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Determining the Optimal Milk Distribution Route Using the Ant Colony Optimization Method on Milk Industry

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ABSTRACT

A good distribution system will ensure the availability of products or goods needed by the community. The objective of this research is to identify the most efficient route for distributing UHT milk on Milk Industry, with the goal of minimizing the overall distance traveled during distribution. The contribution of this study is to determine the optimal distribution route for UHT milk on Milk Industry. Data analysis or data calculation is done using Ant Colony optimization. The independent variables used are the initial distribution route data of the company, agent location data, product demand data, and distance data between agents. The results of this study found that the company's route resulted in a total route distance of 251.95 km while for the optimal total distance Ant Colony Optimization method is the total route distance of 230.2 km. Thus, the optimal route of the distribution of Ant Colony Optimization method is better than the initial route of the company with a total route distance savings of 21.75 km with a percentage of savings of 8.63%.

1. Introduction

The dairy industry is an important sector in the global economy, offering a wide range of health and nutritional benefits to humans. Efficient milk procurement and distribution is a crucial factor in maintaining the quality and availability of dairy products for consumers (Zirmire & Kulkarni, 2019; Marialuisa, 2023). In order to achieve such efficiency, determining the optimal distribution path plays a vital role in optimizing the cost and delivery time (Moghdani et al., 2019; Mohd Salleh et al., 2023). However, determining the optimal distribution path can be a complex challenge, especially when large and complex distribution networks are involved. To address this complex problem, the Ant Colony Optimization (ACO) method has become an attractive research focus in distribution line optimization (Ghosh, 2016; Zhao et al., 2021; Li et al., 2022). This method is inspired by the behavior of ant colonies in finding the shortest path from the nest to the food source and has been successfully applied in various optimization applications. In the context of the dairy industry, the ACO approach has great potential to help find the optimal distribution path by utilizing ant intelligence-based mechanisms. This method is inspired by the behavior of ant colonies that search for the shortest path from the nest to the food source by collaborating, and has been successfully applied in various optimization problems, including distribution and transportation routes (Kamilaris et al., 2020; Tong, 2022).

By using the Ant Colony Optimization method, it is expected that the distribution routing process at milk industry can be significantly improved, thus enabling accurate and timely delivery of products to customers according to their orders. In the context of milk industry, parameters such as distance between distribution points, travel time, vehicle capacity, and customer demand will be incorporated into the ACO model to find the optimal UHT milk distribution route. In addition, the ACO algorithm will be run in multiple iterations to strengthen the pheromone trails and produce better solutions as time goes by (Wu, 2021; Wang & Han, 2021). However, the use of the ACO method specifically in the UHT milk industry still requires further exploration and application in the appropriate context. The contribution of this study is to determine the optimal distribution route for UHT milk on Milk Industry to increase in efficiency and a significant reduction in logistics costs.

2. Method

This research was conducted on milk industry located in Kepuhkiriman Village, Waru District, Sidoarjo regency, East Java. The variables used in this study are dependent variables and independent variables. A dependent variable is a variable that can be influenced by independent variables. The dependent variable in this study is the optimal UHT milk distribution route at milk industry. The independent variables utilized include the company's initial distribution route data, agent location data, product demand data, and distance data between agents.

This research was conducted in the Dairy Industry located in Kepuhkiriman Village, Waru District, Sidoarjo Regency, East Java. The variables used in this study are dependent variables and independent variables. The dependent variable is a variable that can be influenced by the independent variable. In the context of this research, the dependent variable is the optimal UHT milk distribution route at Milk Industri. Meanwhile, the independent variables include data on warehouse locations, factories, distribution points, distance between locations, travel time, vehicle capacity, and customer demand. This data collection will be the basis for the formation of the graph model and programming the ACO algorithm to find the optimal UHT milk distribution route.

