International Journal of Scientific Advances
ISSN: 2708-7972
Volume: 5 | Issue: 1 | Jan – Feb 2024 Available Online: www.ijscia.com
DOI: 10.51542/ijscia.v5i1.16

Determination of the Distribution Route for Bottled Drinking Water Using Sweep Algorithm and Saving Algorithm

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ABSTRACT

The route determination by the heuristic way in the Vehicle Routing Problem (VRP) is an approach to distribution with the goal of minimizing distribution routes, assuming that vehicle routes must depart from and return to the central facility by finding the shortest or fastest route. The heuristic methods used include the sweep method and saving matrix for the grouping phase, while the improvement phase for each formed cluster utilizes the intra-route insertion algorithm. The results show that the heuristic approach indicates that the saving method produces shorter travel distances compared to the sweep method. For the characteristics of this data, the saving method may be better in handling vehicle capacity constraints. The choice between the saving method and the sweep method depends heavily on factors such as the distance between consumers, the number of distribution points, and vehicle capacity constraints.

Keywords: distribution route; Sweep algorithm; saving algorithm

INTRODUCTION

Supply chain management activities generally involve the flow of material, information, and finances throughout the supply chain process [6]. Supply Chain is a sequence of production processes, including raw material supply activities (inbound logistics), production processes, and distribution activities (outbound logistics) [4]. Distribution is the process of delivering goods or services from manufacturer to consumer where the goods or services are needed [12]. Each distribution process has a route or path that will be taken from the departure, travel, and delivery to the consumer. This route or path can affect the distribution process, specifically the speed of the journey to the destination. This can impact the quality of service provided by the company and influence customer satisfaction.

VRP (Vehicle Routing Problem) is a method to minimize transportation operating costs by reducing the number of vehicles and the total distance traveled by those vehicles. VRP focuses more on the sequence of consumers visited and the resulting total distance. If additional time-related information such as departure and arrival times is considered, the problem is further formulated as scheduling problems [12].

The distribution problem with the goal of minimizing distribution, assuming that vehicle routes must depart from and return to the central facility by finding the shortest route and quickest time from the depot to distribution points, is modeled as the Vehicle Routing Problem (VRP) [8].

Additionally, the optimal utilization of the carrying capacity of each type of vehicle has not been maximized by the company. Solving this problem becomes a task for the company, where distribution routes must be precise to ensure efficient distribution timing and minimize the total distance, thus reducing distribution costs.

METHODOLOGY

Distribution encompasses both physical and non-physical activities. Examples of physical activities include the loading and unloading of goods, while non-physical activities include the process of data collection for goods and the communication of shipping information. The Vehicle Routing Problem (VRP) is a distribution problem aimed at minimizing distribution routes, assuming that vehicle routes must depart from and return to the central facility by finding the shortest route and fastest time from the depot to distribution points [8].

Here are various types of routing problems based on their specific challenges and objectives [11]:

(1) Capacited Vehicle Routing Problem (CVRP), deals with a limited number of vehicles.
(2) Vehicle Routing Problem with Time Windows (VRPTW), is a problem where distribution is carried out at a certain time.
(3) Vehicle Routing Problem Pick-up and Delivery (VRPPD), the goods are picked up and delivered to the depot of origin.
(4) Vehicle Routing Problem Multiple Depot (VRPMD), involves multiple depots to supply the customers.

(5) Vehicle Routing Problem Multiple Trips (VRPMT), Fleet vehicles have routes that require returning to the depot before continuing.
(6) Distance Constrainer Vehicle Routing Problem (DCVRP), Involves restrictions on the distance that vehicles are allowed to travel.
(7) Vehicle Routing Problem with Backhauls (VRPB), Allows the picking up of goods from agents after completing all deliveries.
(8) Heterogeneous Fleet Vehicle Routing Problem (HFVRP), Deals with constraints arising from the heterogeneous nature of vehicles.
(9) Heterogeneous Fix Fleet Vehicle Routing Problem (HFFVRP), Considers both heterogeneous vehicle types and a predetermined number of vehicles.

Vehicle Routing Problem Pick Up and Delivery (VRPPD) is a type of VRP in which there is the retrieval of goods owned by the company that must be brought back to the depot. There are two types of services for this model, namely delivery and pickup services, or the implementation of pickup and delivery [3]. Considerations that must be taken into account when dealing with Vehicle Routing Problem Pick Up and Delivery (VRPPD) [3]:
(1) Prioritize pickup requests to precede corresponding deliveries
(2) Vehicle variants, the number of deliveries sometimes needs to match the number of pickups because they are visited by the same type of vehicle.
(3) The load capacity should not exceed the vehicle's capacity.
(4) Time window constraints require operators to serve within specified times at each retailer.
(5) Travel time should not exceed the direct travel time between the origin and destination.

