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Municipal solid waste vehicle routing optimization based on region clustering of Pontianak City West Kalimantan

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Abstract. Solid waste optimization transportation using vehicle routing approach becomes one of the most commonly used techniques to find the most optimal solution with various goals and constraints. Various forms of constraints imposed to the model in order to build closer real world problem. But this approach has an impact on the complexity of the model made and the timing of the calculation that must be taken to obtain optimal results. In previous study, to find the optimal solution of the model made with 6 Temporary Garbage Dump (TGD) takes 1 hour and 5 minutes. Therefore, in this research, we conducted clustering approach to categorize the large number of TGD location in Pontianak City into small cluster and furthermore we consider the results to conduct route optimization of the solid waste transportation vehicle from TGD to the Final Garbage Dump (FGD). The calculation results show that of the 5 clusters formed only 1 cluster can achieved optimal global conditions in vehicle routing, namely cluster 4. This is because the variable dimensions used are still very large, thus further research is needed.

1. Introduction

Pontianak is the regional capital of West Kalimantan which has a population around 621,650 people [1]. Population growth is very influential with the occurrence of waste problems, namely changes in consumption patterns and people's lifestyles that can increase the amount of waste generation, types, and diversity of waste characteristics. Increased volume of waste generation requires management. Waste management organized by the municipal department focuses on collecting and transporting to the Final Garbage Dump (FGD) [2].

Most of the garbage transportation in Pontianak City uses the HCS (Hauled Container System), which is a garbage collection system where the collection container can be moved and brought to the final disposal site. In this HCS system, the transportation pattern used is the emptying pattern of the container, where the truck arm roll containing empty containers will be taken to the TGD and exchanged with a fully loaded container. Given the high volume of waste in Pontianak City, an integrated garbage transport mechanism is needed.

The mechanism for transporting municipal solid waste is expected to be a cost and environmental effective solution [3]. The transport of solid waste is considered to be one of the biggest components that

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contribute to the allocation of waste management costs. According to [4] low and middle income countries spend 80% - 90% and 50% - 80% of the waste management budget, especially solid waste. Therefore, MSW transportation is one of the interesting studies to always find a solution[5,6].

A study of waste in urban areas will help local civil authorities to develop a good waste management strategy, especially in urban areas, one of which is to minimize transportation and waste transportation costs [7]. Optimizing the collection and transportation of waste is an important aspect in the design of transportation systems and garbage transportation. The existence of temporary landfills that are spread heterogeneously in every corner of the city, will cause an increase in resources in garbage collection and especially transportation costs [8]. The proper mechanism for collecting and transporting solid waste can reduce transportation costs significantly.

2. Data Collection and Research Method

2.1. Data collection

TGD location data was obtained from secondary data provided by the Pontianak City Environmental Service. The data includes the TGD location points based on the latitude and longitude coordinates and the amount of waste volume in each location. The coordinates of latitude and longitude are used as a determinant of the location of TGD locations and as a reference for calculating the distance between TGD points. The distance calculation between TGD points is conducted by using Google Map © to obtain an accurate and realistic distance.

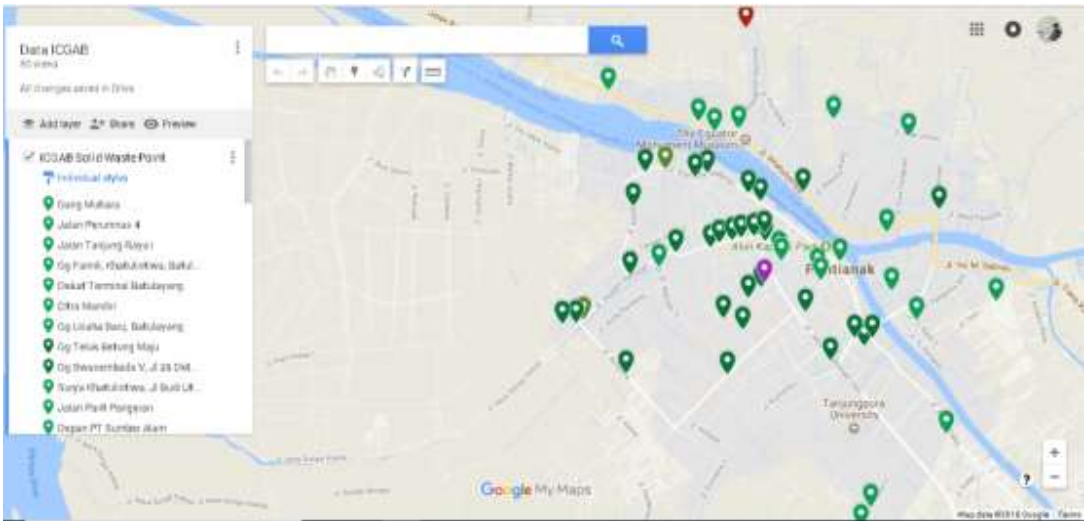


Figure 1. Node location.

