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Determining the Shortest Route of Distribution to Reduce Environmental Emissions Using Saving Matrix and Nearest Neighbor Methods

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ABSTRACT

One of the problems with the Vehicle Routing Problem (VRP) is the problem of fulfilling customer requests according to the location that must be supplied from depots that have limited vehicle capacity. This also happened to Distributor PT. XYZ is located in Lamongan. Every day the distributor of PT. XYZ distributes fertilizer to several cities in East Java, one of which is in the city of Blitar. The problem that happened to the distributor of PT. XYZ does not yet have an optimal distribution route, resulting in delays in the delivery process. Optimization of distribution routes can be done by finding the shortest route in fertilizer distribution in the Blitar area. With the saving matrix and nearest neighbor method, the best route arrangement can shorten the distance and product delivery time. The final result will be savings in distribution costs because it can reduce fuel consumption for fertilizer trucks, reducing the company's variable costs and reducing environmental emissions.

Keywords: Nearest neighbor, saving matrix, environmental emissions

Introduction

One of the important steps in creating a competitive advantage in managing a product distribution network consisting of delivery time, distribution distance, and vehicle capacity (Wang et al., 2019). In this condition, optimizing distribution channel arrangements has an important role in increasing operational efficiency and reducing costs (Xing et al., 2016). Optimization of distribution channels can minimize the distance based on vehicle capacity (Rizwanullah & Nilofer, 2018). One of the problems with the Vehicle Routing Problem (VRP) is the problem of fulfilling customer requests according to the location that must be supplied from depots with limited vehicle capacity. The problem should not be an obstacle to delivering the product on time to the customer. The fixed carrying capacity makes the VRP model develop into many methods.

This also happened to Distributor PT. XYZ is located in Lamongan. Every day the distributor of PT. XYZ distributes fertilizer to several cities in East Java, one of which is in the town of Blitar. For the Blitar area, the distributor of PT. XYZ has seven agents that must be visited every time they make a delivery process. The problem that happened to the distributor of PT. XYZ does not yet have an optimal distribution route, resulting in delays in the delivery process. Optimization of distribution routes can be done by finding the shortest route in fertilizer distribution in the Blitar area. The best route arrangement can shorten the distance and product delivery time, so the final result will be savings in distribution costs because it can reduce fuel consumption for fertilizer trucks. Other problems arise related to the increased consumption of energy, fuel, and motor vehicles, which impact the degradation of environmental quality (Li et al., 2015). The negative

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impact can be seen from the decrease in air, water, and soil quality. In terms of air quality, a decrease is seen in carbon emissions (Wang et al., 2019). The transportation sector is the largest emitter, which is dominated by land transportation (Coloma et al., 2019). Saving matrix is one of the methods used to optimize shipments with limited vehicle capacity to get an efficient route and optimum transportation costs. The saving matrix method solves transportation problems to minimize costs in product distribution routes by combining several delivery lines according to vehicle capacity (Iriani & Asmara, 2020). The saving matrix method is easy to solve complex distribution line problems to get the optimal route (Adam et al., 2020). The nearest neighbor method is a simple method with the concept of the nearest neighbor. Route determination begins with the route closest to the distribution center and the next route according to the most immediate route from the last visited customer (Sarjono, 2014). Determining the number of product deliveries to customers who enter the route does not violate the existing vehicle capacity limits. The process of determining the next vehicle path is also the same until all customers are visited, or the vehicle capacity is full (Rahma et al., 2020).

Based on these problems, to minimize the distribution distance to reduce fuel consumption and environmental emissions, this research focuses on optimizing the vehicle routing problem with the saving matrix and nearest neighbor methods. This method is used to determine distribution channels to minimize distances, find the shortest route that will have an impact on reducing environmental emissions, and calculate distribution costs while maximizing the vehicles used. Changes in distribution routes are expected to optimize distribution costs to be more efficient by optimizing vehicle capacity and minimizing distances.