Heterogeneous Fleet Vehicle Routing Problem (HFVRP) is a type of VRP that uses heterogeneous vehicles. The purpose of a Heterogeneous Fleet Vehicle Routing Problem (HFVRP) is to optimize the utilization of the number of vehicles in the available fleet [5]. An overview of the VRP for distribution solutions can be seen in Figure 1.

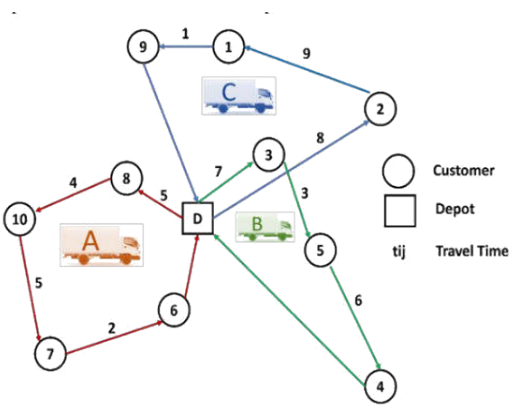

FIGURE 1: Vehicle Routing Problem.

SWEEP Method

The sweep algorithm is a two-phase algorithm, where the first phase involves clustering customers based on the location. and vehicle availability. Next, the second phase involves organizing routes for each cluster [7]. There are two types of sweep algorithms: forward sweep involves grouping consumer points following the direction of radial line rotation, starting from angle 0 to angle 360, commonly known as counterclockwise direction, which is opposite to the clockwise direction. Meanwhile, a backward sweep involves grouping in a clockwise direction [10]. The approach using the sweep algorithm is quite accurate with an error rate of around 10% mainly attributed to the route creation process [1].

Tahapan pada algoritma sweep [7] :
(1) Clustering involves several process steps in the clustering process:
  a. Determining the positions of the consumer in Cartesian coordinates and the location of the depot as the central point of the coordinates.
  b. Determine the polar coordinates of each consumer with the initial depot:

$$r = \sqrt{x^2 + y^2}$$

$$= \arctan \frac{y}{x} \quad (1)$$

  c. Creatine the clustering starting from the consumer point with the smallest polar angle and progressing to the largest while taking into account vehicle capacity.
  d. Ensure that all consumer points are included in the clustering.
  e. The clustering process will be stopped if one cluster is estimated to exceed maximum vehicle capacity.
  f. If point e occurs, repeat the cluster creation process as in the previous step.

(2) Formation of distribution routes from each cluster, consisting of:
  a. Initialization Stage, consisting of:
    - Determining the starting point, starting from the company's depot.
    - Identifying a set of points denoted by C, which that point will be visited by the vehicle.
    - Creating a temporary sequence of distribution routes.
  b. Determining the next point to be visited
    - If n_1 is the last point in the route sequence R, then the next point n_2 must have the minimum distance from n_1, where n_2 is a member of set C. If there is more than one choice of points that have the same distance from the last point in route R where that point is the minimum distance, then choose randomly.
    - Select the chosen point for the next route sequence, point n_1 is placed at the end of the temporary route, and removing the selected point from the list of points yet to be visited.
    - If all points have been put on order, conclude the route by adding the initiation point at the end of the route.

SAVING METHOD

Clarke and Wright or Savings Matrix Algorithm was first introduced by Clarke dan Wright in 1964. This algorithm is included in the category of heuristic algorithm which has not yet obtained an optimal solution to the problem to the problem being solved, However, Clarke and Wright are able to produce a relatively good solution that deviates slightly from the optimal solution [2]. The saving Matrix Algorithm is a method for minimizing distance, time, and cost by considering existing constraints [6].

The savings method refers to the initial formation of routes, this method will explain the steps involved in creating distribution routes for products. The steps of route formation using the Clarke and Wright algorithm will be explained as follows:

(1) Clustering by calculating distance savings for each customer. An example of distance savings calculation for consumer 1 and consumer 2 is as follows:

$$S(i,j) = J(D, i) + J(D,j) - J(i,j) \quad (2)$$

Where,
S(i, j) = Saving value for distance from 1 to 2
J(D,1) = Distance from the depot to customer 1
J(D,2) = Distance from the depot to customer 2

(2) Formation of distribution of routes by determining the starting point for distribution (depot). Determining the first tour by considering service and vehicle capacity. Selecting pairs by choosing customers based on the highest distance-saving value.