The distance between nodes (TGD, FGD and Vehicle Depo) was used as asymmetrical distance matrix in vehicle route optimization. In addition to data on location and volume of waste, data were also obtained on the number and type of vehicles, vehicle operating costs and the capacity of each vehicle. Based on the data obtained, there are 52 points of temporary landfill, where each point consists of 2-3 garbage collection containers with HCS system. Only a few polling stations are permanently built using cement tanks. The total amount of trash bins recorded in the Pontianak city environmental service is 114 temporary garbage dump (TGD). Each polling station is evenly distributed in 6 sub-districts in the entire city of Pontianak. The location of each FGD can be seen in Figure 1.

Table 1. Vehicle type and capacity.

No	Vehicle Type	Cost/Km (IDR/Km)	Capacity (m^3)	Unit
1	Fuso Truck	18,000.00	17	2
2	Armroll Truck	16,000.00	6	23
3	Dump Truck	17,000.00	8	16
4	Pick-Up Truck	15,000.00	1.5	4
5	Tossa	10,000.00	1	8
	Total		33.5	53

Garbage transport vehicles owned by the municipal authorities consist of 53 vehicles that can operate properly. The entire vehicle consists of 5 types of vehicles with different capacities and operating costs. The type and capacity of the vehicle in detail can be seen in Table 1 above.

2.2. Research method

2.2.1. Vehicle routing problem

VRP problems can be defined as the problem of finding a route with a minimal cost from a depo to a customer that is located scattered with a different number of requests [9,10]. Routes are made in such a way that each customer is visited only once by one vehicle. The entire route starts and ends at the depot, and the number of requests on one route must not exceed capacity vehicle. The basic form of VRP assumes that the vehicle is homogeneous (has the same capacity), only served by one route, and the total demand of all customers on one route does not exceed the capacity of the vehicle serving the route.

Solid waste vehicle routing problem often occurs in cases of urban waste transportation and solid waste management in urban municipal waste routing problems and transport management. The model built varies according to the conditions that occur. Some other terms and approaches used are Vehicle Routing Problem with Multiple Trips and Intermediate Facility (VRPMTIF) [11].

In the case of garbage transportation, vehicles that are still not charged leave the depot and start transporting garbage from a number of polling stations. When the garbage has reached vehicle capacity, the vehicle goes to the intermediate facility, the final garbage dump (FGD) to unload the garbage. After the garbage has been unloaded, the vehicle can start the transport again and return to the depot when the working hours have finished. This transportation problem is different from shipping so it requires a special model.

2.2.2. K-Means algorithm

This study uses the K-Means algorithm to divide TGD locations into several groups. Through the clustering of TGD locations, it is expected that waste transportation is more effective because it is looking for adjacent TGD locations. In addition, the grouping of TGD in waste transportation is expected to shorten the data processing time for determining the optimal route. In this study the routing of garbage transport vehicles consisted of 54 points with 52 TGD points and 2 points of Vehicle Depot and FGD. The vehicle routing process using the VRP approach refers to previous research that has been carried out.

The K-Means algorithm is a clustering algorithm that classifies data based on the center point of the cluster (centroid) closest to the data. The purpose of K-Means is to group data by maximizing the similarity of data in one cluster and minimizing the similarity of data between clusters. The similarity size used in the cluster is the distance function. Thus, maximizing the similarity of data is obtained based on

the shortest distance between data to the centroid point. The steps of the K-means algorithm are as follows:

1. Determine K data as centroid, K is the number of clusters desired (determined by the researcher).
2. Each point (data) is then searched for the nearest centroid.
3. Each set of points (data) that becomes a centroid is called a cluster.
4. Calculate the centroid from each cluster.
5. Repeat steps 1-4 until the centroid does not change. [12]

Clustering method uses K-means algorithm, a measure of proximity data is calculated using Euclidean distance. According to [13] the k-means algorithm divides data into predetermined cluster pieces. K-means algorithm aims to minimize the total distance between each point, and the nearest cluster [14]. There are several ways that can be used to calculate distance, among others by using Euclidean distance, Manhattan distance, and Chebyshev distance. In this study Euclidean distance calculation is used with the following equation:

$$d_{ij} = \sqrt{\sum_{k=1}^{n}\{x_{ik} - x_{jk}\}^2} \quad (1)$$

Where,

d_{ij} = distance between data *i* and data *j,*
n = data dimension,
x_{ik} = coordinate of data *i* on dimension *k*
x_{jk} = coordinates of the *j* data on dimension *k*

3. Model and Assumption

The model and assumptions imposed based on previous research. In previous research, there was a function that seek minimum total transportation cost. The model consists of 15 constraint functions and 5 decision variables [15].

4. Results and Discussion

4.1. Clustering results

Based on the results of clustering data processing using the k-means algorithm in the Weka application obtained 5 groups of TGD areas. The number of groups is conducted subjectively by paying attention to the total number of location.

Name: Cluster Type: Nominal
Missing: 0 (0%) Distinct: 5 Unique: 0 (0%)

No.	Label	Count	Weight
1	cluster0	18	18.0
2	cluster1	9	9.0
3	cluster2	9	9.0
4	cluster3	6	6.0
5	cluster4	10	10.0

Figure 2. Clustering result (Weka Output).

