DETERMINING THE ROUTE FOR SOLID WASTE TRANSPORTATION FROM TPS TO SPA USING VRP – NEAREST NEIGHBOR FOR 10m³ VEHICLE ON SERVICE AREA SOUTHERN BANDUNG AND EASTERN BANDUNG

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ABSTRACT

One of reason to manage solid waste problem is to make the waste transportation effectively. Route effectivity is measured by transported solid waste volume and the distance from transfer station (TPS) to intermediate facility (SPA) then from SPA to landfill (TPA), however, in this research was subjected to transported solid waste from TPS to SPA and for 10m³ dump truck (DT).
This research objective was to find an alternative effective route of waste transporting and to find the number of vehicle be used to serve solid waste transportation using Nearest Neighbor (NN) method by Vehicle Routing Problem with Multiple Trips and Intermediate Facility (VRPMTIF).
VRPMTIF is a model that can be applied to solid waste transportation problem on PD Kebersihan Bandung, in area of Southern Bandung and Eastern Bandung
For area of Eastern Bandung, there were 3 DT involved covering 68.73 km of total distance for 12 TPS's, while on area of Southern Bandung, there were 4 DT involved covering 123.43 km of total distance for 11 TPS's.

Keywords: VRP, Nearest Neighbor, Solid Waste Transportation

1. INTRODUCTION

Waste or garbage has become a common problem in the cities in Indonesia, it starting from littering, waste transportation, until the problem at landfill (TPA).
Managing the waste, usually starting from settlements to TPS, from TPS to TPA. Bandung has another policy concerning the waste management, which is build an intermediate facility (SPA) due to large amount of solid waste volume, and traffic problem, so that the solid waste will be transferred from TPS to SPA then with another vehicle the solid waste will be transferred to landfill (TPA).
Based on the above scheme, it can be described that the logistics system is a system that addresses the relationship between the entities as an integrated logistics activity from solid waste generation to SPA for each distribution networks to generate the waste transportation. Planning a public waste management also requires the design and operation of the logistics system in order to create efficiency and effectiveness of transporting waste. Thus in order to obtain orders, cleanliness and beauty, need to research about the route of transporting waste in Bandung.

1.1 Research Identification

The basic problem on waste transportation in Bandung is less effective of solid waste transportation in many TPS in several areas.

1. How to determine an alternative route of solid waste transportation to minimized operational cost in a single trip per day.
2. How many vehicle needs to pick up the solid waste in order to all TPS will be served in a single trip per day.

1.2 Research Objectives

1. To determine an alternative route of solid waste transportation to minimized operational cost in a single trip per day.
2. To determine number of vehicle needs to pick up the solid waste in order to all TPS will be served in a single trip per day.

2. THEORETICAL BACKGROUND

Vehicle Routing Problem (VRP) is the backbone in distribution management and physical distribution (Laporte, 1992a; Ghiani, Guerriero, Laporte, & Musmanno, 2003). It can be described as the "problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers, subject to side constraints" (Laporte, 1992a). VRPs are combinatorial optimization problems (NP-hard). Optimization problems can be divided into two categories: problems with continuous variables and problems with discrete variables, which are called combinatorial. In combinatorial problems, the goal is to find the best solution among a set of finite solutions (Papadimitriou & Steiglitz, 1998). Some examples of combinatorial optimization problems are: integer programming, vehicle routing problem, traveling salesman problem, etc. Mathematical definition of VRP is as follows:

