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Optimizing Paint Distribution Routes with CVRP-Based Ant Colony Optimization

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Abstract

PT XYZ is a manufacturing company engaged in paint production with complex product distribution activities. The company currently determines distribution routes based on drivers' experience and habits without systematic route optimization, resulting in less efficient travel distances and distribution costs. This study aims to optimize product distribution routes using the Ant Colony Optimization (ACO) method based on the Capacitated Vehicle Routing Problem (CVRP). The study utilizes data consisting of distributor locations, inter-distributor distances, product demand, vehicle capacity, and the company's actual distribution costs. The ACO method was applied to generate alternative distribution routes by considering vehicle capacity constraints and minimizing total travel distance. The results indicate that the proposed routes generated using ACO based on CVRP are more efficient than the company's existing routes. The optimization reduced the total travel distance by 6.79% and lowered distribution costs by 6.40%. These findings demonstrate that the ACO method is effective in improving distribution efficiency and can serve as a decision-support approach for distribution route planning at PT XYZ.

Keywords: Ant colony optimization; CVRP; distribution costs; distribution routes; efficiency

1. Introduction

Supply chain management plays an important role in supporting the operational continuity of manufacturing companies by regulating the flow of materials, information, and products from production processes to final consumers. One of the most influential activities within the supply chain is product distribution, as it is directly related to delivery timeliness and transportation efficiency [1]. Distribution activities involve the movement and storage of goods from the point of origin to the destination with the objective of minimizing delivery costs and ensuring products arrive in good condition [2]. Inefficient route planning may lead to excessive travel distances, delivery delays, and increased operational costs, particularly when distribution activities are carried out without systematic route optimization. Therefore, determining an optimal distribution route is essential to improve delivery efficiency, reduce transportation costs, and enhance customer service performance [3]. In distribution systems, route optimization can be achieved by minimizing total travel distance, reducing the number of vehicles used, and balancing vehicle routes according to travel time and vehicle capacity constraints [4], [5]. In this context, distribution routes play an important role in supporting the smooth flow of goods because proper route determination can reduce transportation costs, optimize delivery time, and improve customer service quality [6].

PT XYZ is a manufacturing company engaged in paint production and distribution activities across various regions in East Java Province, Indonesia. The company produces various paint products under the Paragon brand, including interior wall paint, exterior wall paint, wood and metal paint, automotive paint, waterproof coatings, thinner, and floor coatings. Among these products, decorative wall paint represents the dominant product category due to its high demand in the construction and renovation sectors. Approximately 55% of total sales are contributed by interior and exterior wall paints, followed by wood and metal paints at around 30%, waterproof products at 10%, and supporting products at 5%. This condition indicates that paint distribution activities constitute one of the main operational processes within the company's supply chain system. Along with the wide marketing coverage area and multiple delivery destinations, the company faces challenges in managing an effective and efficient distribution system. Distribution activities involving numerous customer locations, varying travel distances, and vehicle utilization require proper route planning to support operational efficiency.

In actual operational conditions, the company's distribution routes are still determined based on driver

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experience and habitual route selection without systematic distance optimization calculations. Although vehicle loading capacity utilization has generally been appropriate, the resulting distribution patterns have not comprehensively considered travel distance efficiency. Consequently, several delivery periods still experience shipment delays caused by non-optimal route selection and relatively long travel distances. Based on the company's operational data in 2025, the total travel distance of the existing distribution routes reached 3,011 km with a total distributed demand of 20,285 kg. Several routes also required relatively long delivery times ranging from 9 to 25 hours, indicating inefficiencies in the current routing system. These conditions demonstrate the need for a more structured and calculation-based distribution route planning approach in order to minimize travel distance and reduce the potential for delivery delays.

The distribution activities analyzed in this study focus on the 2025 operational period covering distribution areas throughout East Java Province. Based on demand data in 2025, total paint product demand in the region reached approximately 215,500 cans, causing distribution activities to become increasingly complex, particularly in determining efficient delivery routes. Distribution activities are carried out using heterogeneous fleets consisting of 4-ton Truck Engkel Long vehicles and 2.5-ton Truck Engkel vehicles to deliver products to multiple distributors within a single distribution trip. To address these issues, this study models the company's distribution problem as a Capacitated Vehicle Routing Problem (CVRP), which considers vehicle capacity limitations and multiple delivery destinations within a single route. Metaheuristic algorithms have been widely applied to solve CVRP problems in modern logistics systems due to their ability to generate efficient routing solutions under operational constraints [7]. The Vehicle Routing Problem (VRP) and its variants have become one of the most widely studied combinatorial optimization problems in logistics and transportation systems because of their significant impact on operational efficiency and transportation costs [5], [8]. However, solving the CVRP model effectively requires an appropriate optimization method capable of generating efficient routing decisions. One of the optimization methods frequently applied in distribution routing problems is the Ant Colony Optimization (ACO) algorithm, which is inspired by the behavior of ants in finding the shortest path toward food sources. The ACO method is considered capable of supporting distribution route optimization, especially in problems involving numerous delivery points and operational constraints [9].

