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Ant Colony Optimization algorithm for determining the shortest routes to reduce distribution costs

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ABSTRACT

Distribution is an important activity that companies need to pay attention to. Improper planning for distribution activities can potentially waste both cost and time. Determining the shortest distribution route could help companies effectively reduce distribution costs. This research was conducted on a small and medium enterprise (SME) located in Rangkasbitung, Indonesia that sells various types of bread. Distribution activities carried out by Jaya Roti were found to be still conventional, while the distribution carried out to the city of Serang has many locations and complex route combinations. This research utilized the metaheuristic method of Ant Colony Optimization (ACO) with MATLAB software to determine the shortest route, which is included in the Travel Salesman Problem (TSP). The result of the shortest route determination was a total distance of 93,484 Km with an efficiency rate of 26.97% and a resulting cost of IDR 170,795.

1. Introduction

Small and Medium Enterprises (SMEs) in Indonesia have suffered from the COVID-19 pandemic, resulting in a decrease in their revenue margins. The weakening economic conditions during the pandemic have also affected the income development of SMEs. In such a devastated economic situation, businesses must make prudent decisions. One such decision is to make all existing activities more effective and efficient.

Distribution is the process of delivering products from manufacturing companies or manufacturers to consumers [1]. The speed, cost, and benefit of vehicle transportation are affected by the path to a certain extent [2]. Therefore, planning the optimal distribution path scientifically and reasonably, according to the actual distribution requirements and the characteristics of the goods, can not only increase the distribution speed but also reduce the distribution cost. This can strive for greater economic benefits for the distribution process, and vice versa [3].

With the development of optimization techniques, it is necessary to find the optimal distribution route according to the needs of the demand points, delivery cost, and delivery time. This forms a multi-objective optimization problem [4, 5]. The determination of the shortest route to minimize the cost of distribution can be categorized as a Traveling Salesman Problem (TSP) [3, 6].

TSP is a combinatorial problem in which a salesman must visit a number of cities, with the constraint that each city can only be visited once, and the salesman must choose the route so that the total distance traveled is minimized [7, 8]. However, to date, there is no exact method that can find the optimal solution to this problem. Combinatorial optimization problems arise in many disciplines, including the basic sciences and applied fields such as engineering, economics, and social sciences [5, 9-12].

One of the most popular combinatorial optimization methods is Ant Colony Optimization (ACO) metaheuristic [13]. ACO is an optimization problem-solving algorithm inspired by the behavior of ants when traveling from nest to food source, and it is one of the metaheuristic approaches that can be used to solve TSP problems [6, 14]. ACO has a much better performance than other algorithms in determining the shortest route, as it can produce optimal results with a small number of iterations based on the principle of approach. Its most significant feature is positive feedback that benefits

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from the pheromone left by ants, which can guide the solution construction process [6]. ACO has been used to solve NP-hard problems such as the Traveling Salesman Problem.

This research aims to determine the shortest route for Jaya Roti's distribution activities using Ant Colony Optimization, to obtain the order of distribution locations and find out the total distribution costs that can be minimized through the total distance produced by the shortest route. The benefits of this research are expected to be applied in Jaya Roti's distribution activities to produce effective and efficient distribution and save distribution costs. Jaya Roti is an SME focused on producing bread, and its demand has decreased up to 5,000 breads due to the pandemic. The company considers the carrying capacity and distribution location but ignores whether the mileage of the resulting route is minimal or not, resulting in less optimal routes and higher distribution costs. One of Jaya Roti's deliveries is made to Serang City and Regency, which has a complex combination of routes with 46 retail locations at varying distances. Improper location determination can lead to wasted distance and large distribution costs that should be minimized under current conditions.

Based on the conditions outlined above, the determination of the shortest route carried out can help Jaya Roti to cut the necessary distribution costs so that Jaya Roti can make cost savings.

2. Material and method

2.1. Optimization

Optimization is an effort to obtain the best results with the given conditions [5]. The main goal of optimization is to achieve maximum profit with minimal effort. Optimization becomes an important part of problem-solving in creating a system since it can minimize delivery or distribution while maximizing profits, minimizing processing time, and achieving other objectives. In troubleshooting with optimization techniques, there are three requirements: the ability to create mathematical models of the problems faced, knowledge of optimization techniques, and knowledge of computer programming [2].

