in S, \forall k \in V \]

TGD with garbage volume of less than or equal to the maximum capacity of vehicles is visited exactly once,

\[ \sum_{k \in V} \sum_{i \in S} x_{ijk} = 1, \forall j \in N \]

TGD with waste volume exceeding the maximum capacity of vehicles are visited more than once,

\[ \sum_{j \in S} f_{ik} = 1, \forall i \in M, \forall k \in V \]

Cumulative waste volume on vehicles leaving TGD will increase

\[ Q_{ik} + s_j - Q_{jk} \leq (1 - x_{ijk}) \text{BigM}, \forall j \in N, \forall i \in S, \forall k \in V \]

\[ Q_{ik} + f_{ik} s_j - Q_{jk} \leq (1 - x_{ijk}) \text{BigM}, \forall j \in M, \forall i \in S, \forall k \in V \]

Constraints of non-negativity,

\[ Q_{ik} \geq 0, \forall i \in S, \forall k \in V \]

\[ 0 \leq f_{ik} \leq 1, \forall i \in M, \forall k \in V \]

Binary constraint

\[ x_{ijk} \in \{0, 1\}, \forall k \in V, \forall i, j \in S \]

\[ y_k \in \{0, 1\}, \forall k \in V \]
The vehicles used should visit the landfill
\[ \sum_{i \in N \cup M} x_{i(n+m+1)k} \leq y_k, \forall k \in V. \]

3.3. Model implementation

The model implementation of garbage transport can be seen in Figure 1. The transport vehicles move starting from the Depo to the TGDs to pick up the scattered waste in several villages. The vehicles continue to haul the garbage up to the maximum capacity of the vehicle. After reaching maximum capacity, the vehicles move to the TGDs to dispose the garbage and empty its load. Then, the vehicle has two options, namely moving to the vehicle Depo or taking the remaining garbage that cannot be transported at the previous TGDs.

\[ \text{Figure 1. Waste transportation mechanism} \]

The optimisation research on garbage transportation was focused on Darat Sekip Village of Pontianak Kota sub-district. In this area, there are 6 TGDs with total capacity equal to 63.62 m³. There is a polling station with a volume of garbage 40.38 m³ located on Jalan Matahari Timur. The location and volume of waste of each TGD can be seen in Table 1 below. This study is limited to six polling stations in Pontianak sub-district because the area is located in the middle of the city. In addition, the area has a high waste load that will disturb the cleanliness and comfort of the city therefore it needs more attention.

\[ \text{Table 1. The location and volume of TGD waste.} \]

| No | Location     | Subdistrict | Volume (m³) |
|----|--------------|-------------|-------------|
| 1  | Jl Serayu    | Darat Sekip | 3.99        |
| 2  | Jl Matahari Timur | Darat Sekip | 40.38      |
| 3  | Jl Tanjungpura Indah | Darat Sekip | 5.03        |
| 4  | Jl KH. Ahmad Dahlan | Darat Sekip | 5.88        |
| 5  | Jl HOS Cokroaminoto | Darat Sekip | 5.88        |
| 6  | Jl Wolter Monginsidi | Darat Sekip | 2.46        |

|     | Total        |             | 63.62       |

The garbage transport vehicles owned by the Pontianak City Government consisted of several types and each vehicle has different transport capacity variations. In this research, the vehicles used were limited to the types of large vehicles (i.e. big trucks and Armroll Trucks). Both types of trucks are the vehicles that are mostly used and considered reliable in carrying out waste transport activities. Five
unit vehicles were allocated for garbage transportation at Pontianak Kota Sub-district. The volume of vehicle transport and travel expenses for each vehicle can be seen in Table 2.

### Table 2. Characteristics of waste transportation vehicles.

| Transportation Type | Volume of Vehicles (m³) | Travel expense (IDR per km) | Unit Amount |
|---------------------|-------------------------|-----------------------------|-------------|
| Dump Truck          | 16.98                   | IDR 30,000                  | 3           |
| Armroll Truck       | 11.32                   | IDR 25,000                  | 2           |

Based on the data from TGD, vehicle depo, and FGD, the nodes or points that must be visited in the routing of garbage transport vehicles can be determined. Distance of each node is used to calculate the cost of the vehicle from each transport route. Node 1 states the vehicle depo is located in the Sanitation Service of Pontianak City, while Node 8 states the FGD. Both nodes do not have capacity because they serve as the starting point and dumping point. Nodes 2 up to 6 are TGD with variations in the volume of waste that must be transported as shown in Table 3.

### Table 3. Point (node) used in the model.

| Node | Description       | Location                        | Capacity (m³) |
|------|-------------------|---------------------------------|---------------|
| 1    | Vehicles Depot    | Sanitary agency of Pontianak city| -             |
| 2    | TGD 001           | Jl Serayu                       | 3.99          |
| 3    | TGD 002           | Jl Matahari Timur               | 40.38         |
| 4    | TGD 003           | Jl Tanjungpura Indah            | 5.03          |
| 5    | TGD 004           | Jl KH. Ahmad Dahlan             | 5.88          |
| 6    | TGD 005           | Jl HOS Cokroaminoto             | 5.88          |
| 7    | TGD 006           | Jl Wolter Monginsidi            | 2.46          |
| 8    | FGD               | Kecamatan Batulayang            | -             |

Based on the data, nodes are made the distance matrix that connects each node. The matrix represents the mileage each vehicle must pass when transporting garbage from the vehicle depots to the TGD. Table 4 shows the distance between nodes from Depo to TGD.

