Shortest Route for Waste Transportation in Northern Bandung using Vehicle Routing Problem - Clarke and Wright - Saving Method

Wahyukaton, Anni Rochaeni

Abstract: Bandung is one of big cities in Indonesia, and like the big city around the world, waste is become the problem to keep the city's clean, and particularly on waste problem is to transporting waste from transfer station (tempat pembuangan sampah – TPS) to intermediate facility (stasiun peralihan antara – SPA) then to a landfill/dump site (tempat pemrosesan akhir – TPA). There are 29 TPS's in Northern Bandung with a difference waste volume for each TPS. The waste will be loaded up and be transferred using stationary container system (SCS) to SPA daily. This paper is discussing waste transportation for 4 trucks of 6 m^3 capacity for each from truck pool to many TPS's and to a single SPA to obtain the shortest route. Using modified VRP – Saving method resulting 11 routes with total travel distance is 466,88 km and total service time is 25.51 hours. Method of Nearest Neighbor is also being used to find the alternate shortest route which are also resulting 11 routes and found alternate shortest route with total travel distance is 450, 25 km and total service time is 24.60 hours.

Keywords: VRP; Saving; Clarke and Wright; Nearest Neighbor; Waste Transportation; Routes

I. INTRODUCTION

Bandung is a rapid growing city in Indonesia and as the big cities around the world, waste is a problem, especially collecting waste from TPS's and transporting them to a landfill. Bandung's government has issued a policy that the waste that has been collected from many transfer stations (*tempat pembuangan sampah* – TPS) will be transported to a site called intermediate facility (stasiun peralihan antara – SPA) then from SPA the waste will be transferred to a landfill (*tempat pemrosesan akhir* – TPA) that located far from the city. There are 4 service areas in Bandung which are Northern Bandung, Southern Bandung, Western Bandung, and eastern Bandung, and there are at least 29 TPS's on Northern Bandung only. The objective of this paper is to find a shortest route for transporting the waste in Northern Bandung service area from TPS's to a single SPA using VRP – Saving method, while waste transporting from SPA to TPA is not be discussed because there is only a single route from SPA to TPA, the trucks maintenance is also not to be discussed and government policy is to be assumed unchanged.

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II. LITERATURE REVIEW

There are many methods were used to design an effective route in transportation system, including waste transportation. Some methods using GIS [1,2,3], some using dynamic system [4,5], the using time series and statistic analysis [6], development from many algorithms 97,8], integer method [9]. The most common method been used is Vehicle Routing Problem. Son [10] using VRP with multiple research to design waste transportation system, while Bing [11] using VRP to collecting plastic waste. Some VRP was developed to optimize waste transportation system. Teixiera [12] was using periodic-VRP in waste recycle collecting system, and Ramos [13] was using multi-depot VRP. Also, VRP was used to minimize gas emission [14].

Vehicle Routing Problem (VRP)

The Vehicle Routing Problem (VRP), introduced by Dantzig and Ramserl in 1959, holds a central position in distribution leadership and has become one of the most commonly researched issues in combinatorial optimization.

The Classical VRP can be officially described as follows. Let G (V, A) be a graph where $V = \{v0, vl, ..., vn\}$ is a vertex set, and $A = \{(vi, vj) : vi, vj\ V, i \neq j\}$ is an arc collection. Vertex *v0* reflects a depot, while the remaining vertices correspond to clients. A cost matrix (*cij*) and a travel time matrix (*tij*) are connected with A. If these matrices are symmetrical, as is frequently the case, then describe the VRP on an undirected chart $G = (V, E)$, where $E = \{(vi, vj) : vi, vj\ V, i < j\}$ is an edge set. Each client has a non-negative *qi* requirement and a *ti*. service time. The depot is based on a fleet of m identical capacity Q vehicles. The number of vehicles is either known in advance or handled as a decision variable. The VRP consists of creating a set of delivery or collection routes at most m such that (1) each route begins and ends at the depot, (2) every customer is visited exactly once by exactly one vehicle, (3) the total demand for every path does not exceed Q, (4) the complete duration of each route (including travel and service times) does not exceed a preset D limit, and (5) the total cost of routing is minimized. A popular version is where a time window [*ai, bi*] is imposed on each customer's visit. Many other extensions have also been studied; the vehicle fleet may be heterogeneous, vehicles may capture and deliver on the same path, some vehicles may not be able to visit certain locations, some clients may require multiple visits over a

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given period of time, there may be more than one depot, deliveries may be split between multiple vehicles [15].