Several previous studies have discussed distribution route optimization using Vehicle Routing Problem (VRP) and Ant Colony Optimization approaches [4]. Previous studies also indicate that ACO provides competitive performance in solving routing optimization problems by generating efficient travel routes and reducing operational transportation costs [10], [11]. Husna et al. [9] applied the Ant Colony Optimization algorithm to determine efficient delivery routes in logistics distribution systems. Other studies conducted by Permatasari [2] and [6] focused on reducing transportation costs and improving delivery efficiency through routing optimization models under capacity constraints. However, most previous studies generally applied homogeneous vehicle assumptions and did not fully consider operational conditions based on driver habits and heterogeneous fleet utilization in actual industrial distribution systems.

The novelty of this study lies in modeling the paint product distribution problem at PT XYZ as a Capacitated Vehicle Routing Problem (CVRP) based on actual operational conditions where route determination still depends on driver experience and habitual practices. In addition, this study considers the distribution of high-demand paint products and the utilization of heterogeneous vehicle fleets, enabling the proposed routing solutions to be more applicable and aligned with the company's operational requirements. The implementation of the Ant Colony Optimization (ACO) method is expected to generate more efficient distribution routes by minimizing total travel distance and supporting improvements in distribution performance and delivery timeliness.

2. Method

2.1. Research location and time

This research was conducted at PT XYZ which is located on Jl. Letjen Suprapto No.26, Kepuh, Tambakrejo, Waru District, Sidoarjo Regency, East Java 61256. This research was carried out in 2025 until the required data was sufficient.

2.2. Data collection technique

Data collection in this study was conducted at PT XYZ and was used as input variables in the development of the distribution routing model. The data collection techniques employed in this study consisted of primary data and secondary data. Primary data were obtained directly through field observations and measurements. The data collection process involved interviews and direct observations with related parties who understood the actual operational conditions of the company, particularly those related to distribution activities and route determination. Meanwhile, secondary data were obtained from documents and archives provided by the company, as well as other relevant sources such as books, journals, and previous studies related to distribution systems, Vehicle Routing Problem (VRP), and Ant Colony Optimization (ACO). The secondary data collected included distributor location data, inter-location distance data, vehicle capacity data, product demand data, and actual distribution route data used by the company during the 2025 operational period.

2.3. Data analysis method

After all required data had been successfully collected, data processing was carried out to solve the distribution routing problems identified in this study using the Ant Colony Optimization (ACO) method. The ACO method was implemented to determine the optimal distribution routes by considering travel distances between distribution locations and vehicle capacity constraints. According to [12], the ACO algorithm utilizes pheromone trail updates and probabilistic transition rules to search for optimal solutions iteratively. The calculation process in the ACO method began with determining the distance matrix between locations, followed by calculating the visibility value, initializing pheromone intensity, constructing routes, and updating pheromone trails iteratively until the optimal route was obtained [13]. For the distance between distribution locations, it was calculated using the Euclidean Distance formula as shown in Eq. (1):

$$\eta_{ij} = \frac{1}{d_{ij}} \quad (1)$$

where:
η_{ij} = Visibility value from node i to node j
d_{ij} = Distance value from node i to node j

The probability of selecting the next distribution node in the Ant Colony Optimization (ACO) method is influenced by the pheromone intensity and visibility values. The transition probability calculation is represented by the following Eq. (2):

$$\tau\,(r\,,s)^{\alpha} \times \eta\,(r\,,s)^{\beta} \quad (2)$$

If the equation is applied to node 1 with parameter values of $\alpha = 1$and $\beta = 2$, the Eq. (3) becomes:

$$\tau\,(1\,,s)^{1} \times \eta\,(1\,,s)^{2} \quad (3)$$

where:
$\tau\,(r, s)$ = Pheromone intensity from node r to node s
$\eta\,(r, s)$ = Visibility value from node r to node s
α = Pheromone control parameter
β = Visibility control parameter

The probability of an ant moving to another distributor node was calculated using the following Eq. (4):

$$P_k(r, s) = \left\{\frac{\tau\,(r,s)^{\alpha} \times \eta(r,s)^{\beta}}{\sum u \in J_k \tau\,(r,u)^{\alpha} \times \eta\,(r,u)^{\beta}}\right\} \quad (4)$$