Let $G = (V, A)$ be a graph, where $V = \{1, \ldots , n\}$ is a set of vertices (nodes) representing cities, where *depot* is located at node 1, and A is the set of arcs (edges). With every arc (i, j) $i \neq j$ there is a corresponding non-negative distance matrix $C = (c_{ij})$. In some cases, c_{ij} can be interpreted as travel cost or travel time between nodes i and j. When C is symmetrical (travel cost of node i to j is equal to travel cost of node j to i), it is convenient to consider the set of arcs as a set E of undirected arcs. Furthermore, assume there are m vehicles available at depot to service the nodes (customers), where $mL \leq m \leq mU$. When $mL = mU$, number of vehicles (m) is said to be fixed. When $mL = 1$ and $mU = n - 1$, m is said to be free. When m is not fixed, it is logical to consider a fixed cost associated with use of a vehicle but usually for the sake of simplicity, this cost is ignored. All vehicles are considered to be identical and have the fixed capacity D. The VRP is to design vehicle routes with least cost in such a way that:

(i) each city in $V\backslash\{1\}$ is visited only once and once by exactly one vehicle;
(ii) depot is the origin and the destination of all routs;
(iii) some side constraints are satisfied. (Laporte, 1992a)

A typical VRP solution is showed in Figure 1. As illustrated in this figure, nodes (cities or customers) are scattered around depot and 4 vehicle routs starting and ending at depot are
designed to serve all the customers.

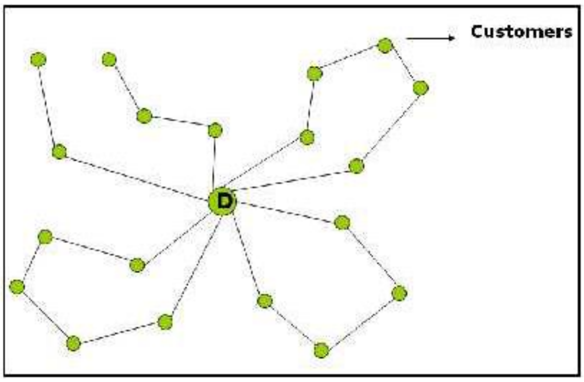

Figure 1: A typical VRP solution with 4 vehicle routes

Different classes of VRPs have been developed to model the problems faced in of real world. Each of VRP categories answers to the specific needs of customers, logistics and distribution departments or both of them. The categories of research in VRP are Capacitated VRPs (CVRPs), Distance-constrained VRPs (DVRPs), VRPs with Time Windows (VRPTW), VRPs with Backhauls (VRPBs) (Toth & Viego, 2002), VRPs with Pick up and Deliveries (VRPPD), (Toth & Viego, 2002), Heterogeneous Fleet Vehicle Routing Problem (HVRP) (Gendreau, Laporte, Musaraganyi, Taillard, 1999).

Nearest Neighbor

This method first introduced in 1983 and it is a simple method. On each iteration, a search of a nearest costumer which is closest to the last customer was done to be will added to the end of a route. A new route will start the same way if there is no feasible position for placing new customer due to capacity or time windows (Braysy & Gendreau, 2005).

Nearest neighbor method is originally a traveling salesman problem (TSP) heuristic. TSP could be defined as the following:

Let $G = (V, A)$ be a graph which V is a set of nodes and A is a set of arcs. A matrix $C = (c_{ij})$ represents the distances (costs) of going from node i to node j. The problem is to determine the shortest path which goes through all the nodes only once and once.

TSP like VRP is a NP-hard combinatorial problem and there is a rich literature on its heuristics.

TSP heuristics could be divided into two main categories (Laporte, 1992b):

(i) tour construction procedures and
(ii) tour improvement procedures. Nearest neighbor belongs to the tour construction heuristics and tries to get the maximum benefit from going one step to the next one.

Hence these kind of heuristics are sometimes called "greedy heuristics". Nearest neighbor algorithm steps according to the Laporte (1992b) are:

(Algorithm 1)

(i) Select an arbitrary point as starting point
(ii) Determine the closest node to the last one already considered and add it to the tour.
Repeat step (ii) if any nodes are not included in the tour.
(iii) Link the last node of the tour to the start point

These steps are designed for TSP. However, Laporte (1992a) argues that TSP algorithms can often be used for solving VRPs. He adds that nearest neighbor method can be used to solve CVRP almost without modification. Hence, steps needed to solve a CVRP with the nearest neighbor algorithm could be defined as follows:

(Algorithm 2)

(i) Dispatch a vehicle from the depot to the closest node to the depot.
(ii) Determine the closest node to the last one already considered and add it to the vehicle tour. Repeat step (ii) as long as vehicle capacity allows.
(iii) Repeat steps (i) and (ii) for new vehicles if any nodes are not visited yet.