Literature Review

Vehicle routing problem

One classification of route-determining and scheduling problems is the Vehicle Routing Problem (VRP). The VRP problem is an integer programming problem, where a set of routes for a vehicle fleet sourced coming from one or several depots should be determined to serve the geographically-dispersed customers. The purpose of VRP is to deliver the product to a group of customers whose demand whose demands are already known by spending a minimum cost, also starting and ending at one or more depots (Afshar-Bakeshloo et al., 2016). The output of this problem is a low-cost and feasible route for each vehicle (the route is a sequence of locations that must be visited with an indication of requiring service). One interesting problem in the discussion of the Vehicle Routing Problem is the Capacitated Vehicle Routing Problem (CVRP). CVRP is a case of determining the route of a K vehicle that aims to minimize the total distance covered by all routes, which will meet the capacity of vehicle Q and serve each customer. The following constraints will exist:

a. Each route will start and end at one depot.
b. Each customer will only be visited by one vehicle
c. The total demand for each route cannot exceed the capacity of vehicle Q.

Saving matrix method

The saving matrix method is a method used to determine the best route by considering the distance, the number of vehicles to be used, and the number of products that can be loaded by vehicles in product delivery to consumers so that the distribution process is optimal. The savings matrix method is also one of the techniques used to schedule a limited number of vehicles from facilities that have the maximum capacity (Adam et al., 2020).

Nearest neighbor methods

The nearest neighbor method is a method used to determine the distance of the shortest route with the closest distance between the customer and other customers (Rahma et al., 2020). Nearest neighbor methods aim to determine the shortest route so that the distribution path can be carried out optimally. Optimal in the number of products shipped, delivery time and distance required. The Nearest Neighbor method is the simplest method to solve the traveling salesman problem.

CO_2 Emissions & Emission Factors

Emissions are air pollutants from activities that use fuel (primary emissions) and electrical power (secondary emissions) (Wulandari et al., 2013). According to Wulandari et al. (2013), the emission factor is a coefficient that connects activities with emission sources. This factor can express emissions for each unit based on fuel (Zhang et al., 2020). Meanwhile, FES is a specific emission factor that refers to the amount of CO_2 per certain unit. However, to find out CO_2 emissions, data is also needed that consumes a lot of fuel (Zhang et al., 2020).

Table 1. Calorific value of Indonesian fuel

Fuel	Calorific value	Calorific value	Use
Premium	33 x 10^{-6} TJ/liter	-	Motor vehicle
Solar (HSD,ADO)	36 x 10^{-6} TJ/liter	9.063 Kkal/liter	Motor vehicles, power plants

Information: HSD: High-Speed Diesel, ADO: Automotive Diesel Oil
Source: Ministry of Environment, 2012

Table 2. Default CO_2 emission factor

Fuel Type	Default (kg/TJ)	Lower	Upper
Gasoline	69300	67.500	73000
Gas/Diesel Oil	74100	72.600	74800

Source: Ministry of Environment, 2012

Material and Methods

Research Methods

1. Determine the distance matrix.
   In determining this distance matrix, data on the distance between the company and its location and location to other locations is very necessary. After knowing the coordinates of each location, the distance between the two locations can be calculated using the formula (Iriani & Asmara, 2020):

   $$J(1,2) = \sqrt{(Xa - Xb)^2 + (Ya - Yb)^2} \text{ ....(1)}$$

   Note : J (1,2) = Distance between points 1 and 2
   X_1,Y_1 = Coordinate of point 1
   X_2,Y_2 = Coordinate of point 2

2. Determine the savings matrix.
   After knowing the overall distance, namely the distance between the company and its location and the location with other locations, in this step, it is assumed that each location will be passed by one truck exclusively. In that savings matrix, the following formula can be used (Rizwanullah and Nilofer, 2018):

   $$S(x, y) = J(0, x) + J(0, y) - J(x, y) \text{ ....(2)}$$

   S(x,y) is the distance savings from merging route x with route y.
3. Allocation of vehicles and routes by capacity.
   For the allocation of vehicles based on location, it is necessary to check whether the merger is feasible or not based on the existing capacity, such as the following formula [17]-[18]:
   Order size route 1 = order size customer 1 + order size customer 2 + customer n ....(3)
   Note: Order size route 1 < vehicle capacity.