If the equation is applied to ant 1, the probability equation becomes:

$$P_1(1, s) = \left\{\frac{\tau\,(1,s)^{1} \times \eta(1,s)^{2}}{\sum u \in J_1 \tau\,(1,u)^{1} \times \eta\,(1,u)^{2}}\right\} \quad (5)$$

where:
$P_k(r, s)$ = Probability ant k moving from node r to node s
$\tau(r, s)$ = Pheromone intensity from node r to node s
$\eta(r, s)$ = Visibility value from node r to node s
α = Pheromone control parameter
β = Visibility control parameter

Ants provide an additional pheromone value to the pheromone matrix along the routes they traverse. The calculation of pheromone intensity changes between nodes is determined using the following Eq. (6):

$$\Delta\tau_{ij} = \frac{Q}{L_k} \quad (6)$$

where:
$\Delta\tau_{ij}$ = Change in pheromone intensity between node i and node j
Q = Pheromone constant
L_k = Total route distance traveled by ant k

The evaporation rate or pheromone factor ρ was set at 0.5. After obtaining the total route distance, the value was used to update the pheromone intensity τusing the following Eq. (7):

$$\tau_{ij}^{t+1} = (1 - \rho)\,\tau_{ij} + \Delta\tau_{ij} \quad (7)$$

Iterations in the Ant Colony Optimization (ACO) method were continuously performed until convergence criteria or the maximum number of iterations was achieved. The optimal distribution route was selected based on the minimum total travel distance while considering vehicle capacity constraints. The resulting routes were subsequently compared with the company's existing distribution routes to evaluate the effectiveness of the proposed model in improving distribution efficiency.

The application of the ACO algorithm in solving CVRP problems has been widely implemented in logistics and transportation optimization studies because of its ability to explore feasible routing solutions effectively under operational constraints [14].

3. Results and Discussion

3.1. Initialization of visibility and pheromone values

The initialization stage in the Ant Colony Optimization (ACO) method involved calculating the visibility values between distribution nodes and determining the initial pheromone intensity. The visibility value (η_{ij})represents the inverse of the distance between node i and node j. Higher visibility values indicate shorter travel distances between distribution locations. The following calculations present examples of visibility values from node 1 to other distribution nodes:

$\eta_{11} = \frac{1}{d_{ij}} = \frac{1}{0} = 0$
$\eta_{12} = \frac{1}{d_{ij}} = \frac{1}{139} = 0.00719$
$\eta_{13} = \frac{1}{d_{ij}} = \frac{1}{146} = 0.00685$
$\eta_{14} = \frac{1}{d_{ij}} = \frac{1}{162} = 0.00617$
$\eta_{15} = \frac{1}{d_{ij}} = \frac{1}{307} = 0.00326$
$\eta_{16} = \frac{1}{d_{ij}} = \frac{1}{199} = 0.00503$
$\eta_{17} = \frac{1}{d_{ij}} = \frac{1}{114} = 0.00877$

The same calculation procedure was applied to all distribution nodes.

After the visibility values between distributors were obtained using the 1/dequation, the next step was to determine the pheromone values. In the initial stage, the pheromone intensity value on each route was set to 1 because no ants had yet traversed the routes between distributors. Therefore, all routes were initially assumed to have the same pheromone intensity value of 1.

3.2. Tabu list initialization

The next step was constructing the tabu list, which is a table used to determine the sequence of distribution routes visited by each ant and to serve as a reference in route selection. In the initial stage of tabu list construction, the starting and returning node was determined [15]. In this study, node 1 represented the factory location, which functioned as both the starting point and the final destination of the distribution route. Therefore, node 1 was excluded from the route selection process by assigning its visibility value to 0. preventing ants from revisiting the starting node during the route construction process.

3.2.1. Iteration

After obtaining the visibility values, the next step was calculating the probability of visiting the next node or distributor. When applied to node 1 with parameter values of α=1and β=2, the calculation results are as follows:

From node 1 to node 2 : $1^1\ x\ 0.00719^2$ = 0.0000516
From node 1 to node 3 : $1^1\ x\ 0.00685^2$ = 0.0000469
From node 1 to node 4 : $1^1\ x\ 0.00617^2$ = 0.0000380
From node 1 to node 5 : $1^1\ x\ 0.00326^2$ = 0.0000106
From node 1 to node 6 : $1^1\ x\ 0.00503^2$ = 0.0000253
From node 1 to node 7 : $1^1\ x\ 0.00877^2$ = 0.0000769

The same calculation procedure was applied to all distribution nodes to obtain the probability values used in the route selection process. The total value of $\tau(1,s)^1 \cdot \eta(1,s)^2$obtained was 0.0008903. Based on this value, the probability of ants moving to other distributor nodes was calculated. When applied to ant 1, the calculation results are as follows:

