VEHICLE ROUTING PROBLEM IN BLOOD DISTRIBUTION USING A HYBRID SWEEP ALGORITHM AND GENETIC ALGORITHM

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Abstract. The Blood Supply Chain (BSC) presents significant logistical challenges due to the perishable nature and varied shelf lives of blood products. Efficient delivery route planning is crucial for optimizing blood distribution and enhancing overall operational efficiency. This study addressed the complex problem of determining optimal delivery routes using variants of the Vehicle Routing Problem (VRP): the Capacitated Vehicle Routing Problem (CVRP) and the Vehicle Routing Problem with Pick-Up and Delivery (VRPPD). The solution of CVRP and VRPPD was done by using metaheuristic methods, namely hybrid sweep algorithm and genetic algorithm. In addition, a numerical comparison was made using this proposed hybrid algorithm with a genetic algorithm, both applied to the same mathematical model. The comparative analysis revealed that the proposed hybrid algorithm generated 2 clusters with a total vehicle mileage of 225.60 km, whereas the genetic algorithm yielded 3 clusters with a total vehicle mileage of 248.80 km. The genetic algorithm resulted in a 10.28% (23.2 km) increase in total mileage compared to the proposed hybrid algorithm, demonstrating the superior efficiency of the hybrid approach for optimizing blood delivery routes.

Keywords: Blood supply chain, vehicle routing problem, hybrid metaheuristics, sweep algorithm, genetic algorithm

1. Introduction

Blood is considered a rare commodity due to the absence of blood substitutes or chemical processes that can produce blood, where blood can only be produced by humans. Blood is constantly needed for various treatments, such as in accident victims or other medical treatments. Blood is a perishable product and has a different shelf life [1]. As with other perishable products, blood has a supply chain which is then called the Blood Supply Chain (BSC). BSC is a complex activity because blood products are perishable and have different shelf lives [1]. Blood distribution activities become very complex due to the demand for different quantities and types of blood components [2]. The complexity of BSC also involves different interconnected parameters and various stakeholders, such as donors, hospitals, and blood banks [3]. Therefore, the complexity of BSC must be carefully managed in an effort to fulfill patient needs, both in quality and quantity.

In Indonesia, blood supply services are carried out by the Blood Transfusion Unit (UTD). UTD is a health service facility that organizes blood donation, blood supply, and blood distribution. In addition, UTD is responsible for ensuring blood availability and being able to distribute it to hospitals in need [1]. UTD PMI Cirebon City is one of the blood supply units in Indonesia located in Cirebon City. This unit serves blood requests from various hospitals that reach up to hospitals in the Tegal City area. The wide scope of blood distribution means that UTD PMI Cirebon City must be able to ensure blood availability and distribution efficiently so that blood can be available at the right time, place, and amount according to hospital demand.

The blood distribution process of this unit still does not have a fixed route in delivering blood to each hospital. When conducting distribution, the determination of this unit's delivery route uses driver preferences. This approach is inherently inefficient because it fails to account for the complex interactions and feedback loops within the logistics network, such as varying time windows and fluctuating demand. Historical data and experience in this unit indicate that relying on driver intuition leads to unplanned outcomes, where a route perceived as a shortcut by one driver may inadvertently cause delays in the overall system's schedule. These delays frequently push the delivery beyond the predetermined time window, proving that the collection of individual driver decisions is insufficient to achieve an optimal solution for the system as a whole.. Blood delivery in this unit must be done appropriately in determining the route to optimize the distance and time of distribution [4]. Therefore, delivery route planning information is important to optimize blood delivery to increase efficiency when making blood deliveries. In addition, delivery route planning information can assist drivers in making deliveries so that route determination does not use driver preferences.