2.2. Traveling Salesman Problem (TSP)

The Traveling Salesman Problem (TSP) is a common problem in combinatorial optimization, where a salesman must visit N number of cities, ensuring that each city is visited only once. Therefore, the salesman must choose a route that results in minimum mileage. This problem can be mathematically formulated as follows [2]:

$$\text{Min} \sum_{i=1}^{N} \sum_{j=1}^{N} c_{ij} x_{ij} \tag{1}$$

subject to

$$\sum_{j=1}^{N} x_{ij} = 1, i = 1,2, \dots, N \tag{2}$$

$$\sum_{i=1}^{N} x_{ij} = 1, j = 1,2, \dots, N \tag{3}$$

$$u_i - u_j + N x_{ij} \le N - 1, i \ne j, i = 2, \dots, N, j = 2, \dots, N \tag{4}$$

$$u_i, u_j \ge 0 \tag{5}$$

where c_{ij} is the distance between city i to city j and $x_{ij} = 1$ of there is a salesman's journey from city i to city j, 0 otherwise.

2.3. Graph theory

A G-directional graph is a set pair (V, E), where V is an infinite set of vertices with an infinite number of elements, and E is a set of dot pairs in $V \times V$, which can be empty. Graphs are tools used to represent discrete objects as well as the relationships between them. TSP cases are typically represented by a weighted graph type. Figure 1 shows a graph $G = (V, E)$ with a set of vertices V = {A, B, C, D, E, F} and a weight value assigned to each edge in E.

The shortest path is defined as the path with the minimum length from the starting point to the end point [4]. The determination of the shortest route is a problem that is a part of determining optimal solutions in TSP. TSP conditions typically use weighted graphs to solve the problem because the distance between the traveled cities is represented as a graph with weights assigned to its edges.

2.4. Ant Colony Optimization (ACO)

Ant colony optimization (ACO) belongs to the swarm intelligence group, which is a type of paradigm development used to solve optimization problems by drawing inspiration from the behavior of groups or swarms of insects [14, 17]. Similar to the way ants search for food, this algorithm mimics the behavior of ants in determining the shortest path or route for carrying food back to the nest by leaving pheromone trails as markers for other ants. Pheromones left as trail marks become signals for other ants, and the shortest path will have a more concentrated pheromone, attracting more ants to pass through it. This happens because pheromones passed by many ants will evaporate slower than others.

After initialization, each ant fills the first element of the taboo list with the index of a specific city. Then, the status transition rules are carried out as a step in preparing the route for each ant's visit to each city. The random proportional rule for transition rules can be seen in the Eqs. (6)-(7).

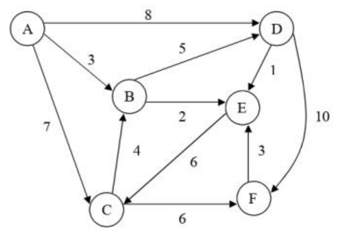

Figure 1. A graph

$$P_{rs}^{k} = \frac{[\tau_{rs}]^{\alpha}.[\eta_{rs}]^{\beta}}{\sum_{u \in J_r^k}[\tau_{rs}]^{\alpha}.[\eta_{rs}]^{\beta}}, s \in J_r^k \quad (6)$$

$$P_{rs}^{k} = s \in J_r^k \quad (7)$$

where τ_{rs} is the number of pheromones found on the edge between point r and point s, $\eta_{rs} = \frac{1}{d_{rs}}$ is the visibility (Distance Invers d_{rs}), d_{rs} is the distance of r point to point s, α is the parameter that control the relative weight of pheromone, β is the distance control parameters ($\alpha, \beta > 0$), J_r^k is the set of points that the k ants will visit which are at the r point.

After spreading out to each city, the ants will travel from the first city of each ant as the hometown to other cities as destination cities. In the second city, the ants will continue on to the next city but choose a city that is not on the taboo list as the next destination. This continues until all cities have been visited or the ants have returned to their hometown. Therefore, in Eqs. (6)-(7) above, we can choose a shorter edge even if it has a large amount of pheromone to determine the destination city.