Let there be n demand points in a specified region, each requiring a amount of weight Qi (i = 1, 2, …, n) of products to be supplied to it (products are assumed to be indistinguishable but for their weight). The goods in question are stored at a depot, D, where a fleet of vehicles is also stationed. Vehicles have identical maximum weight capacities and limitations on maximum route time (or distance). At the depot, D, they all have to start and finish their routes. The issue is to get a set of delivery routes from the depot, D, to the different request points to minimize the complete distance covered by the entire fleet. It is assumed that the weights of Qi (i = i , …, n) of the quantities required are less than the total weight capacity of the vehicles and we require that the entire quantity of Qi required at a given point be delivered by a single vehicle (i.e., we do not allow the possibility that one third, say, of Qi will be delivered by one vehicle and the remaining two thirds by another).

Thus, the VRP applies equally well to collecting solid waste from a specific set of points and delivering parcels to a set of points. For example, a significant current application has been in the routing of newspaper delivery vehicles distributing editions of a well-known newspaper to newsstands in an urban area. Either the maximum weight or the maximum route-time limitations can be relaxed in particular VRP apps. However, both generally play a part. For example, in the newspaper delivery issue just stated, one constraint, in relation to the maximum amount of newspapers a vehicle can carry, was that all deliveries to newsstands must be made within an hour of press time.

If no constraint applies, the VRP reduces to a traveling salesman problem: if the goal is simply to reduce total distance, it is a 1-TSP; if the number of vehicles to be used is specified, it is a m-TSP. It can therefore be seen that TSPs can be viewed as special cases of VRPs. As far as optimum solutions are concerned, it can be expected that VRP's will be more difficult than TSP's. Indeed, although several versions of VRP's have been formulated by various investigators as mathematical programming problems, less than 30 delivery points have been reportedly involved in the largest vehicle routing problems of any complexity that have been exactly solved.

In contrast, even with thousands of delivery points, the heuristic approaches we will describe next can be used.

Multi-depot vehicle routing problem with time windows (MDVRPTW) is used to determine the optimum set of fleet routes to meet the delivery requirements of a customer set in multiple depots at different locations under time window constraints. Extending MDVRPTW, a practical and difficult issue in logistics and supply chain management, to a research of service cars used to deliver and install electronics. MDVRPTW findings can be used to minimize fixed depots and vehicle delivery and installation costs as well as travel distance and labor costs. A heuristic and genetic algorithm were created to define a near-optimal solution along with a mixed integer programming model. Computational findings show that the suggested algorithms can be used effectively to fix comparatively big problems [17].

Due to the complexity of the problem, heuristics are usually used to solve waste collection problems with VRP efficiently. A capable clustering-based algorithm is to solve their waste collection vehicle routing issue with time windows considering a solution's path compactness and workload balancing. Generating an initial solution using a method that fully uses a vehicle and improves the initial solution using an interchange procedure. Urban waste collection problem is described as an arc routing problem. Applying a process of transforming the issue into a node routing one and solving it with heuristics of ant colony. A tabu search heuristics was used for the issue of truck and trailer routing and found that the tabu search acquired better alternatives compared to the other building heuristics used [11].

The classical problem of pickup and delivery (PDP) to an embedded routing and three-dimensional loading issue, called PDP with three-dimensional loading limitations (3L-PDP). Suppose you have provided a number of demands and a homogeneous fleet of Vehicles. A set of paths of minimum complete duration must be determined so that each application is transported from a loading site to the respective unloading site. Each request is given as a set of 3D rectangular items (boxes) in the 3L-PDP and the vehicle capacity is replaced by a 3D loading space. Investigation which limitations will guarantee that no reloading effort occurs, i.e. that no box is shifted after loading and before unloading. A spectrum of 3L-PDP varieties is implemented with different features in terms of reloading effort. A hybrid algorithm for solving the 3L-PDP consisting of a routing and packing procedure. A well-known big neighborhood search for the 1D-PDP is modified by the routing procedure. A tree search heuristic is accountable for packing boxes. Computational studies were conducted using 54 newly suggested 3L-PDP benchmark instances [18].