From node 1 to node 2 : 0.0000516 / 0.00089 = 0.0578
From node 1 to node 3 : 0.0000469 / 0.00089 = 0.0527
From node 1 to node 4 : 0.0000380 / 0.00089 = 0.0427
From node 1 to node 5 : 0.0000106 / 0.00089 = 0.0119
From node 1 to node 6 : 0.0000253 / 0.00089 = 0.0284
From node 1 to node 7 : 0.0000769 / 0.00089 = 0.0864

Furthermore, the cumulative probability values obtained from the previous calculations are presented as follows:

Node 2 = 0.058
Node 3 = 0.111
Node 4 = 0.153
Node 5 = 0.165
Node 6 = 0.194
Node 7 = 0.280
Node 8 = 0.333
Node 9 = 0.399
Node 10 = 0.593
Node 11 = 0.607
Node 12 = 0.639
Node 13 = 0.666
Node 14 = 0.690
Node 15 = 0.814
Node 16 = 0.962
Node 17 = 1.000

These cumulative probability values were subsequently used as the basis for determining the next distribution node selected by the ants during the route construction process. The next step involved generating a random number (r) to determine the next distributor node to be visited by comparing it with the cumulative probability values. In this calculation, the generated random number was (r = 0.687). The random number was then matched with the cumulative probability values obtained previously. Since the random number (0.687) was located below the cumulative probability value of (0.690), node 14 was selected as the next distributor node to be visited from node 1.

After node 14 was selected as the next destination, the node could no longer be revisited within the same route according to the tabu list concept in the Ant Colony Optimization (ACO) method. The route construction process continued iteratively until all nodes had been visited. Furthermore, to prevent repeated visits, the visibility values in column 14 were changed to 0 for all nodes, ensuring that node 14 no longer had a probability of being selected in the subsequent iteration.

At this stage, the temporary route formed by the ant was 1-14-8-13. The calculation process was then continued iteratively until all nodes had been visited. In this study, the number of ants represented the number of distribution vehicles available in the company. This stage was repeated for all routes traversed by the ants in order to determine the total travel distance generated by each route. Based on the calculations performed in the first iteration, the resulting route was 1-14-8-13-12-5-6-10-3-7-15-4-2-16-9-17-11-1 with a total travel distance of 2,093.6 km.

Ants deposit additional pheromone values on the pheromone matrix along the routes they traverse. The change in pheromone intensity between nodes was calculated:

$$\Delta\tau_{ij} = \frac{Q}{LK} = \frac{1}{2{,}093.6} = 0.00048$$

The pheromone evaporation rate ρwas set to 0.5. After obtaining the total route distance, The updated pheromone intensity value was obtained as follows:

$$\tau_{ij}^{t+1} = (1 - 0.5)\ 1 + 0.00048 = 0.50048$$

For routes that were not traversed by ants, only pheromone evaporation occurred without additional pheromone reinforcement. Using the updated pheromone value $\tau_{ij}^{(t)}$, the calculation steps were repeated iteratively until the convergence condition was achieved, namely when all ants selected the same best route or when the maximum number of iterations had been reached. In each subsequent iteration, the calculations were repeated starting from the initial stage until the maximum iteration limit was achieved. At the end of the iteration process, the routes with the highest pheromone intensity values indicated the best distribution paths, allowing the shortest distribution route to be identified.

3.3. Distribution route allocation using the Capacitated Vehicle Routing Problem (CVRP)

At this stage, the distribution routes were allocated using the Capacitated Vehicle Routing Problem (CVRP) method with the assistance of MATLAB R2007b . Data processing was carried out using the Ant Colony Optimization (ACO) algorithm based on inter-distributor distance data, distributor demand, and vehicle capacity constraints in order to obtain distribution routes with minimum total travel distance while satisfying vehicle capacity limitations. Similar approaches have been widely applied in transportation and logistics optimization studies to improve route efficiency and reduce operational costs [10], [14].

In this study, the program was executed through 50 running iterations using the same parameter values. The repeated running process was conducted because the ACO algorithm is probabilistic in nature, utilizing random probability values during the route search process, which may produce different routing solutions in each run. Based on the evaluation of the 50 running results, the best solution obtained produced a total distribution distance of 2,806.5 km with a program computation time of 3.1845 seconds. This result was selected as the final solution because it provided shorter distribution distances and more effective vehicle route allocation compared to the company's previous distribution conditions.

Figure 1. Distribution routes generated using the CVRP method

The blue lines represent two distribution routes for the 4-ton Truck Engkel Long vehicle (1), where each route serves two and three different destinations, respectively. In the first route, the vehicle departs from the depot, proceeds to CV Warna Mulia, continues to Distributor Karya Mandiri, and finally returns to the depot. In the second route, the vehicle starts from the depot, then visits Distributor Lancar Jaya, continues to CV Mega Jaya, and ends at Distributor Bumi Saka before returning to the depot.