3. RESEARCH METHOD

To solve the problem as mentioned earlier, Vehicle Routing Problem was used as a technique to solve a transportation problem involving vehicle routes to serve spreading customer.

Waste transportation service in Bandung is divided into 4 solid waste transportation regions as seen on Figure 2.

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The solid waste transporting in Bandung is done by two systems, which are Haul Container System (HCS) and Stationary Container System (SCS). This research was focused on SCS because it will serve more than one TPS in every trip, so that it needs an effective route.

This research is discussing for area of Southern Bandung and Eastern Bandung because the number of TPS's by SCS in those areas are more than area of Northern and Western Bandung, and $10m^3$ vehicles/dump trucks to transporting solid waste from 12 transfer stations (TPS's) in Southern Bandung to SPA and 10 TPS's in Eastern Bandung to intermediate facility (SPA). The location of SPA is in Gede Bage while the landfill (TPA) is in Legoknangka

	ke	1	2	3	4	5	6	7	8	9	10	11	12
dari	TPS	pol	panorama	simpang sari	buni sari	rs hermina	cicukang	bojong awi	griya uber	tanabe	sentosa asih	saluyu	cipamokolan
1	pol												
2	panorama	2,675											
3	simpang sari	2,795	120										
4	buni sari	3,065	390	270									
5	rs hermina	2,965	355	475	745								
6	cicukang	3,130	2,410	2,530	2,800	2,635							
7	bojong awi	3,005	2,285	2,405	2,675	2,510	875						
8	griya uber	4,970	4,250	4,370	4,640	4,475	2,840	2,235					
9	tanabe	5,755	5,035	5,155	5,425	5,260	3,625	3,020	1,865				
10	sentosa asih	9,755	9,035	9,155	9,425	9,260	7,625	7,020	5,865	4,000			
11	saluyu	10,395	9,675	9,795	10,065	9,900	8,265	7,660	6,505	4,640	640		
12	cipamokolan	9,860	9,140	9,260	9,530	9,365	7,730	7,125	5,970	4,105	875	1,515	

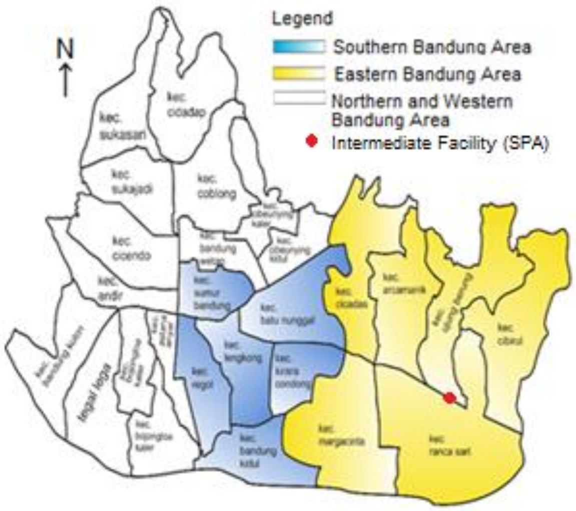

Figure 2. Map of Bandung Service Area

Using Nearest Neighbor (NN) – Vehicle Routing Problem Multiple Trips and Intermediate Facility (VRPMTI) – to solve a route problem by determining a closest node with a shortest distance. It becomes a measurement of whether the system can work well to optimize the waste transportation by one round so that there will be no solid waste were stacked at TPS.