Heuristics for the Single-Depot VRP

Clarke and Wright's "savings" algorithm is by far the best-known strategy to the VRP issue. His fundamental concept is very easy. Consider depot D and n request points as shown in Figure 1a. Suppose the VRP solution initially consists of using n vehicles and dispatching one vehicle to each of the n request points.

Obviously, this solution's complete tour duration is,

$2\sum_{i=1}^{n} d(D,i)$, so that

$$s(i,j) = 2d(D,i) + 2d(D,j)$$

If a single vehicle is used to serve two points, say i and j, on a single journey, the complete distance traveled is decreased by the quantity shown in Figure 1b,

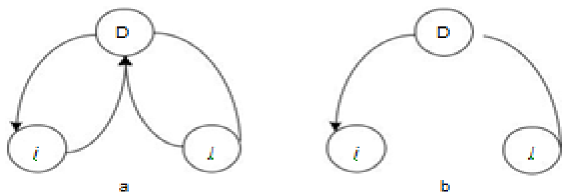

Fig. 1 Single Depot VRP

$$s(i,j) = 2d(D,i) + 2d(D,j) - [d(D,i) + d(i,j) + d(D,j)] = d(D,i) + d(D,j) - d(i,j) \quad (1)$$

The quantity s(i, j) is known as the "savings" resulting from the combination of points i and j into a single tour. The bigger s(i, j) is, the more desirable it becomes to merge i and j in a single tour. However, I and j cannot be paired if the resulting trip violates one or more of the VRP's constraints [16].

This saving method can be modified in regards of waste transportation. Consider that a truck pool *D*, while *i* and *j* are two TPS's that the waste need to be transported to SPA *S*, as shown on Figure 2a.

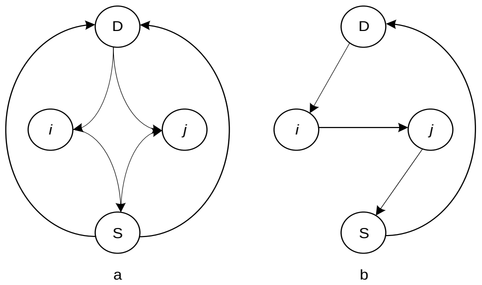

Fig. 2 Modified VRP – Saving Method

If a single vehicle is used to represent two TPS's, say I and j, on a single trip, the total distance traveled will be reduced by the amount shown in Figure 2b.

$$s(D,S) = [d(D,i) + d(i,S) + d(D,j) + d(j,S) + 2d(S,D)] - [d(D,i) + d(i,j) + d(j,S) + d(S,D)] = d(i,S) + d(D,j) + d(S,D) - d(i,j) \quad (2)$$

The difference of this modified is after collecting waste on *i*, the truck will not travel back to the pool instead of travel to *j* to collect the waste and transporting the waste to SPA and after unload the waste in SPA, the vehicle will travel back to the truck pool.

III. METHOD

VRP – Clarke and Wright (Saving) and Nearest Neighbor

The modified VRP – Saving is used to solve the waste transportation problem, and the algorithm as follows,

Step 1: construct a distance matrix for pool to every TPS and from every TPS to SPA.

Step 2: calculate the saving based on the distance matrix using formula (2)

Step 3: determining a cluster based on Step 2,

Step 4: within the cluster, assign a truck to load the waste, subject to truck capacity. Truck capacity is 6 m^3 with compact factor 12% so that the truck capacity become 7.2 m^3.

Step 5: If the truck capacity has been reached, then the truck will travel to SPA, else repeat Step 4

Step 6: assign another truck to do Step 4 for another cluster and stop if all cluster have been served.

The cluster now has become a new shortest route.

To find an alternative shortest route, Nearest Neighbor method is being used, and the algorithm as follows

Step 1: based on cluster that has been created by Saving method, assign a truck to travel to the nearest TPS from the truck pool.

Step 2: loading the waste to the truck subject to truck capacity

Step 3: if the truck capacity has not been reached then assign the truck to travel to the second nearest TPS.

Step 4: if the truck capacity has been reached, assign the truck to travel to SPA, else repeat Step 3.

Step 5: assign another truck to do Step 1 – 4 for another cluster and stop if all cluster have been served.