The best way to deliver blood in this unit can be determined using the Vehicle Routing Problem (VRP). In general, VRP is defined as determining the route in serving customers with known demand that connects depots with customers and between other customers [5]. The types of VRP used in supporting the resolution of blood distribution optimization are the Capacitated Vehicle Routing Problem (CVRP) and Vehicle Routing Problem With Pick-Up And Delivery (VRPPD). CVRP in this study, used as a solution in making clustering. While VRPPD is used to solve the determination of hospital distribution routes that have been clustering. CVRP and VRPPD solutions are carried out using metaheuristic methods to produce more optimal solutions [6]. This study proposed a new hybrid method that combines two approaches: the sweep algorithm and the genetic algorithm. The sweep algorithm is a two-step process. First, it groups delivery points into clusters, taking into account the delivery capacity. Then, it uses the nearest neighbor method to find the most efficient route within each cluster [7]. Meanwhile, the genetic algorithm is the result of the biological evolution of living things that inspires the search mechanism [8]. In addition, a comparison of the results between calculations using the proposed hybrid algorithm and a genetic algorithm is also carried out using the same mathematical model reference

2. Methods

Data collection was conducted through observation and interviews to obtain information on blood distribution activities and total blood demand for each hospital. Data on capacity, number of vehicles, and types of vehicles used were also obtained through interviews. The type of vehicle used is Daihatsu Grand Max that can accommodate 3 cool boxes with a cool box capacity of 80 flasks. Determination of blood distribution policy is done using VRP using a proposed hybrid algorithm, namely sweep algorithm and genetic algorithm. Sweep algorithm is used for clustering and genetic algorithm is used for route determination after clustering.

The mathematical model reference used in calculating the hybrid algorithm, namely the sweep algorithm and genetic algorithm is as follows.

Objective Function

$$Z_{min} = Min \sum_{i=1}^{N} \quad \sum_{j=1}^{N} \quad C_{ij} \times X_{ij} \qquad (1)$$

Constraint

$$\sum_{j=1}^{N} \quad X_{ij} = 1 \qquad \forall i \in V \ \{1, 2, …., \mathrm{N}\} \qquad (2)$$

$$\sum_{j=1}^{N} \quad X_{ji} = 1 \qquad \forall i \in V \ \{1, 2, …., \mathrm{N}\} \qquad (3)$$

$\sum_{j=1}^{N} \quad D_{ji} - \sum_{j=1}^{N} \quad D_{ij} = d_i \qquad \forall i \in V \{1, 2, \ldots, N\} \qquad (4)$

$\sum_{j=1}^{N} \quad P_{ji} - \sum_{j=1}^{N} \quad P_{ij} = p_i \qquad \forall i \in V \{1, 2, \ldots, N\} \qquad (5)$

$D_{ij} + P_{ij} \leq K_i \qquad \forall i \in V \{1, 2, \ldots, N\} \qquad (6)$

$a_i \leq T_i \leq b_i \qquad \forall i \in V \{1, 2, \ldots, N\} \qquad (7)$

$D_{ij} \geq 0 \qquad \forall (i,j) \in A \qquad (8)$

$P_{ij} \geq 0 \qquad \forall (i,j) \in A \qquad (9)$

Decision Variable

$X_{ij} \in \{0, 1\}, \qquad \forall (i,j) \in A \qquad (10)$

A: A network formed from the combination of i and j or vice versa

N: Number of blood supply delivery recipient locations

i: Index representing the departure location $(1,2, \ldots, N)$

j: Index representing the destination location $(1,2, \ldots, N)$

Cij: Distance between location i to j (km)

Ki: Maximum vehicle capacity (box)

Dij: Quantity of product held and needing delivery in network (i, j) (box)

Pij: Quantity of product held and needing pickup in network (i, j) (box)

di: Quantity of product delivered to customer i (box)

pi: Quantity of product picked up from customer i (box)

ai: Start time limit for blood supply delivery

bi: End time limit for delivery that must be completed

Ti: Vehicle arrival time at each location (hours)

Xij: Binary decision variable indicating whether the route from i to j is chosen or not

Based on the mathematical model above, the objective function in equation (1) is to minimize the delivery distance. Equations (2) and (3) explain that delivery can only be visited and left once. Equation (4) is the concept of delivery, where delivery must be in accordance with the model, while equation (5) is a limitation so that product pickup is in accordance with the model. Then, equation (6) is an equation to ensure that the products delivered and picked up do not exceed the capacity of the vehicle. Equation (7) explains the time windows, where deliveries must meet the specified delivery time window. Equations (8) and (9) are restrictions to ensure that the value used during delivery is not negative.