4. Determine the shortest route to the destination using Nearest Neighbor Method.
   Nearest neighbor method consists of several steps in the method are as follows:
   a. Step 1, Start with any node as the beginning of the path.
   b. Step 2, Find the node closest to the last node added to the path.
   c. Step 3, repeat Step 2 until all nodes are contained in the path.
   d. Then, join the first and last nodes.
5. Determine CO_2 Emissions.
   The equation below refers to the Ministry of Environment (2012) for different fuels having different calorific values.

   Greenhouse Gas Emissions (kg/year) = KE x FE x NK ....(4)

   Note: KE = Energy Consumption (TJ/year)
   FE = Emission Factor (TJ/lt)
   NK= Calorific Values (kg/TJ)

Result and Discussion

Data collection

Table 3. Initial delivery route

Route	Customer Code	Transportation Type	Distance (km)
1	A-C7-C3-C2-A	CLD1	391.4
2	A-C6-C5-A	CLD2	345.2
3	A-C4-C1-A	CLD3	407.2
	Total		1143.8

Source: Data processing

Table 4. Code of agents & number of demands

No	Code	Demand (box)	No	Code	Demand (box)
1	C1	165	5	C5	160
2	C2	145	6	C6	155
3	C3	150	7	C7	170
4	C4	155	Total		1100

Source: Data processing

Delivery is carried out using truck transportation (Colt Diesel), transportation data used for distribution from the warehouse to the customer is by using a truck with a capacity of 800 boxes/truck. In one month the distributor of PT XYZ sends fertilizer 10 times. The price of solar fuel is IDR 9,600.00/liter and 1 liter of solar fuel can cover a distance of 6 km type Truck (Colt Diesel).

Determine the distance matrix

The first step in this research is to identify the distance matrix between warehouses to each agent and the distance between stores/agents presented in Table 5.

Table 5. Distance between warehouse and agent

	0	C1	C2	C3	C4	C5	C6	C7
0	0	173	202	165	191	175	156	149
C1	173	0	38.8	49.2	43.2	37.7	37.4	67.9
C2	202	38.8	0	18.5	12.6	7.1	12.8	37.3
C3	165	49.2	18.5	0	22.8	13.2	12.3	21.9
C4	191	43.2	12.6	22.8	0	17.7	30.3	43.5
C5	175	37.7	7.1	13.2	17.7	0	14.2	31.8
C6	156	37.4	12.8	12.3	30.3	14.2	0	19.8
C7	149	67.9	37.3	21.9	43.5	31.8	19.8	0

Determine the savings matrix

The next step is to identify the savings matrix with the assumption that each agent will be visited by one truck exclusively. In other words, there will be 7 different routes with one destination each.

Table 6. Results of distance savings calculation (Saving matrix)

	0	C1	C2	C3	C4	C5	C6	C7
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C1	0.0	346.0	336.2	288.8	320.8	310.3	291.6	254.1
C2	0.0	336.2	404.0	348.5	380.4	369.9	345.2	313.7
C3	0.0	288.8	348.5	330.0	333.2	326.8	308.7	292.1
C4	0.0	320.8	380.4	333.2	382.0	348.3	316.7	296.5
C5	0.0	310.3	369.9	326.8	348.3	350.0	316.8	292.2
C6	0.0	291.6	345.2	308.7	316.7	316.8	312.0	285.2
C7	0.0	254.1	313.7	292.1	296.5	292.2	285.2	298.0