4.1.1. Centroid node and solid waste volume

Based on the determination of the nodes clustering, we obtained centroid node for each cluster. The centroid of each cluster shown in table 2 below. The highest total amount of waste is in cluster 3, which is 278 m^3 more than in the other clusters. While the least volume of waste is in cluster 4 with TGD 21 as the centroid of cluster location.

Table 2. Centroid node and solid waste volume.

Node	Location Name	Cluster Centroid	Total Solid Waste Volume (m^3)
16	Hotel Borneo, Jl Merdeka Barat	1	231
1	Gang Mutiara	2	252.45
3	Jalan Tanjung Raya I	3	278
21	Jembatan, Jl Dr Wahidin S Jawi	4	58
4	Gg Famili, Khatulistiwa, Batulayang	5	130
Total Solid Waste Volume			949.45

4.1.2. Cluster region

The results of clustering 53 TGD locations in 5 clusters in detail can be seen in the table 3 below. Cluster 1 has the highest number of TGD compared to other clusters, namely as many as 18 TGD location points. The total amount of waste volume in all TGD and cluster points is 949.45 m^3.

Table 3. Temporary garbage dump clustering result.

TGD Node	Cluster	Solid Waste Volume (m^3)	TGD Node	Cluster	Solid Waste Volume (m^3)
16	1	19.5	3	3	26.5
17	1	6.5	8	3	6.5
22	1	19.5	9	3	6
23	1	36.5	10	3	6
24	1	13	11	3	6
25	1	19.5	12	3	8
26	1	6.5	18	3	13
27	1	19.5	19	3	198
29	1	6	20	3	8
38	1	13	21	4	19.5
39	1	26	28	4	13
40	1	6.5	34	4	6.5
41	1	6.5	35	4	6
42	1	6.5	36	4	6.5
43	1	6.5	37	4	6.5
44	1	6.5	4	5	26

45	1	6.5	5	5	6.5

TGD Node	Cluster	Solid Waste Volume (m^3)	TGD Node	Cluster	Solid Waste Volume (m^3)
46	1	6.5	6	5	6.5
1	2	19.5	7	5	6.5
2	2	29.5	47	5	13
13	2	6.5	48	5	26
14	2	30	49	5	6.5
15	2	6.5	50	5	6.5
30	2	108.45	51	5	13
31	2	19.5	52	5	19.5
32	2	19.5	53	-	
33	2	13	54	-	
Total Solid Waste Volume					949.45

4.2. Vehicle routes

Based on simulation and optimization results using the LINGO © application it is known that optimal global results only could be achieved on cluster 4 with a total distance as far as 171.842 Km and a total cost of IDR. 3,049,156.00 as depict in figure 3 below. Vehicle routing in cluster 4 has 2 routes with 2 vehicles that must be used. The results of routes for these 2 vehicles can be seen in Table 4 as follows:

```
Global optimal solution found.
Objective value:                              3049156.
Objective bound:                              3049156.
Infeasibilities:                          0.1776357E-14
Extended solver steps:                           160702
Total solver iterations:                       16070042


  Export Summary Report
  ---------------------
  Transfer Method:       OLE BASED
  Workbook:              cluster 4.xlsx
  Ranges Specified:                1
      x
  Ranges Found:                    1
  Range Size Mismatches:           0
  Values Transferred:            320

                      Variable           Value        Reduced Cost
                          BIGM         1000000.            0.000000
                         DEPOT         8.000000            0.000000
                           TPA         7.000000            0.000000
                           TPS         6.000000            0.000000
                    MAX_VOLUME         19.50000            0.000000
                  TOTAL_VOLUME         58.00000            0.000000
                 MAX_KAPASITAS         17.00000            0.000000
```

Figure 3. LINGO output of cluster 4

Table 4. Vehicle routes of cluster 4

Vehicle Type	Vehicle Route	Distance (Km)	Cost (IDR)
Fuso	54 → 35 → 36 → 37 → 53 → 21→ 53 → 34 → 13 → 53 → 54	127.842	2,301,156.00
Dump Truck	54 → 34 → 35 → 21 → 53 → 54	44	748,000.00
	Total	171.842	3,049,156.00

The results of vehicle routing in clusters 1, 2, 3 and 5 cannot achieve optimal global conditions. This is because the variable used is still too large even though TGD grouping has been conducted. The clustering approach can only reduce the number of TGD points for each cluster, thus only feasible conditions can be obtained.

5. Conclusion

The calculation does not reach optimal global conditions in 4 cluster of 5 cluster due to the magnitude of the variables and constraints applied, even though the clustering approach has been used to reduce the location of the TGD, it cannot reduce the variable dimension for most cluster. Therefore, it is necessary to review the form of the model that has been applied in order to gain better solution. If the searching method to find global solution is unreliable then it is necessary to use another searching method such as non linier programming and the metaheuristic approach.

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