Data collection related to the distribution infrastructure of Milk Industry, including the locations of warehouses, factories, and distribution points. Data regarding the distance between these locations, travel time, vehicle capacity, and customer demand will be collected to build the distribution model (Luan et al., 2019). Next, the analysis step begins by modeling the distribution problem as a graph, with vertices representing each location and edges representing the distances between these locations. After the graph model is formed, an ACO algorithm will be built to determine the optimal distribution path. Parameters such as the number of artificial ants, pheromone intensity, and pheromone evaporation factor will be determined and adjusted to achieve better results. During the optimization process, data will continue to be collected and analyzed to evaluate the performance of the ACO algorithm in finding the optimal solution (Gao, 2023).The results of each iteration will be measured based on criteria such as total distribution distance, travel time, and logistics cost Furthermore, the best result of the optimization process will be selected as the optimal UHT milk distribution route solution for Milk Industry.

3. Results and Discussion

3.1. Initial Route Distribution Company

After collecting data on all variables used in this study, then the next is the calculation of the initial distribution route of milk industry company. From the calculation that has been done, it is found that for the company's distribution routes are as follows Route 1 total mileage 108.5 km, route 2 total mileage 72.8 km and Route 3 total mileage 70.65 km. From the data of this route is the route used by the company in the distribution of goods.

3.2. Initialization Node Visibility and Pheromone

Visibility calculation is done using the formula or equation as follows in Equation (1).

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

With the recapitulation of visibility results for Inter-agent is in the Table 1.

Table 1. Visibility Between Agents

Visibilitas	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0.0263	0.0232	0.0277	0.0285	0.0277	0.0277	0.0277	0.0294	0.0303	0.0294	0.0285
2	0.0263	0	0.1923	0.1204	0.1470	0.1851	0.129	0.1639	0.1612	0.1449	0.1639	0.2272
3	0.0232	0.1923	0	0.1960	0.1785	0.1960	0.1694	0.1785	0.1587	0.1408	0.1515	0.1639
4	0.0277	0.1204	0.1960	0	0.7692	0.4545	0.3571	0.7692	0.5263	0.3703	0.3030	0.2941
5	0.0285	0.1470	0.1785	0.7692	0	0.7692	0.5882	1.5384	0.7692	0.7142	0.4761	0.3703
6	0.0277	0.1851	0.1960	0.4545	0.7692	0	0.3846	1	1	0.4545	0.4	0.4
7	0.0277	0.1298	0.1694	0.3571	0.5882	0.3846	0	0.5882	0.4347	0.4761	0.2702	0.2631
8	0.0277	0.1639	0.1785	0.7692	1.5384	1	0.5882	0	1.5384	0.5555	0.4	0.4761
9	0.0294	0.1612	0.1587	0.5263	0.7692	1	0.4347	1.5384	0	0.8333	0.8333	0.3571
10	0.0303	0.1449	0.1408	0.3703	0.7142	0.4545	0.4761	0.5555	0.8333	0	0.6666	0.3448
11	0.0294	0.1639	0.1515	0.3030	0.4761	0.4	0.2702	0.4	0.8333	0.6666	0	0.4545
12	0.0285	0.2272	0.1639	0.2941	0.3703	0.4	0.2631	0.4761	0.3571	0.3448	0.4545	0

Then after knowing the visibility for all agents with r using the Formula 1 / d the next step is to determine the amount of pheromone. For the first time, the number of pheromones on each route is a number of 1 because the ants have not passed between agents so that the number of pheromones is considered equal to the number 1 (Table 2).

Table 2. Initial Pheromone Value of Each Agent

Pheromone	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1	1	1	1	1
12	1	1	1	1	1	1	1	1	1	1	1	1

3.3. Tabu List

The next step is to fill out the tabu list. Tabu list this is a table that is used to determine the route to be visited and can be a reference for a route to be taken. The first time in filling out the tabu list is to determine which node will be used as the starting point of departure and as a point to return. In this case, the first node or node 1 is the node or location of the company which is the starting point and the return point. Therefore, so that node 1 is not included in the calculation because it is the starting point then node 1 level or visibility value is made into 0 (Table 3).