(3) Calculating the remaining vehicle capacity by subtracting the previous vehicle capacity from the capacity usage. If the remaining vehicle capacity is ≥ the consumer's demand, then the vehicle returns to the depot, and a new route is added. If the remaining vehicle capacity is < the consumer's demand, the vehicle can serve another customer.

Algoritma insertionintra–route method

The Intra-Route Insertion Algorithm is a process of exchanging and moving a destination point (customer) within the same route with the aim of minimizing distance or time and reducing distribution costs [9].

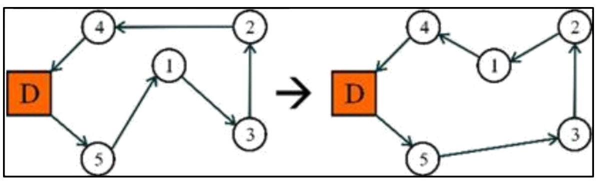

FIGURE 2: Algoritma Local Search Insertion Intra – Route.

The route exchange is done repeated until the best solution with the minimum distance is found. The steps performed in the intra-route insertion algorithm (1-0) are as follows:

(1) Input the tour and routes obtained using the nearest neighbour algorithm including distance matrix, loading time, unloading time, customer demands (Di), and vehicle capacity (Q).
(2) Initiate process starting from tour 1, i = 1.
(3) Perform the exchange of service route sequences at each point within the same route for each vehicle.
(4) Execute the exchange for each route until all points are completed, and choose the route with the shortest total distance.
(5) If there are customer points that have not undergone exchange, repeat step c.
(6) If the total distance obtained is greater than the previous total distance, then use the route obtained from the previous algorithm.

RESULT

The implementation of the Sweep Method and saving matrix method is carried out at the Perumda Tirtawening Kota Bandung which produces mineral drinking water with two brands, namely Hanaang and RO (reverse osmosis). One type of Perumda Tirtawening Kota in Bandung AMDK product is 19-litre gallon water. Every day the company distributes gallons of water to consumers with varying demands from each customer. The Perumda Tirtawening Kota in Bandung AMDK company has a distribution fleet consisting of 4 types of vehicles, namely the Mitsubishi Colt-Diesel 110 ps canter box, Mitsubishi Colt L300 pick up, Mitsubishi Colt L300 box, and Daihatsu Grand Max Blind Van. This vehicle distributes the products with different routes for each departure. Each type of vehicle has different load capacities and fuel consumption. This, of course, can affect the distance, travel time, and distribution costs for each route. The Bandung City Municipal Drinking Water Company distributes gallons of water every day to several locations scattered throughout Bandung City using four-wheeled vehicles of different types. The depiction of consumer points can be seen in Figure 1.

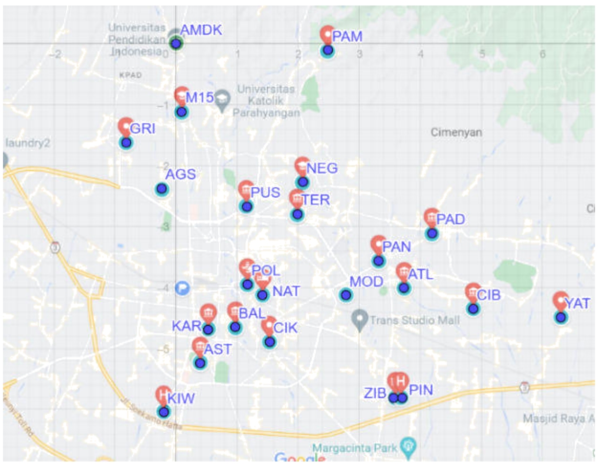

FIGURE 3: Lokasi Konsumen.

Each type has different load capacities and fuel consumption. The following is a table containing data on the fleet of distribution vehicles used by the Perumda Tirtawening Kota in Bandung (AMDK Kota Bandung).

TABLE 1: Vehicle Types and Capacities.

NO.	TYPE	CAPACITY (GALLON)
1	Canter box	250
2	Blind van	85
3	Box	130
4	Pick up	80

The loading and unloading time are the time to complete loading and unloading gallons on the vehicle. The time measured for loading is 24 seconds/gallon, while unloading time is 25 seconds/gallon, and empty gallon pick-up time is 17 seconds/gallon. The distribution time for distributing AMDK drinking water every day is 8 hours.