The green lines represent two distribution routes for the 4-ton Truck Engkel Long vehicle (2), with each route serving three and two different destinations, respectively. In the first route, the vehicle departs from the depot, delivers products to Distributor Sentral Bangunan, continues to CV Putra Mandiri, and ends at Distributor Cahaya Abadi before returning to the depot. In the second route, the vehicle starts from the depot, then visits CV Warna Abadi and Distributor Makmur Jaya before returning to the depot after completing all deliveries.

The red line represents one route serving three destinations. The route starts from the depot, proceeds to CV Anugerah Warna, continues to Distributor Berkah Jaya, and ends at Distributor Sinar Abadi before returning to the depot. The black line represents one route serving two destinations, beginning from the depot and continuing to CV Mitra Cat Sejahtera and Distributor Jaya Abadi. Meanwhile, the magenta line represents one route serving a single destination, starting from the depot and proceeding to Distributor Makmur Sentosa before finally returning to the depot after all deliveries were completed. All routes were designed by considering distributor locations, travel distances, and vehicle capacity constraints in order to ensure optimal distribution performance.

3.4. Total distance calculation of CVRP route results

Based on the distribution route allocation using the Capacitated Vehicle Routing Problem (CVRP) method by considering distributor locations, travel distances, and vehicle capacity constraints, seven different distribution routes were obtained as follows:

3.4.1. First route

Fig. 2 illustrates the first distribution route generated using the Ant Colony Optimization (ACO) method.

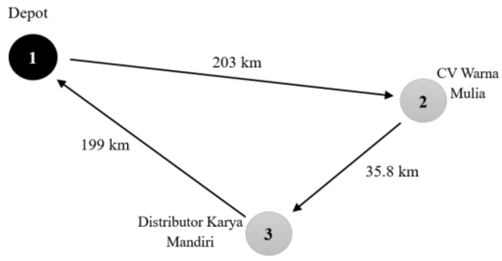

Figure 2. First route of the ant colony optimization method

The distribution process starts from the depot, represented by node 1, and continues to CV Warna Mulia and Distributor Karya Mandiri, represented by nodes 2 and 3. The travel distance from the depot to CV Warna Mulia is 203 km, followed by 35.8 km to Distributor Karya Mandiri, and 199 km for the return trip to the depot, resulting in a total travel distance of 437.8 km. Based on Fig. 2, the resulting route forms a relatively efficient distribution path because the travel sequence follows geographically connected distributor locations. This route configuration helps reduce unnecessary travel distance and supports more efficient vehicle utilization during the distribution process. The total demand for each distributor served on the first distribution route is presented in Table 1.

Table 1. Total demand of each distributor on the first route

No.	Distributor Name	Demand (kg)
1	CV Warna Mulia	1,395
2	Distributor Karya Mandiri	1,545
Total Number of Demand		2,940

Based on Table 1, the total demand allocated to the first route is 2,940 kg, which is still within the vehicle capacity limit. This indicates that the ACO method successfully generated a feasible distribution route while maintaining efficient vehicle capacity utilization.

3.4.2. Second route

Fig. 3 illustrates the second distribution route generated using the Ant Colony Optimization (ACO) method.

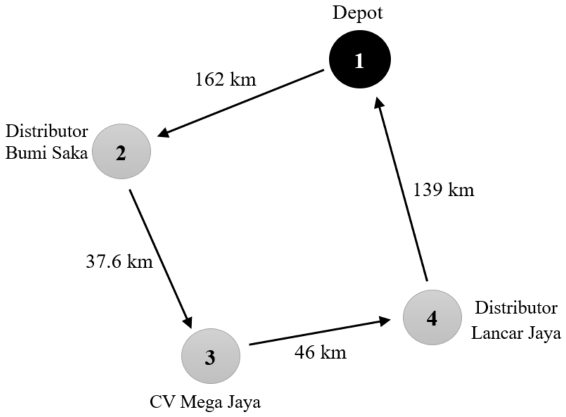

Figure 3. Second route of the ant colony optimization method

The distribution process starts from the depot, represented by node 1, and continues to Distributor Lancar Jaya, CV Mega Jaya, and Distributor Bumi Saka before returning to the depot. The total travel distance for the second route is 384.6 km. Based on Fig. 3, the second route is capable of serving three distributor locations within a relatively shorter travel distance compared to several other routes. This indicates that the route allocation generated by the ACO method effectively combines multiple destinations while maintaining travel efficiency and reducing unnecessary travel movements. The total demand for each distributor served on the second distribution route is presented in Table 2.

Table 2. Total demand of each distributor on the second route

No.	Distributor Name	Demand (kg)
1	Distributor Lancar Jaya	985
2	CV Mega Jaya	835
3	Distributor Bumi Saka	1,020
Total Number of Demand		2,840

Based on Table 2, the total demand allocated to the second route is 2,840 kg, which remains within the available vehicle capacity limit. The results indicate that the proposed routing model successfully distributes delivery loads efficiently across multiple destinations without exceeding vehicle constraints.