The NN method on each iteration is searching a nearest customer to the last customer to be added into that last route. The steps are as follows,

Step 1. Set a node pool (depot) and node TPS or waste bin for each vehicle on transporting solid waste area.

Step 2. Make a distance matrix to describe TPS locations and the distance inter TPS.

Step 3. Searching for shortest distance. Starting from vehicle pool, then searching a TPS with the shortest distance to vehicle pool as the first location.

Step 4. Continue to the next TPS location with the shortest distance to selected TPS earlier and the solid waste volume does not exceed the vehicle capacity.

a. If there is a selected TPS as a next TPS location and there is a remaining capacity on the vehicle, back to step 4.

b. If there is no remaining capacity on the vehicle, back to step 3.

c. If there is TPS location is selected due to waste volume has exceed the vehicle capacity, then back to step 3.

d. Start again from the pool to visit TPS location that has not been visited and has the closest distance. If all TPS has been visited right one time, then the algorithm is ended.

Step 5. Optimal calculation by summing the starting distance to the end of the trip.

4. RESULT AND DISCUSSION

4.1 Route

Every vehicle was operated daily from 04:00 until 17:00 or 19:00, it is depending on solid waste volume to be transported and traffic. The fix service route is Pool – TPS's – SPA – TPA. Vehicle pool for Southern Bandung is in Jl. Soekarno-Hatta, while vehicle pool for Eastern Bandung is in Pasir Impun.

From vehicle pool, the vehicle will go to TPS on stated route then collecting solid waste to the vehicle on that TPS. If there was a remaining capacity on the vehicle, the vehicle will go to the next TPS on the next stated route to do the same job. If the capacity has achieved, then the vehicle will go to SPA at Gede Bage, Eastern Bandung. And from SPA there will be another vehicle to transporting the solid waste to the landfill (TPA) at Legoknangka, Kabupaten Bandung.

Figure 3 and 4 show waste transporting route for Eastern Bandung and Southern Bandung

	ke	1	2	3	4	5	6	7	8	9	10	11
dari	TPS	pol	SDM	RM sari sunda	Primarasa	jl Windu	SMA BPI	slai brand	pasar kosambi	TD cicaheum	RHB	borma antapani
1	pol											
2	SDM	2,000										
3	RM sari sunda	2,530	530									
4	Primarasa	1,700	2,730	2,200								
5	jl Windu	4,000	5,030	4,500	2,300							
6	SMA BPI	4,640	5,670	5,140	2,940	640						
7	slai brand	6,600	10,570	10,040	4,900	3,340	2,700					
8	pasar kosambi	7,520	11,490	10,960	5,820	4,260	3,620	920				
9	TD cicaheum	8,400	9,430	8,900	6,700	8,660	8,020	5,320	4,400			
10	RHB	12,520	10,670	10,140	7,940	5,640	5,000	6,820	5,900	1,500		
11	borma antapani	12,865	11,015	10,485	8,285	5,985	5,345	7,165	6,245	1,845	345	

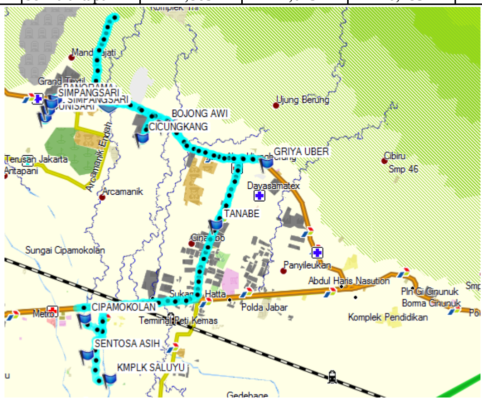

Figure 3. Route for Eastern Bandung

Figure 4. Route for Southern Bandung

Table 1. Distance Matrix for Eastern Bandung

Table 2. Waste Capacity for Eastern Bandung

No	TPS	TPS Capacity (m^3)	Loading Time (minute)
1	a (Panorama)	3	54
2	b (Simpang sari)	3	54
3	c (Buni sari)	4	72
4	d (RS. Hermina)	2	36
5	e (Cicukang)	6	108
6	f (Bojong awi)	2	36
7	g (Griya Uber)	2	36
8	h (Tanabe)	2	36