2.1. Sweep Algorithm

The sweep algorithm is used to cluster hospitals by taking into account the demand and capacity of the delivery vehicle

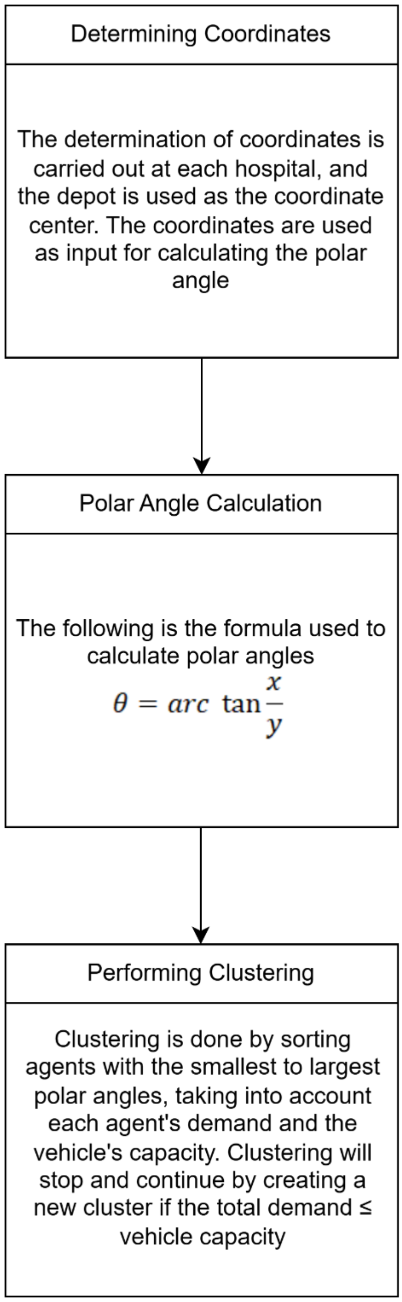

Figure 1. Sweep Algorithm

2.2. Genetic Algorithm

Genetic algorithm is used to determine the route for each cluster after clustering using the sweep algorithm.

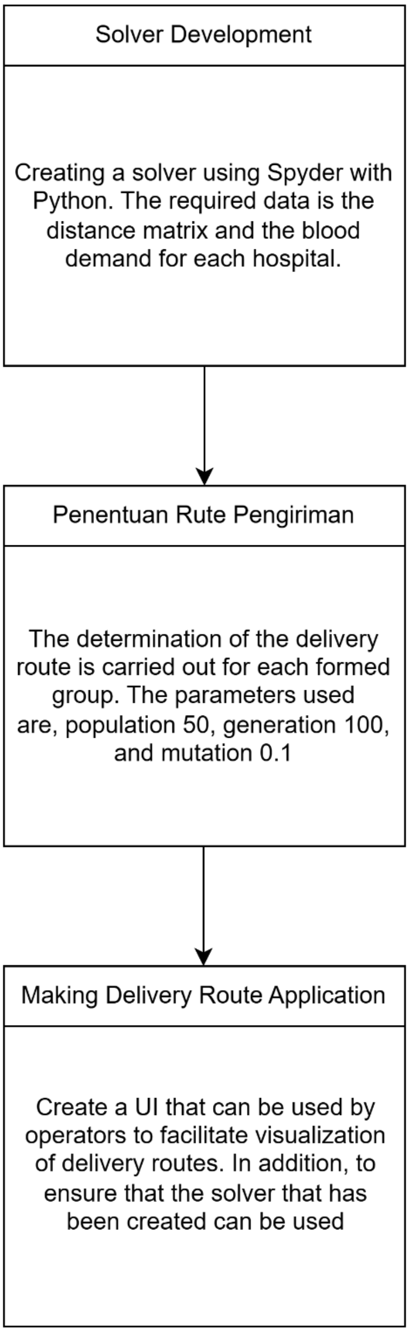

Figure 2. Genetic Algorithm

3. Results And Discussion

3.1. Description

The initial stage carried out is clustering using the sweep algorithm. The first step is to determine the location points of 16 hospitals which are determined based on latitude (X) and longitude (Y) points. Next, the polar angles of the 16 hospitals were calculated based on cartesian coordinates. Clustering is done by sorting the polar angles from smallest to largest by integrating the capacity of the delivery vehicle with the blood demand of each hospital. After obtaining the number of clusters formed, the determination of delivery routes for each cluster is carried out by using genetic algorithm. The determination of the delivery route is to minimize the delivery distance according to the objective function in the mathematical model used.