The alternative shortest route has been found.

Comparing the Saving method result to Nearest Neighbor result, then the shortest route has been created

Data collection

A survey conducted on Northern Bandung region to collect the data regarding the distance from truck pool to every TPS, the distance among TPS, and the distance from every TPS to SPA, waste volume in every TPS, time to load the waste to the truck, as follows

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Table. 1 Distance, Volume of Waste

BANDUNG UTARA															
Truck	TPS	VOLUME	POOL	MUSEUM GEOLOGI	HEGARMANAH RW [illegible]	JL. SILIWANGI	RS ADVENT	KANTOR BKN	BAK C59	CIGADUNG	PAHLAWAN	DAGO TEA HOUSE	TAMANSARI RW10	SURAPATI CORE	PUSDAI
	POOL														
1	MUSEUM GEOLOGI	3	3810												
	HEGARMANAH RW 08/09	2	5860	6850											
	JL. SILIWANGI	3	2900	3180	2080										
	RS ADVENT	2	4480	4800	2300	1594									
	KANTOR BKN	1.5	3010	1257	5250	4540	3200								
2	BAK C59	1.5	1360	3510	8430	7720	6380	3190							
	CIGADUNG	2	1871	4020	8940	8230	6890	3700	721						
	PAHLAWAN	2	1921	2800	6770	6060	4720	1528	2110	2620					
	DAGO TEA HOUSE	1.5	5340	6490	5130	2870	5920	5030	4400	3680	7510				
	TAMANSARI RW10	2	4880	3130	3860	3150	1811	1878	5070	4230	4140	4430			
	SURAPATI CORE	2.5	3910	4020	8940	8230	6880	3690	4090	4600	3170	8680	5300		
	PUSDAI	2	2800	687	5920	3870	3870	1488	2990	3500	2060	5670	2300	3380	

This table is shown a quarter for the entire table, due to large table.

IV. RESULT

Saving Matrix

Based on distance matrix that has been constructed, the saving value can be obtained using formula 2, for example, obtaining saving value from pool (D) – TPS Bak Samami (BS) – TPS Dago Tea House (DTH) – SPA – pool, as follows,

$SDTH,BS = d(DTH,SPA) + d(SPA,D) + d(D,BS) – d(DTH,BS)$

$= 1680 + 16760 + 1113 – 3550 = 31183$ By the same calculation, saving matrix as follows

Table. 2 Saving Matrix

BANDUNG UTARA															
Truck	TPS	VOLUME	KODE	MUSEUM GEOLOGI	HEGARMANAH RW [illegible]	JL. SILIWANGI	RS ADVENT	KANTOR BKN	BAK C59	CIGADUNG	PAHLAWAN	DAGO TEA HOUSE	TAMANSARI RW10	SURAPATI CORE	PUSDAI
	KODE			A	B	C	D	E	F	G	H	I	J	K	L
1	MUSEUM GEOLOGI	3	A												
	HEGARMANAH RW 08/09	2	B	29750											
	JL. SILIWANGI	3	C	30460	31970										
	RS ADVENT	2	D	30420	33330	34756									
	KANTOR BKN	1.5	E	32493	28910	30340	29270								
2	BAK C59	1.5	F	28590	24080	25510	24440	28920							
	CIGADUNG	2	G	28591	24081	25511	24441	28921	35080						
	PAHLAWAN	2	H	29861	26301	27731	26661	31143	33741	33741					
	DAGO TEA HOUSE	1.5	I	29590	31360	34340	28880	31060	34870	35100	30100				
	TAMANSARI RW10	2	J	32490	32170	33600	32529	33752	33740	35090	33010	34070			
	SURAPATI CORE	2.5	K	30630	26120	27550	26490	30970	33750	33750	33010	28850	27980		
	PUSDAI	2	L	32853	28030	30800	28390	32062	33740	33740	33010	30750	29870	33860	

This table is shown a quarter for the entire table, due to large table.

Clustering

After saving matrix is formed, then cluster is determined by sorting the saving value from the biggest to the smallest.