The temporary route formed from ants is 1-3-4. From the above calculation then proceed again until all nodes have been visited. The number represents the number of fleets available by the company. This stage will be looping of all the routes passed by the ants will be known the total distance that has been traveled by the ants. From the explanation of the calculations performed in the 1st iteration obtained the route is 1-3-4-12-8-9-11-5-7-6-10-2-1 with a total of 108.95 Km. The ants will add pheromones to the pheromone matrix they pass through. In other segments that are not traversed by ants, there will only be evaporation without the addition of pheromones. With the value of t_ij^((t)) we repeat the above steps until the process converges i.e. when all the ants choose the same best trajectory. Or we can stop once its maximum iteration is reached. We will give this change to the segments that ants pass in the pheromone Matrix (Table 4).

Table. 3 New Visibility

Visibility	1	2	3	4	5	6	7	8	9	10	11	12
1	0	0.0263	0.0232	0.0277	0.0285	0.0277	0.0277	0.0277	0.0294	0.0303	0.0294	0.0285
2	0	0	0.1923	0.1204	0.1470	0.1851	0.1298	0.1639	0.1612	0.1449	0.1639	0.2272
3	0	0.1923	0	0.1960	0.1785	0.1960	0.1694	0.1785	0.1587	0.1408	0.1515	0.1639
4	0	0.1204	0.1960	0	0.7692	0.4545	0.3571	0.7692	0.5263	0.3703	0.3030	0.2941
5	0	0.1470	0.1785	0.7692	0	0.7692	0.5882	1.5384	0.7692	0.7142	0.4761	0.3703
6	0	0.1851	0.1960	0.4545	0.7692	0	0.3846	1	1	0.4545	0.4	0.4
7	0	0.1298	0.1694	0.3571	0.5882	0.3846	0	0.5882	0.4347	0.4761	0.2702	0.2631
8	0	0.1639	0.1785	0.7692	1.5384	1	0.5882	0	1.5384	0.5555	0.4	0.4761
9	0	0.1612	0.1587	0.5263	0.7692	1	0.4347	1.5384	0	0.8333	0.8333	0.3571
10	0	0.1449	0.1408	0.3703	0.7142	0.4545	0.4761	0.5555	0.8333	0	0.6666	0.3448
11	0	0.1639	0.1515	0.3030	0.4761	0.4	0.2702	0.4	0.8333	0.6666	0	0.4545
12	0	0.2272	0.1639	0.2941	0.3703	0.4	0.2631	0.4761	0.3571	0.3448	0.4545	0

Table 4. Pheromone Matrix For Ants

Pheromone	1	2	3	4	5	6	7	8	9	10	11	12
1	0.5000	0.5000	0.5091	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
2	0.5091	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
3	0.5000	0.5000	0.5000	0.5091	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
4	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5091
5	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5091	0.5000	0.5000	0.5000	0.5000	0.5000
6	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5091	0.5000	0.5000
7	0.5000	0.5000	0.5000	0.5000	0.5000	0.5091	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
8	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5091	0.5000	0.5000	0.5000
9	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5091	0.5000
10	0.5000	0.5091	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
11	0.5000	0.5000	0.5000	0.5000	0.5091	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000
12	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5000	0.5091	0.5000	0.5000	0.5000	0.5000

Then in the next iteration, count again starting from the initial stage until the maximum number of iterations is reached. At the end of the iteration will be recorded in the segments that get high pheromone levels. These segments can be determined the best route with the shortest distance.