Table 3 Algorithm Result for Vehicle 1 Eastern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
a	3 m^3	71	Route (K) = 1 Trip (t) = 1
b	3 m^3	56	
c	4 m^3	78	
d	2 m^3	48	
Total	12 m^3	253	

Table 4 Algorithm Result for Vehicle 2 Eastern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
e	6 m^3	120	Rute (K) = 2 Trip (t) = 2
f	2 m^3	43	
g	2 m^3	49	
h	2 m^3	27	
Total	12 m^3	253	

Table 5 Algorithm Result for Vehicle 3 Eastern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
i	4 m^3	111	Rute (K) = 3 Trip (t) = 3
j	4 m^3	81	
k	4,5 m^3	101	
Total	12,5 m^3	293	

- T_{max} = 370 minutes, the average of total trip time from Pool to the last TPS and it was added by total loading time.
- Maximum vehicle's capacity is 10 m^3 but it has to be added by compaction factor 1.2, so that the final vehicle's capacity is 10 + (10 x 1.2) = 12 m^3

Table 6 Total Distance for Eastern Bandung

Vehicle	Vehicle Trip	Distance (meters)		
		Last TPS to SPA	SPA to Pool	Total
D 8733 A	3.810	7.100	10.100	21.010
D 8730 A	8.105	1.900	10.100	20.105
D 8249 C	11.910	5.600	10.100	27.610
Total	23.825			68.725

Table 7 Distance Matrix for Southern Bandung

Table 8. Waste Capacity for Eastern Bandung

No	TPS	TPS Capacity (m^3)	Loading Time (minute)
1	a (SDM)	2	36
2	b (RM. Sari Sunda)	2	36
3	c (Primarasa)	1,5	27
4	d (Jl. Windu)	2	36
5	e (SMA BPI)	2	36
6	f (Slai Brand)	0,5	10
7	g (Psr Kosambi)	12	180
8	h (TD Cicaheum)	20	324
9	i (RHB)	3	54
10	j (Borma Antapani)	1,5	27

Table 9. Algorithm Result for Vehicle 1 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
a	2 m^3	58	Rute (K) = 1 Trip (t) = 1
b	2 m^3	40	
c	1,5 m^3	44	
d	2 m^3	48	
e	2 m^3	40	
i	3 m^3	76	
Total	12,5 m^3	306	

Table 10. Algorithm Result for Vehicle 2 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
f	0,5 m^3	40	Rute (K) = 2 Trip (t) = 2
g	12 m^3	188	
Total	12,5 m^3	228	

Table 11. Algorithm Result for Vehicle 3 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
h	12 m^3	213 menit	Rute (K) = 3 Trip (t) = 3
total	12 m^3	213 menit	

Table 12. Algorithm Result for Vehicle 4 Southern Bandung

Route	TPS Capacity (Q)	Completion Time (CT) (minute)	
h	8 m^3	177 menit	Rute (K) = 4 Trip (t) = 4
j	1,5 m^3	29 menit	
ttotal	10 m^3	226 menit	

- T_{max} = 353 minutes, the average of total trip time from Pool to the last TPS and it was added by total loading time.
- Maximum vehicle's capacity is 10 m^3 but it has to be added by compaction factor 1.2, so that the final vehicle's capacity is 10 + (10 x 1.2) = 12 m^3

Table 13. Total Distance for Southern Bandung

Vehicle	Vehicle Trip	Distance (meters)		
		Last TPS to SPA	SPA to Pool	Total
D 8728 A	12.670	10.900	9.500	33.070
D 8249 C	7.520	12.800	9.500	29.820
D 8364 C	8.400	12.300	9.500	30.200
D xxxx A	10.245	10.600	9.500	30.345
Total	38.835			123.435

The result of Southern Bandung's iterations, the new route cannot make shorten the distance due to there was an addition of one vehicle to serve the untransported solid wasted on a certain TPS, so that the new route will travel 123 km, that was longer than the existing route was 110 km, and travel time will be 6 – 7 hours. The operational cost cannot be lowered but serving for solid waste transporting became more efficient, because solid waste transporting can be done in one trip in one day.