Source: Data processing

Table 7. Ranking of savings in KM

No	Edge	Sij	No	Edge	Sij	No	Edge	Sij
1	4.2	380.4	8	5.3	326.8	15	7.4	296.5
2	5.2	369.9	9	4.1	320.8	16	7.5	292.2
3	3.2	348.5	10	6.5	316.8	17	7.3	292.1
4	5.4	348.3	11	6.4	316.7	18	6.1	291.6
5	6.2	345.2	12	7.2	313.7	19	3.1	288.8
6	2.1	336.2	13	5.1	310.3	20	7.6	285.2
7	4.3	333.2	14	6.3	308.7	21	7.1	254.1

Source: Data processing

The results of the calculation of the distance using the savings matrix are presented in table 6. The next step is to rank the saving matrix from the distance savings with the largest value first to the savings with the smallest value according to the kilometer. The ranking results are presented in Table 7.

Allocating agents to vehicles or routes

Based on the distance saving calculation, the next step is allocating agents to vehicles or routes. With the initial assumption of 7 different routes, but in allocating, the agents can be combined to the limit of the existing truck capacity. The combination starts from the largest savings to maximize savings.

Table 8. Allocating agents to vehicles or routes

Edge	Merge	Result (Demand < C=800 box)	Decision
4.2	0,4,0 and 0,2,0	155+145=300	0-4-2-0
5.2	0,5,0 and 0,4,2,0	160+155+145=460	0-4-2-5-0
3.2	0-3-0 and 0-4-2-5-0	160+155+145+150=610	0-4-3-2-5-0
6.2	0-6-0 and 0-4-3-2-5-0	160+155+145+150+155=765	0-4-3-6-2-5-0
2.1	0-1-0 and 0-4-3-6-2-5-0	160+155+145+150+155=765 165	0-4-3-6-2-5-0 0-1-0
7.2	0-4-3-6-2-5-0 and 0-7-1-0	160+155+145+150+155=765 170+165=335	0-4-3-6-2-5-0 save 0-7-1-0

Source: Data processing

Table 9. Delivery route and capacity with saving matrix

No	Route	Capacity (Box)	Distance (KM)
1	0-4-3-6-2-5-0	160+155+145+150+155=765	191+22.8+12.3+12.8+7.1+175= 421
2	0-7-1-0	170+165=335	149+67.9+173= 389.9
			Total Distance = 810.9 (KM)

Source: Data processing

Based on calculations in allocating agents into routes or vehicles, the results of the calculation of agents' allocation into the route or delivery vehicle are known to be carried out with 2 shipping routes:

Route 1: Warehouse, agent C4, agent C3, agent C6, agent C2, agent C5, Warehouse (Load 765 Box)

Route 2: Warehouse, agent C7, agent C1, Warehouse (Load 335 Box)

Determine the order of destination locations in the route using the nearest neighbor method

After the route allocation is done, the next step is to determine the order of delivery routes. Determining the order of this delivery route using the Nearest Neighbor Method.

Table 10. Route 1 Distance Matrix Using Nearest Neighbor

	0	C2	C3	C4	C5	C6
0	0	202	165	191	175	156
C2	202	0	18.5	12.6	7.1	12.8
C3	165	18.5	0	22.8	13.2	12.3
C4	191	12.6	22.8	0	17.7	30.3
C5	175	7.1	13.2	17.7	0	14.2
C6	156	12.8	12.3	30.3	14.2	0

Source: Data processing

Table 11. Route 2 distance matrix using nearest neighbor

	0	C1	C7
0	0	173	149
C1	173	0	67.9
C7	149	67.9	0

Source: Data processing

Table 12. Total Distance for Route 1 Using Nearest Neighbor

Nodes Added	Tour	Total Distance
0	0	0
6	0-6	156
3	0-6-3	168
5	0-6-3-5	182
2	0-6-3-5-2	189
4	0-6-3-5-2-4	201
Route	0-6-3-5-2-4-0	392 km

Source: Data processing

Table 13. Total Distance for Route 2 Using Nearest Neighbor

Nodes Added	Tour	Total Distance
0	0	0
7	0-7	149
1	0-7-1	217
	0-7-1-0	389.90 km

Source: Data processing

From the calculation using the Nearest Neighbor method, it produces a minimum total distance. Based on the table above, the total minimum distance traveled on route 1 is 392 km and the second route has a minimum distance of 389.90 km. In detail the recap of determining the distance and order of delivery can be seen from the table 14.