3.4. The Result of Ant Colony Optimization

The results of running the program from the MATLAB application using the Ant Colony Optimization algorithm method can be seen in the image below. The results of this MATLAB application show several optimal methods of the Ant Colony Optimization algorithm in solving solutions to the Traveling Salesman Problem at milk industry. It is known that the calculation using the Ant Colony Optimization method shows that the optimal route is obtained in the 22nd iteration, but to ensure that the route selection is correct and optimal, the iteration set is continued until the 100th iteration. And get from the 22nd internal to the 100th iteration route calculation with using the Ant Colony Optimization algorithm shows the same results continuously. The Table 5 is explaining the output of the optimization Ant Colony Program.

From the table above, the results obtained are the order of the tour salesman route, the distance traveled and the proposed total mileage according to the Ant Colony Optimization running program using MATLAB of 93.5 Km. However, from the calculation of the route above, it is known that the product demand capacity exceeds the capacity of the transportation equipment available by the company. Therefore, it is necessary to divide the delivery capacity and the total distance of the visiting route in the Ant Colony Optimization calculation using the MATLAB application (Nurbaya, 2022)

From all the results of existing calculations it is found that the sequence of distribution routes before and after the calculation is carried out with the Ant Colony Optimization method. The Table 6 is the result of the calculation.

Table 5. Optimal Ant Colony Program Output Route

No.	*Tour Salesman Route*	Mileage (Km)	Total Mileage (Km)
1	Milk industry –Sarikat Store - Gresik Susu Store - Nirwana Store - Jaya Abadi Store – Sinar Kurnia Store - Sumatra Mitra Retail Store - K3PG Store – Matul Store – Pak Amin Store–Nanda Swalayan Store –Idaman Store – Milk Industry	34+1.5+2.1+1,7+ 0.65+0.65+1+2.2 +5.1+5.2+4.4+35	93.5

Table 6. Sequence of Routes Before and After using the Ant Colony Optimization Method

Initial Route and Mileage from the Company			Proposed Routes and Mileage Using the Ant Colony Optimization Method		
Route	**Node**	**Weight Order (kg)**	**Route**	**Node**	**Weight Order (kg)**
1	1-3-10-2-4-12-7-1	3,975	1	1-11-10-1	3,975
2	1-6-5-1	3,510	2	1-7-5-8-9-6-1	3,3975
3	1-9-8-1	2,475	3	1-4-3-2-12-1	2,5875
Total Weight Order (kg)		**9,960**	**Total Weight Order (kg)**		**9,960**

From the results above, it can be concluded that there are no additional routes after using the Ant Colony Optimization method, but there are changes regarding the flow of the distribution, namely route 1 1-11-10-1 with orders carried a total of 3,975 kg, route 2 1-7- 5-8-9-6-1 with orders carried totaling 3,397.5 kg and route 3 with orders carried totaling 2,587.5 kg for a total order of 9,960 kg. The results obtained from the Ant Colony Optimization method will be selected as the proposed route, with a total distance of 230.3 km and a total initial company distance of 251.95 km, a total distance savings of 21.75 km is obtained with a saving percentage of 8 .63%. This efficiency can be measured by reduced travel distance or time required to deliver milk to the destinations. In the distribution industry, higher efficiency can save operational costs and reduce delivery time. The ACO method can help find optimal distribution routes, thereby reducing fuel costs, vehicle maintenance costs, or other costs associated with the milk delivery process (Gao, 2023)

3.5. Discussion

The results of research using the Ant Colony Optimization (ACO) method to determine the distribution route of UHT milk at Milk Industry show an increase in efficiency in the distribution of goods. From the calculation results, three distribution routes were obtained that have been used by the company, namely Route 1 with a total mileage of 108.5 km, Route 2 with a total mileage of 72.8 km, and Route 3 with a total mileage of 70.65 km. Next, the next step is to fill in the tabu list, which is a table used to determine the route to be visited and can be a reference for the route to be taken.