### Table 4. Distance between nodes (km).

| Node | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|------|----|----|----|----|----|----|----|----|
| 1    | 0  | 4.8| 4.2| 5.1| 5.3| 5.4| 5.2| 14.6|
| 2    | 5.3| 0  | 0.95| 2.4| 2.6| 2  | 1.8| 8  |
| 3    | 4.4| 0.95| 0  | 2.4| 2.6| 2  | 1.8| 8  |
| 4    | 6.6| 2.4| 1.9| 0  | 0.7| 0.8| 0.5| 7  |
| 5    | 7.3| 3.6| 2.5| 1.2| 0  | 0.079| 1.4| 7.1|
| 6    | 7  | 2.9| 2.4| 1.2| 0.079| 0  | 1  | 7.2|
| 7    | 6.6| 2.4| 1.3| 0.19| 0.23| 0.3| 0  | 7.2|
| 8    | 14 | 6.5| 5.8| 6.3| 6.7| 6.7| 6.5| 0  |

### 4. Results and Discussion

Based on the calculation obtained, it was found that 3 vehicle with 3 routes are able to transport all the volume of waste in Pontianak Kota District optimally with the lowest cost. The route of the 3 vehicles is the best route that will provide the least cost. The total cost generated by the 3 routes through which 3 vehicles are IDR 778,870. The calculation results show optimum global solution parameters which
means the solution is the best solution in terms of the number of vehicles used, the route travelled and the cost incurred. The global optimal solution is the best search result above the near optimal and satisfied solution criteria [7]. Computational results can be seen in Figure 2. Vehicles used for garbage transport at 6 TGD in Pontianak Kota sub-district are as many as 3 vehicles out of 5 vehicles. The 3rd vehicle must visit node 3 twice as the volume of garbage if the node exceeds the maximum capacity of the vehicle. The vehicle route and the volume of waste that can be transported by each vehicle can be seen in Table 5.

**Table 5. Route of garbage transport.**

| Code Transport | Type of Transport | Trip | Transportation route |
|----------------|-------------------|------|----------------------|
| TRCK001        | Big Truck         | 1    | 1 → 2 → 3 → 8 → 1   |
|                |                   |      | [0] [3.99] [11.46] [0] [0] |
| TRCK002        | Big Truck         | 1    | 1 → 3 → 4 → 8 → 1   |
|                |                   |      | [0] [11.94] [5.03] [0] [0] |
| TRCK003        | Big Truck         | 2    | 1 → 3 → 8 → 7 → 6 → 5 → 8 → 1 |
|                |                   |      | [0] [16.95] [0] [0] [0] [0] |

**Figure 2.** Minimum cost of transport routing with Branch and Bound algorithms

The model built on the waste transport research in Pontianak City consist of 360 decision variables which 285 of them are in the form of integer variables. Meanwhile, the constraints in the created mathematical model consisted of 657 constraints. The number of variables and constraints raised generated the solution space in the search for optimal value becomes very large. In addition, most variables are integer constraints. The amount of search space and enumeration of candidate solutions into variables make the complexity of the problem higher [8]. The consequence is that the time spent on finding the optimal solution becomes very long. In this research, it took a computation time of
1:00:45, to find the minimal cost of the vehicle routing with 8 points (node) of TGD and 5 vehicles. The computation time of optimal solution could affect the application of vehicle route optimisation with the number of points and larger vehicles. The computation time is affected by the type of variables and constraints.

5. Conclusion
The findings confirmed that the obtained minimum cost of MSW transportation in Pontianak City was equal to IDR 778,870, - for one day. The computation results suggest that the most optimal solution is to use 3 travel routes for MSW transport with only 3 vehicles from the total of 5 vehicles provided. Particularly on the third vehicle, it must carry two trips to transport garbage at the third TGD because it exceeds the carrying capacity. The computation time to find the optimal solution is still very high because of the number constraints and integer decision variables. Therefore, the complexity to find the optimal solution is needed to be further studied by simplifying the model equations and using better searching algorithms.

References
[1] Lestari S, Nurlaili S, Fitrianingsih Y 2016 Evaluasi pengangkutan sampah kota Pontianak (Evaluation on the municipal solid waste transportation in Pontianak City) J. Mahasiswa Teknik Lingkungan UNTAN 1 1–10 [In Indonesian]
[2] Vigo D, Toth P 2014 Vehicle Routing: Problems, methods, and Applications 2nd Edition mathematical Optimization Society Bologna Italy 467
[3] Sahoo S, Kim S, Kim B-I, Kraas B, Popov A 2005 Routing optimization for waste management Interfaces 35 24–36
[4] Son L H, Louati A 2016 Modeling municipal solid waste collection: A generalized vehicle routing model with multiple transfer stations, gather sites and inhomogeneous vehicles in time windows Waste Manag. 52 34–49
[5] Golden B, Assad A, Levy L, Gheysens F 1984 The fleet size and mix vehicle routing problem Comput. Oper. Res. 11 49–66
[6] Archetti C, Bianchessi N, Speranza M G 2014 Branch-and-cut algorithms for the split delivery vehicle routing problem Eur. J. Oper. Res. 238 685–98
[7] Fischetti M, Toth P, Vigo D 1994 A Branch-and-bound algorithm for the capacitated vehicle routing problem on directed graphs Oper. Res. 42 846–859
[8] Klein C M, Morin T L 1991 Conjugate duality and the curse of dimensionality Eur. J. Oper. Res. 50 220–8