3.4.3. Third route

Fig. 4 illustrates the third distribution route generated using the Ant Colony Optimization (ACO) method.

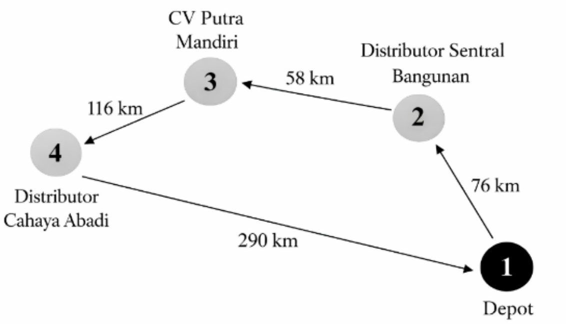

Figure 4. Third route of the ant colony optimization method

The distribution process starts from the depot, represented by node 1, and continues to Distributor Sentral Bangunan, CV Putra Mandiri, and Distributor Cahaya Abadi before returning to the depot. The total travel distance for the third route is 540 km. Based on Fig. 4, the third route covers a wider distribution area compared to the previous routes, resulting in a longer total travel distance. However, the route arrangement generated by the ACO method remains efficient because it is capable of serving multiple distributors within a single trip while considering vehicle capacity constraints and minimizing unnecessary route overlaps. The total demand for each distributor served on the third distribution route is presented in Table 3.

Table 3. Total demand of each distributor on the third route

No.	Distributor Name	Demand (kg)
1	Distributor Sentral Bangunan	1,765
2	CV Putra Mandiri	920
3	Distributor Cahaya Abadi	905
Total Number of Demand		3,590

Based on Table 3, the total demand allocated to the third route is 3,590 kg, which indicates a high level of vehicle capacity utilization. This result demonstrates that the ACO method effectively allocates distributor demand into a single distribution route while maintaining feasible vehicle loading conditions.

3.4.4. Fourth route

Fig. 5 illustrates the fourth distribution route generated using the Ant Colony Optimization (ACO) method.

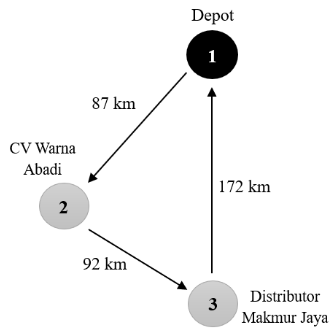

Figure 5. Fourth route of the ant colony optimization method

The distribution process starts from the depot, represented by node 1, and continues to CV Warna Abadi and Distributor Makmur Jaya before returning to the depot. The total travel distance for the fourth route is 351 km. Based on Fig. 5, the fourth route produces a relatively shorter travel distance while serving two distributors with high product demand. This indicates that the route allocation generated by the ACO method is capable of improving distribution efficiency by minimizing travel distance while maintaining effective delivery coverage. The total demand for each distributor served on the fourth distribution route is presented in Table 4.

Table 4. Total demand of each distributor on the fourth route

No.	Distributor Name	Demand (kg)
1	CV Warna Aabadi	1,275
2	Distributor Makmur Jaya	2,250
Total Number of Demand		3,525

Based on Table 4, the total demand allocated to the fourth route is 3,525 kg, which indicates that the vehicle capacity is utilized efficiently without exceeding operational limitations. This result demonstrates that the ACO method successfully balances travel efficiency and vehicle load allocation within the distribution process.

3.4.5. Fifth route

Fig. 6 illustrates the fifth distribution route generated using the Ant Colony Optimization (ACO) method.

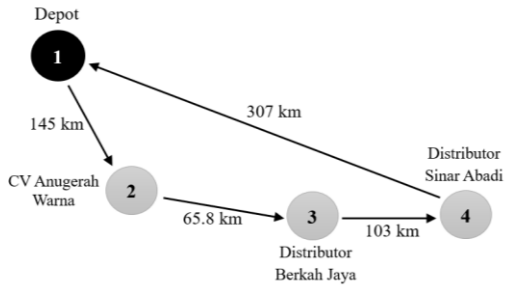

Figure 6. Fifth route of the ant colony optimization method

The distribution process starts from the depot, represented by node 1, and continues to CV Anugerah Warna, Distributor Berkah Jaya, and Distributor Sinar Abadi before returning to the depot. The total travel distance for the fifth route is 620.8 km. Based on Fig. 6, the fifth route has the longest travel distance among the generated distribution routes because it covers several distributor locations with relatively wider geographical coverage. However, the route arrangement generated by the ACO method remains efficient since multiple distributor demands can still be accommodated within a single delivery trip while considering vehicle capacity constraints. The total demand for each distributor served on the fifth distribution route is presented in Table 5.