Table. 3 Sorting Saving Value

No.	Saving	N. Saving	No.	Saving	N. Saving
1	Z-AB	48456	**50**	O-V	35327
2	AA-AB	47307	**51**	M-V	35324
3	Z-AA	47306	**52**	S-V	35321
4	AB-AC	46369	**53**	U-V	35319
5	Z-AC	46366	**54**	B-N	35240
6	AA-AC	46285	**55**	G-J	35090
7	W-Z	45229	**56**	F-G	35080
8	W-AC	45226	**57**	A-M	35068
9	W-AA	45223	**58**	F-I	34870
10	W-AB	45220	**59**	C-Y	34770
11	B-AC	38690	**60**	C-N	34770
12	B-Z	38690	**61**	C-D	34756
13	B-W	38680	**62**	G-Q	34737
14	B-AA	38680	**63**	A-U	34674
15	B-AB	38680	**64**	M-X	34628
16	Y-Z	38500	**65**	U-X	34622
17	Y-AA	38500	**66**	G-Y	34450
18	Y-AC	38500	**67**	G-M	34440
19	Y-AB	38490	**68**	G-O	34440
20	N-Z	38120	**69**	G-S	34440
21	N-AC	38120	**70**	G-T	34440
22	N-W	38110	**71**	G-U	34440
23	N-AA	38110	**72**	G-V	34440
24	N-AB	38110	**73**	C-I	34340
25	C-Z	37880	**74**	T-X	34329
26	C-W	37870	**75**	O-X	34328
27	C-AA	37870	**76**	S-X	34323
28	C-AB	37870	**77**	A-S	34311
29	C-AC	37870	**78**	A-O	34310
30	G-W	37540	**79**	C-R	34130

This table is shown a quarter for the entire table, due to large table.

For instance, if the largest saving in at node *i* and *j*, then node *i* and *j* are grouped into the same cluster, then find the second largest in terms of waste quantity until truck capability is achieved. This will be called as the first cluster.

The same algorithm is applied to obtain the next cluster, then the cluster as follows,

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Table. 4 Cluster

Cluster	TPS	Total	Route
1	PL-Z-AB-Y-Spa-PL	6.8	POOL - A.PERMAI - ELDORADO - LIPPI - SPA - POOL
2	PL-AA-AC-W-Spa-PL	7	POOL - LGI - P. SETIABUDHI - ABADI ASRI - SPA - POOL
3	PL-M-U-S-Spa-PL	6	POOL - GD. WANITA - TARBAK - POS GIRO - SPA - POOL
4	PL-O-T-X-Spa-PL	7	POOL - SAPARUA - RIUNGSARI - TOTAL BUAH - SPA - POOL
5	PL-G-I-J-F-Spa-PL	7	POOL - CIGADUNG - DAGO T.HOUSE - RW 10 TAMSAR - C59 - SPA - POOL
6	PL-C-D-R-Spa-PL	6.5	POOL - SILIWANGI - ADVENT - RW16 LINGGAWASTU - SAPA - POOL
7	PL-K-L-P-Spa-PL	7	POOL - SURAPATI - PUSDAI - PU BINAMARGA - SPA - POOL
8	PL-E-V-Q-Spa-PL	7	POOL - BKN - SARININGSIH - SAMAMI - SPA - POOL
9	PL-A-H-B-Spa-PL	7	POOL - GEOLOGI - PAHLAWAN - RW 08/09 HEGARMANAH - SPA - POOL
10	PL-Y-Spa-PL	7.2	POOL - LIPPI - SPA - POOL
11	PL-N-Spa-PL	6	POOL - KARANG SETRA - SPA - POOL

From 11 routes, the total travel distance is 466,88 km and total service time is 25.51 hours

V. DISCUSSION

The inherent nature of municipal solid waste collection is related to the growth of efficient vehicle routing (VR) models that optimize complete vehicle travel distances, environmental emissions and investment charges. VR is a planned method that enables vehicles to load waste at collection locations (a.k.a. sites) and dump it at a landfill with a single or multiple goal. Waste generation and collection cannot be evaluated in detail, allowing further assessment of disposal practices, modifications and trends so that MSW collection modeling is of specific significance.