3.2. Figures and Tables

Table 1 is a table of hospital data with cartesian coordinates at each hospital location. Table 1 is also the order of hospitals based on the results of polar angle calculations based on cartesian coordinates with flask demand data for each hospital

Table 1. Polar Angle of Each Hospital

Code	Hospital	Latitude (X)	Longitude (Y)	θ (º)	Demand (flask)
AK10	Panti Abdi Dharma Hospital	-6.72384147602746	108.56895580659862	16.9	19
AK8	Pelabuhan Hospital	-6.712076532109704	108.56734523272183	50.6	22
AK2	Sumber Kasih Hospital	-6.707372861651949	108.55992216573553	74.1	24
AK9	Pertamina Hospital	-6.681574236983047	108.5522442130363	92.1	21
AK11	Muhammadiyah Hospital	-6.707353046232779	108.55139848830186	96.9	9
AK6	Permata Hospital	-6.7056590010262	108.53379681521132	131.5	44
AK15	Mitra Plumbon Hospital	-6.697617025163793	108.48095153369586	157.1	68
AK12	Sumber Waras Hospital	-6.674767055821113	108.38287570214631	162.6	10
AK14	Hasna Medika Hospital	-6.7048511299975	108.43263528599435	169	10
AK3	Cahaya Bunda Hospital	-6.73070103230156	108.53922778469925	188.9	6
AK13	Budi Asta Hospital	-6.741631477377162	108.53417490447929	213.8	8
AK5	Medimas Hospital	-6.741755428396842	108.5402222943524	224.2	9
AK7	Ciremai Hospital	-6.736970872681501	108.54977929857314	244.1	63
AK4	Putera Bahagia Hospital	-6.745669336101973	108.5626167362008	296.7	27
AK1	Gunung Jati Hospital	-6.730598540524632	108.55537919535858	303.1	74
AK16	Harapan Anda Hospital	-6.852096970754905	109.12814249463685	347.8	48

Table 2 is a matrix of distances between UTD PMI and hospitals and between hospitals. The distance in table 2 is obtained from measurements using google maps. The distance inputted is the shortest distance from several distance options available on google maps.

Table 2. Distance Matrix

	AK0	AK1	AK2	AK3	AK4	AK5	AK6	AK7	AK8	AK9	AK10	AK11	AK12	AK13	AK14	AK15	AK16
AK0	0	0.5	3.9	2.4	4	3.1	5.1	1.5	3.5	6	2.9	2.7	21.8	3.6	15.8	9.8	80.7
AK1	0.5	0	3.8	2.8	3.9	2.9	5.9	1.3	3.3	6.4	2.7	3.1	22.2	3.5	16.2	10.2	80.5
AK2	3.9	3.8	0	4.9	5.1	5.7	4	4.1	1.1	3.8	2.6	1.6	21	6.2	15	9	79.1
AK3	2.4	2.8	4.9	0	4.4	2.2	4.5	2.4	5.6	7.3	4.8	4	20.8	4	14.8	8.8	81
AK4	4	3.9	5.1	4.4	0	3.6	7.7	2.7	6.3	10.9	3.5	5.8	28.1	4.2	22.1	16.1	77.2
AK5	3.1	2.9	5.7	2.2	3.6	0	5.5	1.6	5.8	8.3	5	4.7	25.9	1	19.9	13.9	78.9
AK6	5.1	5.9	4	4.5	7.7	5.5	0	5.5	5.2	4.8	6.9	3.1	18.9	6.3	12.9	6.9	84.1
AK7	1.5	1.3	4.1	2.4	2.7	1.6	5.5	0	4.3	6.6	3.5	3.3	22	2.2	20.2	14.1	79.2
AK8	3.5	3.3	1.1	5.6	6.3	5.8	5.2	4.3	0	4.6	1.6	4	23.9	9.6	17.9	11.9	77.9
AK9	6	6.4	3.8	7.3	10.9	8.3	4.8	6.6	4.6	0	6.6	3.4	23.3	8.8	17.3	11.3	82.4
AK10	2.9	2.7	2.6	4.8	3.5	5	6.9	3.5	1.6	6.6	0	3.5	23.9	4.9	17.8	11.8	76.8
AK11	2.7	3.1	1.6	4	5.8	4.7	3.1	3.3	4	3.4	3.5	0	20.2	5.4	14.2	8.2	82.4
AK12	21.8	22.2	21	20.8	28.1	25.9	18.9	22	23.9	23.3	23.9	20.2	0	25.7	6.5	12.6	97.1
AK13	3.6	3.5	6.2	4	4.2	1	6.3	2.2	9.6	8.8	4.9	5.4	25.7	0	20.2	14.2	79.2
AK14	15.8	16.2	15	14.8	22.1	19.9	12.9	20.2	17.9	17.3	17.8	14.2	6.5	20.2	0	6.6	91
AK15	9.8	10.2	9	8.8	16.1	13.9	6.9	14.1	11.9	11.3	11.8	8.2	12.6	14.2	6.6	0	85.4
AK16	80.7	80.5	79.1	81	77.2	78.9	84.1	79.2	77.9	82.4	76.8	82.4	97.1	79.2	91	85.4	0