Table 5. Total demand of each distributor on the fifth route

No.	Distributor Name	Demand (kg)
1	CV Anugerah Warna	985
2	Distributor Berkah Jaya	1,785
3	Distributor Sinar Abadi	1,050
Total Number of Demand		3,820

Based on Table 5, the total demand allocated to the fifth route is 3,820 kg, which indicates a high level of vehicle capacity utilization. This result demonstrates that the ACO method effectively combines several distributor demands into a single route while maintaining feasible operational capacity and supporting distribution efficiency.

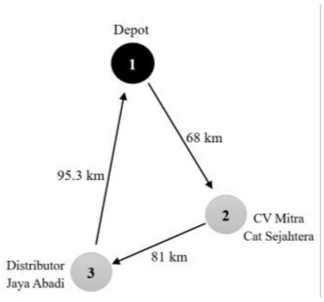

Figure 7. Sixth route of the ant colony optimization method

3.4.6. Sixth route

Fig. 7 illustrates the sixth distribution route generated using the Ant Colony Optimization (ACO) method.

The distribution process starts from the depot, represented by node 1, and continues to CV Mitra Cat Sejahtera and Distributor Jaya Abadi before returning to the depot. The total travel distance for the sixth route is 244.3 km. Based on Fig. 7, the sixth route produces one of the shortest travel distances among all distribution routes. This indicates that the distributor locations served in this route are relatively close to each other, allowing the ACO method to generate a more compact and efficient travel path that minimizes transportation distance and delivery time. The total demand for each distributor served on the sixth distribution route is presented in Table 6.

Table 6. Total demand of each distributor on the sixth route

No.	Distributor Name	Demand (kg)
1	CV Mitra Cat Sejahtera	870
2	Distributor Jaya Abadi	1,045
Total Number of Demand		1,915

Based on Table 6, the total demand allocated to the sixth route is 1,915 kg, which is considerably lower than the maximum vehicle capacity. This condition indicates that the route allocation remains operationally feasible while still supporting efficient product distribution to the assigned distributors.

3.4.7. Seventh route

Fig. 8 illustrates the seventh distribution route generated using the Ant Colony Optimization (ACO) method.

The distribution process starts from the depot, represented by node 1, and continues to Distributor Makmur Sentosa before returning to the depot.

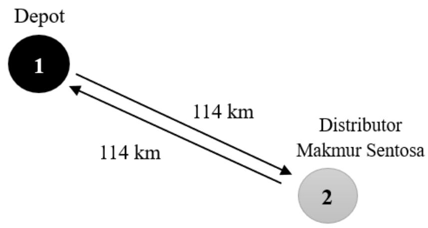

Figure 8. Seventh route of the ant colony optimization method

The total travel distance for the seventh route is 228 km. Based on Fig. 8, the seventh route has the shortest distribution path among all generated routes because it only serves a single distributor destination. This route configuration enables the delivery process to be completed more quickly and efficiently, thereby reducing travel distance and operational transportation time. The total demand for the distributor served on the seventh distribution route is presented in Table 7.

Table 7. Total demand of each distributor on the seventh route

No.	Distributor Name	Demand (kg)
1	Distributor Makmur Sentosa	1,655
Total Number of Demand		1,655

Based on Table 7, the total demand allocated to the seventh route is 1,655 kg, which is still within the available vehicle capacity limit. This result indicates that the generated route is operationally feasible and supports efficient product distribution for single-destination delivery routes.

3.5. Comparison of distribution distances between the company's existing routing and the ant colony optimization method

Comparing the company's distribution distance with the Ant Colony Optimization (ACO) method is conducted to evaluate the efficiency of the resulting routes. The evaluation is based on the total travel distance of each distribution route. The results show differences between the company's original routes and the optimized routes generated by the ACO method, where some routes experience an increase in distance while others show a significant reduction. Overall, the total distribution distance decreases from 3,011 km to 2,806.5 km, indicating that the Ant Colony Optimization (ACO) method improves distribution routing efficiency.

3.5.1. Distance difference

= Company Routes – ACO Method Routes
= 3,011 km – 2,806.5 km
= 204.5 km

3.5.2. Percentage of savings

$$= \frac{Company\ Routes - ACO\ Method\ Routes}{Company\ Routes}\ x\ 100\%$$
$$= \frac{3{,}011\ km - 2{,}806.5\ km}{3{,}011\ km}\ x\ 100\% = 6.79\ \%$$

3.6. Calculation of the company's existing distribution costs

The calculation of the existing distribution cost is conducted to determine the total cost incurred by the company based on the current distribution routes. The cost components considered include fuel costs, labor costs (drivers), toll fees, and loading and unloading costs. The results of the existing distribution cost calculation are presented as follows.