Several VR models were described in the literature with multiple goals such as minimum fuel consumption, minimum travel distances and environmental emissions [11]. VRP – Clarke and Wright (saving) method works by clustering the nodes and routes are formed, these routes can be modified by finding alternative shortest route which is possible to obtain a shortest route. In this paper alternative shortest route is calculated using Nearest Neighbor method. Comparing to saving method, routes that are formed by Nearest Neighbor has the shortest total distance (km) and fastest travel time (hours), as follows

Table. 6 Comparison of Clarke and Wright method and Nearest Neighbor method within clusters

Cluster	Route (Saving)	Distance (km)
1	POOL - A.PERMAI - ELDORADO - LIPPI - SPA - POOL	57.3
2	POOL - LGI - P. SETIABUDHI - ABADI ASRI - SPA - POOL	47.61
3	POOL - GD. WANITA - TARBAK - POS GIRO - SPA - POOL	38.28
4	POOL - SAPARUA - RIUNGSARI - TOTAL BUAH - SPA - POOL	37.05
5	POOL - CIGADUNG - DAGO T.HOUSE - RW 10 TAMSAR - C59 - SPA - POOL	48.98
6	POOL - SILIWANGI - ADVENT - RW16 LINGGAWASTU - SAPA - POOL	35.95
7	POOL - SURAPATI - PUSDAI - PU BINAMARGA - SPA - POOL	40.09
8	POOL - BKN - SARININGSIH - SAMAMI - SPA - POOL	41.48
9	POOL - GEOLOGI - PAHLAWAN - RW 08/09 HEGARMANAH - SPA - POOL	44.53
10	POOL - LIPPI - SPA - POOL	40.05
11	POOL - KARANG SETRA - SPA - POOL	35.56
	Total Distance (km)	466.88
	Total Travel Time (hours)	25.51

Cluster	Route (Nearest Neighbor)	Distance (km)
1	POOL-LIPPI-ELDORADO-ALAM PERMAI-SPA-POOL	50.5
2	POOL-ABADI ASRI-P.SETIABUDHI-LGI-SPA-POOL	47.61
3	POOL-POS GIRO-TARUNA BAKTI-GD. WANITA-SPA-POOL	38.28
4	POOL-TOTAL BUAH-RIUNGSARI-SAPARUA-SPA-POOL	37.5
5	POOL-C59-CIGADUNG-DAGO T.HOUSE-RW10 TAMSAR-SPA-POOL	43.81
6	POOL-SILIWANGI-ADVENT-RW16 L.WASTU-SPA-POOL	35.95
7	POOL-PU BINAMARGA-PUSDAI-SURAPATI-SPA-POOL	40.49
8	POOL-SAMAMI-BKN-SARININGSIH-SPA-POOL	37.78
9	POOL-PAHLAWAN-GEOLOGI-RW08/09 H.MANAH-SPA-POOL	42.72
10	POOL-LIPPI-SPA-POOL	40.05
11	POOL-KARANG SETRA-SPA-POOL	35.56
	Total Distance (km)	450.25
	Total Travel Time (hours)	24.6

As the routes have been formed, there are 11 routes to be served by 6 m^3 truck, then the schedule of all trucks can be built as follows,

Table 7. Truck Schedule

	Route to be served on day number					
Truck No	1	2	34		5	6
1	Route 1	Route 2	Route 3	Route 1	Route 2	Route 3
2	Route 4	Route 5	Route 6	Route 4	Route 5	Route 6
3	Route 7	Route 8	Route 9	Route 7	Route 8	Route 9
4	Route 10	Route 11		Route 10	Route 11	

From Table 7, it can be seen that there are routes to be served two times in a week, so that all routes have been scheduled.

The operational cost for trucks and operators can be calculated as,

Fixed Cost = Driver Cost + Assistant Cost, one driver and 4 assistants for every truck, Variable Cost = Fuel Cost (Diesel) x Distance

Table 8. Operational Cost

Route	Operational Cost (Rp)
1	494,807
2	488,844
3	469,634
4	468,019
5	481,020
6	464,816
7	474,178
8	468,602
9	478,774
10	473,270
11	464,023

Table 8 resulting average of operational cost is Rp. 470,590

VI. CONCLUSION

This paper obtaining the result using modified VRP – Clarke and Wright which is never been used, and the conclusions are as follows,

1. There are 11 clusters/routes to serve 29 TPSs regarding waste transportation from every TPS to SPA in Northern Bandung with total travel distance is 450,25 km and total service time is 24.60 hours.
2. There are 4 trucks to serve all the clusters 2 times a week.
3. The average operational cost is Rp. 470,590.

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