Table 14. Recapitulation of distribution route distance

Route	Order of Delivery	Distance (KM)
Route 1	Warehouse-C6-C3-C5-C2-C4-Warehouse	392
Route 2	Warehouse-C7-C1-Warehouse	389.90
		Total Distance = 781.9 KM

Source: Data processing

Determining variable cost savings and calculating co_2 emissions

From the data obtained, the next step is to calculate costs by comparing the initial costs that have been spent by the company. For 1 liter of solar fuel can cover a distance of 6 km type truck (Colt Diesel). Within one month, the distributor of PT. XYZ delivered 10 times of fertilizer.

Table 15. Comparison of cost saving results

Route	Total distance (km)	Fuel Consumption (Liter/Month)	Total Cost (Fuel Price x Fuel Consumption)
Existing Route PT. XYZ	1143.8	1906	IDR 18,297,600.00
This research	781.9	1303	IDR 12,508,800.00
Savings	361.9	603	IDR 5,788,800.00

Source: Data processing

The next step is calculating CO_2 emissions based on fuel consumption from the transportation sector, which is using a truck with solar fuel. The following is the calculation of the total fuel usage of PT. XYZ for one year.

Table 16. Total fuel consumption

Attribute	Total Distance (km)	Fuel Consumption (Liter/Month)	Fuel Consumption (Liter/Year)
Existing Route PT. XYZ	1143.8	1906	22876
This research	781.9	1303	15638

Source: Data processing

From the data above, then the CO_2 emission calculation is carried out according to equation 4 with solar fuel, namely by comparing the CO_2 emissions of the existing route with the route of this study. The following calculations are:

a. CO_2 emissions solar fuel (kg/year) Existing Route PT. XYZ = KE x FE x NK
   CO_2 emissions = 22876 liter/year x (36 x 10^{-6} TJ/liter) x 74100 (kg CO_2/TJ)
   = 61024.01 kg CO_2/year
b. CO_2 emissions solar fuel (kg/year) Nearest Neighbor Method (This research) = KE x FE x NK
   CO_2 emissions = 15638 liter/year x (36 x 10^{-6} TJ/liter) x 74100 (kg CO_2/TJ)
   = 41715.9 kg CO_2/year

From the results of the calculation of solar fuel, it is found that the difference in total emissions from the transportation sector using trucks with the route of existing conditions versus the nearest neighbor route, the difference in emissions is 19308.11 kgCO_2/year.

Conclusion

This research concludes that in the distribution of the company's existing conditions, using three routes turns into two new routes after using the saving matrix method. The order of recommendation routes using the nearest neighbor method can shorten the distance traveled by the company's trucks from 1143.8 km to 781.9 km or savings of 361.9 km. The distribution uses two trucks of the CLD (Cold Diesel) type, with a maximum capacity of 800 boxes. The route obtained after using the nearest neighbor method is Route 1 (Warehouse-C6-C3-C5-C2-C4-Warehouse) with a distance of 392 km; Route 2 (Warehouse-C7-C1-Warehouse) with a length of 389.90 km. After getting the order of the shortest route using the nearest neighbor method, the fuel cost on the existing route is IDR 18,297,600.00/month, but after using the saving matrix and nearest neighbor method, the fuel cost is IDR 12,508,800.00/month. Cost minimization is recommended based on delivery to customers using the nearest neighbor method by saving IDR 5,788,800.00 then reducing the company's variable costs and reducing environmental emissions of 19308.11 kgCO_2/year. The company is expected to use a new distribution channel using the saving matrix method and the nearest neighbor method to control costs by going through shorter routes, making the expenses optimal, and reducing environmental emissions.

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