3.6.1. Calculation

$$Distance\ x\ (Fuel\ Cost + Driver + Toll\ Road) + Loading\ and\ Unloading\ x\ Number\ of\ Destination$$

3.6.2. Distribution cost – route 1

= 390 km × (Rp 1,500 + Rp 1,750 + Rp 1,100) + Rp 100,000 × 3
= 390 km × (Rp 4,350) + Rp 300,000
= Rp 1,696,500 + Rp 300,000 = Rp 1,996,500

3.7. Comparison of company distribution costs with distance distribution costs using the ant colony optimization method

Comparison is conducted between the company's existing distribution cost and the optimized cost using the Ant Colony Optimization (ACO) method to evaluate efficiency in reducing travel distance and cost. The analysis is carried out for each route based on vehicle type.

3.7.1. Cost difference

= Existing Company Cost – ACO Method Cost
= Rp14,750,000– Rp13,808,275
= Rp 941,725

3.7.2. Percentage of savings

$$= \frac{Company\ Costs - ACO\ Method\ Cost}{Company\ Costs}\ x\ 100\%$$
$$= \frac{\text{Rp14,750,000} - \text{Rp13,808,275}}{\text{Rp14,750,000}}\ x\ 100\%$$
= 6.40 %

Results show variations in distribution costs between the existing and optimized conditions, where some routes decrease while others increase. However, overall distribution cost decreases from Rp 14,750,000 to Rp 13,808,375 after applying ACO, indicating improved cost efficiency. Based on the results obtained from the data processing above, the findings are as follows: Distribution route sequence before and after using the Ant Colony Optimization method. The distribution sequence of paint products from the depot to distributors and back to the depot is presented by comparing the company's initial route with the route generated using the Ant Colony Optimization method.

Table 8. Route sequence before and after using the ant colony optimization method

Initial Route and Mileage from the Company			Initial Route and Distance Traveled using Ant Colony Optimization method		
Route	Node	Demand (kg)	Route	Node	Demand (kg)
1	1 – 2 – 3 – 4 – 1	2,840	1	1 – 13 – 6 – 1	2,940
2	1 – 5 – 6 – 1	2,595	2	1 – 4 – 3 – 2 – 1	2,840
3	1 – 7 – 8 – 1	2,640	3	1 – 10 – 9 – 11 – 1	3,590
4	1 – 9 – 10 – 11 – 1	3,590	4	1 – 16 – 17 – 1	3,525
5	1 – 12 – 13 – 1	3,180	5	1 – 8 – 12 – 5 – 1	3,820
6	1 – 14 – 15 – 1	1,915	6	1 – 14 – 15 – 1	1,915
7	1 – 16 – 17 – 1	3,525	7	1 – 7 – 1	1,655
Load Amount (kg)		20,285	Load Amount (kg)		20,285

Summary results and distribution distance savings percentage.

Table 9. Recapitulation and percentage of distribution distance savings

Total Distance (km)		Distance Savings (km)	Distance savings (%)
Company Initial Route	Ant Colony Optimization Method Route		
3,011	2,806.5	204.5	6.79

Summary results and percentage of distribution cost savings.

Table 10. Summary and percentage of distribution cost savings

Total Distribution Costs		Cost Saving	Cost Saving (%)
Initial Company Costs	Ant Colony Optimization Method Costs		
Rp 14,750,000	Rp 13,808,275	Rp 941,725	6.40

Based on the results of the data processing, the Ant Colony Optimization method shows a more efficient outcome compared to the company's current method. Therefore, this method is proposed as the recommended approach in this study. The results indicate that the total distribution cost under the existing condition is Rp 14,750,000. while after applying the Ant Colony Optimization method it decreases to Rp 13,808,275. Thus, a cost saving of Rp 941,725 or approximately 6.40% is achieved.

4. Conclusion

The Ant Colony Optimization (ACO) method applied in this study is proven to generate a more optimal proposed distribution route by considering the total demand at each destination. The results show that this method effectively improves operational efficiency and reduces overall distribution costs. Based on the data processing, the distribution of paint products at PT XYZ improved through the use of Truck Engkel Long (4 tons) and Truck Engkel (2.5 tons). The total travel distance decreased from 3,011 km to 2,806.5 km, a reduction of 204.5 km or 6.79%. This reduction directly impacts distribution cost efficiency, decreasing from Rp 14,750,000 to Rp 13,808,275. with a saving of 6.40%, indicating that changes in travel distance proportionally affect distribution costs. The reduction in travel distance leads to lower operational costs such as fuel, labor, and transportation expenses. In addition, the optimized distribution routes improve delivery time efficiency and support better vehicle load allocation, ensuring more optimal utilization of vehicle capacity.

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