The ACO optimization process is then carried out by calculating the temporary routes formed from the ants. After several iterations, the calculation results show the best route with a total distance of 108.95 km, after which the ants will add pheromones to the pheromone matrix through which they travel. With the next iteration, continued until the maximum number of iterations is reached, the results show that the route calculation using the Ant Colony Optimization method shows the same results continuously at the 22nd iteration until the 100th iteration.

The optimal results of the Ant Colony Optimization method show that the salesman visit route with a distance of 93.5 km, but it is known that the capacity of product demand exceeds the capacity of the company's conveyance. Therefore, the division of shipping capacity and the total distance of the visit route is carried out in the Ant Colony Optimization calculation using the MATLAB application. From the calculation results, a total distance savings of 21.75 km or 8.63% was obtained. Thus, the results showed that the Ant Colony Optimization method can provide an optimal solution in determining a more efficient UHT milk distribution route and produce significant distance savings for Milk Industry.

Compared to previous research conducted by Risqiyanti, et al. (2019), which used the Ant Colony Optimization method in finding the shortest path for distribution at PT Distriversa Buana Mas and research by Manuputty and Manurung (2021) which used the Ant Colony Optimization method to determine mineral water distribution routes. The results of this study also show that after applying ACO, the mineral water distribution route results in a shorter total mileage compared to using the Google Maps application. This shows that ACO can provide a more efficient solution in determining distribution routes as well as research by Eraniola and Suhendar (2021) who used the Ant Colony Optimization method to determine the vehicle route of PT Sarana Cahaya Makmur. The results of this study indicate that after applying ACO, the vehicle route results in a lower total mileage and more efficient travel time, so that truck drivers can travel shorter distances and return earlier to the company.

Overall, the research at Milk Industry and other previous studies show that the Ant Colony Optimization method is an effective approach to solving distribution route optimization problems. ACO is able to provide an optimal solution by producing more efficient distribution routes and saving mileage, time, and operational costs for distribution companies (Yue, 2015).

In the context of distribution, companies often face combinatorial optimization problems, such as determining the most efficient and profitable routes to distribute products to various destination locations (Huizhen, 2019). This problem involves selecting a combination of routes from different origin locations to different destination locations, taking into account certain constraints and criteria, such as distance, travel time, and cost. The Ant Colony Optimization method is one of the effective techniques in solving combinatorial optimization problems, including route distribution problems (Balseiro et al., 2011).The ACO approach mimics the behavior of ants in finding the shortest path from the nest to the food source, and by collaborating, these ants can find optimal routes through increasing and decreasing the intensity of pheromones on the paths they pass through (Yue, 2015).ACO's ability to find optimal solutions in distribution route optimization problems is very useful for distribution companies such as Milk Industry. By using ACO, companies can optimize their distribution route arrangements to achieve the highest efficiency in the delivery of UHT milk products, reduce logistics costs, and improve customer satisfaction (Wang, 2021).

4. Conclusion

Based on the results of data processing and data analysis, the Ant Colony Optimization (ACO) method for determining UHT milk distribution routes at Milk Industry shows an increase in efficiency in the process of distributing goods. The use of ACO in distribution route optimization is able to produce more efficient routes with shorter total distance traveled, so that companies can save operational costs and delivery time. The ACO optimization process is carried out by calculating the temporary route formed from ants and several iterations are carried out until the best route is found with the optimal total mileage. The optimal results of ACO show that the route of the salesman's visit with a distance of 93.5 km, but by considering the capacity of the company's conveyance, a total distance savings of 21.75 km or 8.63% is obtained. By using ACO, companies can optimize the delivery of their products more efficiently, improve customer satisfaction, and achieve a competitive advantage in a competitive market. Besides that, it can also be recommended thon milk industry is expected to be able to use the distribution channel from the results of applying the Ant Colony

Optimization method, namely the optimal route obtained after calculations with the Ant Colony Optimization method and it is necessary to carry out trials on calculations after applying the method to test the extent to which the proposed method This can be applied in the field.

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