After obtaining the polar angle for each hospital, each hospital is grouped based on the smallest to largest polar angle by considering the demand and capacity of the delivery vehicle. The clusters formed are as many as 2 clusters. Table 3 is the first cluster consisting of 10 hospitals with a total demand of 233 flasks and table 4 is the second cluster consisting of 6 hospitals with a total demand of 229 flasks.

Table 3. First Cluster Using Hybrid Algorithm

Code	Hospital	θ (º)	Demand (flask)
AK10	Panti Abdi Dharma Hospital	16.9	19
AK8	Pelabuhan Hospital	50.6	22
AK2	Sumber Kasih Hospital	74.1	24
AK9	Pertamina Hospital	92.1	21
AK11	Muhammadiyah Hospital	96.9	9
AK6	Permata Hospital	131.5	44
AK15	Mitra Plumbon Hospital	157.1	68
AK12	Sumber Waras Hospital	162.6	10
AK14	Hasna Medika Hospital	169	10
AK3	Cahaya Bunda Hospital	188.9	6
	Total		233

Table 4. Second Cluster Using Hybrid Algorithm

Code	Hospital	θ (º)	Demand (flask)
AK13	Budi Asta Hospital	213.8	8
AK5	Medimas Hospital	224.2	9
AK7	Ciremai Hospital	244.1	63
AK4	Putera Bahagia Hospital	296.7	27
AK1	Gunung Jati Hospital	303.1	74
AK16	Harapan Anda Hospital	347.8	48
	Total		229

Based on the clustering results, the determination of the delivery route is carried out for each cluster using a genetic algorithm. The route formation for each cluster using a genetic algorithm aims to get optimal route results with a short total distance traveled. Route formation is carried out by selecting the starting point and end point of delivery is UTD PMI. The following is the delivery route for each cluster formed.

a) First Cluster

UTD PMI-Muhammadiyah Hospital-Panti Abdi Dharma Hospital-Pelabuhan Hospital-Sumber Kasih Hospital-Pertamina Hospital-Permata Hospital-Mitra Plumbon Hospital-Hasna Medika Hospital-Sumber Waras Hospital-Cahaya Bunda Hospital-UTD PMI

b) Second Cluster

UTD PMI-Gunung Jati Hospital-Putera Bahagia Hospital-Harapan Anda Hospital-Budi Asta Hospital-Medimas Hospital-Ciremai Hospital- UTD PMI

Table 5 is a summary of the distribution route results for each cluster using the hybrid algorithm. The total distance that must be traveled for all vehicles is 225. 60 km. In the first cluster, the total distance traveled for vehicles in carrying out distribution is as far as 60.70 Km. While in the second cluster, the total distance traveled by vehicles is 164.90 Km.