4.2 Cost

To obtain the total variable cost is given by the formulas,

TVC = Total Variable Cost (Rp)
VC = Distance Variable Cost (Rp)
Q = Trip Mileage (km)
= Fuel Index (0.33) x Vehicle Trip (km)
TVC = VC x Q

a. Existing Route

Eastern Bndung
$VC_{D\ 8733\ A}$ = 0.33 x 30 = 9.9
TVC = 5,000 x 9.9 = Rp 49,500

$VC_{D\ 8730\ A}$ = 0.33 x 28 = 9.24
TVC = 5,000 x 9.24 = Rp 46,200

$VC_{D\ 8249\ C}$ = 0.33 x 40 = 13.2
TVC = 5,000 x 13.2 = Rp 66,000

Total Cost = Rp (49,500 + 46,200 + 66,000) = Rp 161,700

Southern Bandung
$VC_{D\ 8728\ A}$ = 0.33 x 46 = 15.18
TVC = 5,000 x 15.18 = 75,900

$VC_{D\ 8364\ A}$ = 0.33 x 26 = 8.58
TVC = 5,000 x 8.58 = 42,900

$VC_{D\ 8249\ C}$ = 0.33 x 38 = 12.54
TVC = 5,000 x 12.54 = 62,700

Total Cost = Rp (75,900 + 42,900 + 62,700) = Rp 181,500

b. Alternative New Route

Eastern Bandung
$VC_{D\ 8733\ A}$ = 0.33 x 21 = 6.93
TVC = 5,000 x 6.93 = 34,650

$VC_{D\ 8730\ A}$ = 0.33 x 20 = 6.6
TVC = 5,000 x 6.6 = 33,000

$VC_{D\ 8249\ C}$ = 0.33 x 27 = 8.91
TVC = 5,000 x 8.91 = 44,550

Total Cost = Rp (34,650 + 33.000 + 44.550) = Rp 112,200

Southern Bandung
$VC_{D\ 8728\ A}$ = 0.33 x 33 = 10.89
TVC = 5,000 x 10.89 = 54,450

$VC_{D\ 8364\ A}$ = 0.33 x 29 = 9.57
TVC = 5,000 x 9.57 = 47,850

$VC_{D\ 8249\ C}$ = 0.33 x 30 = 9.9
TVC = 5,000 x 9.9 = 49,500

$VC_{D\ xxxx\ A}$ = 0.33 x 30 = 9.9
TVC = 5,000 x 9.9 = 49,500

Total Cost = Rp (54,450 + 47,850 + 49,500 + 49,500) = Rp 201,300

All those Total Costs were calculated for one-day operation ofr solid waste transporting by 10 m^3 SCS vehicles/dump trucks.

5. CONCLUSION

1. The new route in Eastern Bandung can be an alternative to minimized operational cost, because the new route has shortened the distance from 98 km to 68 km (one trip in one day) with travel time 5 – 6 hours. While the new route in Southern Bandung cannot shortened the distance, it was 110 km to 123 km (one trip in one day) with travel time 6 – 7 hours.
2. Addition a vehicle was done in order to maximized the service of solid waste transporting for one trip in one day. Eastern Bandung area was served one trip in one day without addition of vehicle, while Southern Bandung area has to add one vehicle up in order to serve the solid waste transporting due to waste capacity was larger than the existing vehicles capacity.

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