SWEEP ALGORITHM AND NEAREST NEIGHBOR ALGORITHM

The Sweep algorithm and the Nearest Neighbour algorithm aim to create clustering based on vehicle capacities and find the nearest distance between points to obtain the minimum total distance.

(1) Create a Cartesian diagram

This stage involves determining the depot point and the points of all consumers on the Google Maps application. Next, create Cartesian coordinates according to the points marked on Google Maps using the GeoGebra application. Here are the Cartesian coordinates of all consumers, where the depot is used as the central point with coordinates (0,0).

(2) Transforming Cartesian Coordinates into Polar Coordinates

Next, transform the Cartesian coordinates into polar coordinates for all consumer points. The Depot of the AMDK PDAM in the city of Bandung serves as the central point with polar coordinates (0°). The coordinate conversion process is carried out using the GeoGebra application. Here is a summary of the results of the conversion of Cartesian coordinates into polar coordinates, sorted from largest to smallest.

The result of creating a cartesian diagram and transforming cartesian coordinates into polar coordinates can be seen in Table 2 and Table 3.

TABLE 2: Coordinates for Each Consumer.

No.	Code	Cartesius coordinate	
		x	y
1	PIN	3.706	-5.808
2	AGS	-0.233	-2.376
3	PAN	3.319	-3.561
4	PAD	4.197	3.108
5	KIW	-0.200	-6.040
6	BAL	0.971	-4.645
7	POL	1.171	-3.947
8	AST	0.395	-5.238
9	KAR	0.526	-4.688
10	NAT	1.416	-4.121
11	GRI	-0.813	-1.623

No.	Code	Cartesius coordinate	
		x	y
12	ZIB	3.563	-5.808
13	YAT	6.303	-0.487
14	ATL	3.733	-4.003
15	PAM	2.491	-0.100
16	CIK	1.538	-4.889
17	CIB	4.868	-4.347
18	MOD	2.784	-4.123
19	PUS	1.163	-2.673
20	NEG	2.081	-2.266
21	TER	1.991	-2.795
22	M15	0.091	-1.118

TABLE 3: Polar Coordinate.

No.	Code	Polar Coordinate (0)
1	GRI	243.39
2	AGS	264.40
3	KIW	268.12
4	AST	274.31
5	M15	274.66
6	KAR	276.40
7	BAL	281.80
8	POL	286.53
9	CIK	287.46
10	NAT	288.96
11	PUS	293.51

No.	Code	Polar Coordinate (0)
12	ZIB	301.53
13	PIN	302.54
14	MOD	304.04
15	TER	305.70
16	NEG	312.55
17	PAN	312.99
18	ATL	313.00
19	CIB	318.24
20	PAD	323.48
21	YAT	324.55
22	PAM	357.64

(3) Creating distance matric and travel time matrix

A distance matrix is a table containing the distances of fleet movements from one customer to the next customer point. A travel time matrix is a table containing estimates of the time required for vehicles to move from one customer point to the next. The data for the distance and travel time matrices are obtained through the assistance of the Google Maps application. The following is the formula for calculating travel time

$$t = \frac{S}{v} \quad (3)$$

where :

t = Travel time

S = Distance (km)

v = Vehicle average speed (km/hours)

(4) Clustering

The vehicle priority is decided by the vehicle's carrying capacity and variable cost is the determining factor in the priority order of the vehicles used. Based on the calculation of fuel consumption of the four types of vehicles, the vehicle priority order is pick-up with a consumption of Rp. 723.40 / km, blind van Rp. 751.88 / km, box Rp. 755.56 / km and canter box Rp. 1,133/km. After determining the vehicle priority, the load is then divided based on the carrying capacity. If the vehicle capacity no longer fits, the load for the next destination is transferred to the vehicle with the second priority, and so on until all destination points are reached. The sequence of distributing the cargo load is based on distribution points with the smallest to the largest polar angle. The results of the grouping are shown in Table 4.

TABLE 4: Clustering Result.

Cluster	Routes	Distance (km)
1	AMDK– GRI – AGS – KIW – AST – M15– AMDK	27.80
2	AMDK – KAR –BAL – POL – CIK – NAT – PUS – ZIB – PIN – MOD– AMDK	45.75
3	AMDK – TER – NEG – PAN – PAD – ATL – CIB - AMDK	36.40
4	AMDK – PAM – YAT –AMDK	37.20
Total		**147.15**

(5) Establishing Route for Each Cluster

The next step is to determine the route for each cluster by using the nearest neighbour algorithm and ensure that all distribution points are included in the group. The formation of routes using the nearest neighbor algorithm aims to minimize the distance between distribution points in each cluster.