Table 5. Distribution Route Results using Hybrid Algorithm

Cluster	Delivery Route	Distance (Km)
First Cluster	AK0-AK11-AK10-AK8-AK2-AK9-AK6-AK15-AK14-AK12-AK3-AK0	60.70
Second Cluster	AK0-AK1-AK4-AK16-AK13-AK5-AK7-AK0	164.90

Based on calculations using genetic algorithms, the resulting cluster is 3 clusters. Table 6 is the first cluster consisting of 6 hospitals with a total demand of 186 flasks. Table 7 is the second cluster consisting of 9 hospitals with a total demand of 228 flasks. Table 8 is the third cluster consisting of 1 hospital with a total demand of 48 flasks.

Table 6. First Cluster Using Genetic Algorithm

Code	Hospital	Demand (flask)
AK1	Gunung Jati Hospital	19
AK5	Medimas Hospital	22
AK4	Putera Bahagia Hospital	24
AK2	Sumber Kasih Hospital	21
AK6	Permata Hospital	9
AK3	Cahaya Bunda Hospital	44
Total		186

Table 7. Second Cluster Using Genetic Algorithm

Code	Hospital	Demand (flask)
AK7	Ciremai Hospital	19
AK13	Budi Asta Hospital	22
AK10	Panti Abdi Dharma Hospital	24
AK8	Pelabuhan Hospital	21
AK9	Pertamina Hospital	9
AK11	Muhammadiyah Hospital	44
AK12	Sumber Waras Hospital	68
AK14	Hasna Medika Hospital	10
AK15	Mitra Plumbon Hospital	10
Total		228

Table 8. Third Cluster Using Genetic Algorithm

Code	Hospital	Demand (flask)
AK13	Harapan Anda Hospital	48
	Total	48

Table 9 is a summary of the distribution route results for each cluster using genetic algorithm. The total distance that must be traveled for all vehicles is 248.80 Km. In the first cluster, the total distance traveled for vehicles in carrying out distribution is 22.60 Km, in the second cluster, the total distance traveled by vehicles is 64.80 Km, and the third cluster the total distance traveled by vehicles is 161.40 Km.

Table 9. Distribution Route Results Using Genetic Algorithm

Cluster	Delivery Route	Distance (Km)
First Cluster	AK0-AK1-AK5-AK4-AK2-AK6-AK3-AK0	22.60
Second Cluster	AK0-AK7-AK13-AK10-AK8-AK9-AK11-AK12-AK14-AK15-AK0	64.80
Third Cluster	AK16	161.40

As shown in Table 10, the hybrid algorithm proved more efficient in terms of vehicle mileage compared to the genetic algorithm. The hybrid approach created 2 clusters and achieved a total mileage of 225.60 km. Conversely, the genetic algorithm formed 3 clusters and resulted in a higher total mileage of 248.80 km. Consequently, the genetic algorithm led to 23.2 km (10.28%) more total shipping mileage.

Table 10. Comparison of Hybrid Algorithm with Genetic Algorithm

Parameter	Cluster Formed	Total Distance (Km)
Proposed Hybrid Algorithm	2	225.60
Genetic Algorithm	3	248.80
Difference		10.28%

4. Conclusion

This research applied a proposed hybrid algorithm to the Vehicle Routing Problem (VRP). In UTD PMI Cirebon case study, the hybrid approach optimized vehicle routes by first forming two clusters using a sweep algorithm, then finding the shortest route within each cluster with a genetic algorithm. The first cluster resulted in a total vehicle mileage of 60.70 km, while the second generated 164.90 km, for a combined total of 225.60 km. This hybrid method proved highly effective, achieving a 10.28% better total mileage compared to using a standalone genetic algorithm, which yielded a total of 248.80 km across three clusters. Future research could explore additional constraints like delivery costs or investigate other algorithms, such as Tabu Search or Ant Colony Optimization, for another hybrid VRP solutions.

5. Acknowledgement

The author expresses gratitude to Universitas Jenderal Soedirman, particularly through the Institute for Research and Community Service (LPPM) Unsoed, which has provided facilities and research funding support through the Unsoed BLU (Public Service Agency) scheme, enabling this research to be completed.

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