The first stage is finding the nearest distribution point from the depot (AMDK PDAM Kota Bandung) in the cluster. Subsequently, the same process is repeated, finding the nearest distribution point from the previously closest point until all points have been covered. The result of route improvement for each cluster using the nearest neighbor algorithm can be seen in Table 5.

TABLE 5: Route Establishment.

Cluster	Routes	Distance (km)
1	AMDK – AGS – M15 – GRI – AST – KIW – AMDK	29.20
2	AMDK –PUS – KAR – BAL – CIK – NAT – POL – MOD – PIN – ZIB – AMDK	38.25
3	AMDK – TER – NEG – PAN – PAD – ATL – CIB - AMDK	36.40
4	AMDK – PAM – YAT –AMDK	37.20
Total		**141.05**

(6) The (1-0) Intra-Route Insertion Algorithm

Insertion Intra Route Algorithm is an improvement algorithm to find the minimum total distance by exchanging each point in each route group (cluster) until all combinations of exchanges are completed.

The results of route improvement using the (1-0) Intra-Route Insertion Algorithm can be seen in Table 6.

TABLE 6: Routes Improvement.

Cluster	Routes	Distance (km)
1	AMDK – AGS – GRI – AST– KIW – M15– AMDK	26.20
2	AMDK – KAR – BAL – CIK – NAT– POL– MOD – PIN – ZIB –PUS– AMDK	37.35
3	AMDK – NEG – PAN – ATL – CIB – PAD –TER - AMDK	33.60
4	AMDK – PAM – YAT –AMDK	37.20
Total		**134.35**

Saving Matriks Algorithm.

Route grouping is done by calculating the saving value for each distance between the depot and customers, as well as the distance between customers i and j. Subsequently, the saving values are sorted from the highest to the lowest.

The route creation begins with a single route by combining pairs with the highest saving values without violating the vehicle's capacity constraints. The saving method has resulted in 4 routes, which can be observed in Table 7.

TABLE 7: Route Formation Using Saving Matrix.

Cluster	Routes	Distance (km)
1	AMDK – PIN – ZIB – ATL – AST – MOD – AMDK	43.55
2	AMDK – YAT– CIB – PAD – PAN – TER – NEG – PUS – PAM – M15 – AMDK	53.30
3	AMDK – KIW – KAR – BAL – CIK – NAT – POL – AMDK	28.30
4	AMDK – AGS – GRI –AMDK	9.10
Total		**134.25**

The next stage involves route improvement using the intra-route insertion algorithm, resulting in shorter travel distances.

The results of the route improvement are presented in Table 8.

TABLE 8: Route Improvement.

Cluster	Routes	Distance (km)
1	AMDK – PIN – ZIB – ATL – MOD – AST– AMDK	36.65
2	AMDK – YAT– CIB – PAD – PAN – TER – NEG – PUS – PAM – M15 – AMDK	50.90
3	AMDK – KAR – KIW – BAL – CIK – NAT – POL – AMDK	28.10
4	AMDK – AGS – GRI –AMDK	9.10
Total		**124.75**

The comparison of the total distances generated using the sweep method and saving method for the route grouping, as well as the intra-route insertion algorithm, can be observed in Table 9.

TABLE 9: Comparison of Saving Matrix and Sweep.

Description	SWEEP method	SAVING method
Number of routes generated	4 routes	4 routes
Total distance traveled after grouping (km)	141.05	134.25
Total distance traveled after using the intra-route insertion algorithm (km)	134.35	124.75

CONCLUSIONS

The Saving method and the Sweep method are two approaches that can be used to solve distribution problems in determining vehicle routes (Vehicle Routing Problems, VRP). In this case, the routes using the saving method result in shorter routes compared to the use of the sweep method. Some factors that make saving methods produce distribution routes with shorter distances include savings in travel distances or time. In the grouping stage, the saving method has already shown a total distribution time shorter than the sweep method. When using the (1-0) Intra Route Insertion Algorithm to improve the distribution sequence, the improvement results from the grouping of the saving method also show a shorter distribution distance value. The saving method allows for reducing the number of kilometers traveled by distribution vehicles by consolidating adjacent routes.

For the characteristics of this data, the saving method may be better at handling vehicle capacity constraints. The choice between the saving method and the sweep method depends heavily on factors such as the distance between consumers, the number of distribution points, and vehicle capacity constraints.

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