After each ant has completed its task, the pheromone is renewed. The rules for global pheromone update can be seen in Eq. (8).

$$\tau_{rs} \leftarrow 1 - \rho\, \tau_{rs} + {}_{k=1}^{m}\Delta\tau_{rs}^{k} \quad (8)$$

where $\Delta\tau_{rs}^{k} = \frac{1}{C^k}$ if r, s is in tour done by ants and 0 otherwise, τ_{rs} is the number of pheromones found on the edge between point r and point s, C^k is the length of the tour traveled by ants k, ρ ($0 < \rho \leq 1$) is the parameter of pheromone evaporation rate, and m is the number of ants.

ρ becomes a parameter for the rate of pheromone evaporation, where a decrease in the number of pheromones during the exploration stage provides the possibility of different trajectories or routes. This can also limit the possibility of choosing a less precise trajectory. Therefore, each ant is given a taboo list that can store the points it has already visited, so that it cannot revisit these points before completing the tour. When a tour is completed, the taboo list can also be used to calculate the solution found by the ants.

3. Results and discussions

3.1. Location data and coordinates

Figure 2. Distribution location

Table 1.
Vehicle data

No	Vehicle data	Information
1	Vehicle price	141000000
2	Economic period	8 years
3	Fuel type	Gasoline
4	Price/Litre	10000
5	Distance/ Litre	15 km

Table 2.
Shipping cost

No	Information	Price/km
1	Fuel	510
2	Maintenance Price	62
3	Depreciation	317
4	Driver salary/km	938

Jaya Roti carries out its delivery process every day, with one of its distribution destinations being the Serang area of Banten Province, particularly Serang Regency and Serang City. Figure 2 shows the coverage of Jaya Roti's distribution area in Serang Regency and Serang City. Based on the distribution map of distribution locations shown above, there are 12 delivery locations in Serang City and 34 delivery locations in Serang Regency. All delivery locations are serviced by distribution vehicles with open body cars that start from Jaya Roti's location and return there after completing deliveries. Tabel A1 (see Appendices) are the location data and coordinates for Jaya Roti's delivery destinations in Serang City and Serang Regency. During each trip, a total of 3,310 loaves of bread are transported to meet demand. All location data is obtained using Google Maps to acquire the required location coordinates.

Jaya Roti makes deliveries to Serang City and Serang Regency routes four times a month, with one delivery per week. Each delivery is made using Jaya Roti's operational vehicle, an open body car with a capacity of carrying 55 shelves containing bread cans. The shelf size is 70 cm x 50 cm and can accommodate up to 70 loaves per rack. Each rack can contain various bread variants such as chocolate, coffee, strawberry, cheese, and coconut. Jaya Roti can carry a maximum of 3,850 loaves of bread per delivery using an open body car. According to Table 1, gasoline is used as fuel with a price of IDR 7,650 per liter. The economic age of the car used by Jaya Roti is 8 years, in accordance with Regulation of the Minister of Finance No. 96/PMK.03/2009 and has a price of IDR 141,000,000.

Jaya Roti incurs a total shipping cost of IDR 1,827/km per kilometer. This cost includes fuel costs of IDR 510/km, vehicle maintenance costs of IDR 62/km, depreciation costs of IDR 317/km, and driver's salary costs of IDR 938/km. If Jaya Roti makes a delivery to Serang regency and Serang city, based on the route carried out by the driver or employees of Jaya Roti, the total distance covered is 128 km. The total cost incurred for one delivery would be IDR 233,856.

3.2. Determination of the number of vehicles

To facilitate an efficient and effective delivery process, a certain number of vehicles are required to meet the demand needs. Once the vehicle requirements for delivering bread to Serang city and Serang regency have been calculated, one car is needed to carry 3,310 breads. The delivery requests are made once a week for the entire month, and each vehicle can accommodate up to 55 cans of bread. Each can contain 70 breads.

3.3. Ant Colony Optimization Algorithm

Figure 3 displays the pseudocode used to perform ACO calculations in MATLAB for obtaining the results of the proposed shipping routes in this study. The optimal running result is the answer to the calculation of the shortest route determination using the ACO algorithm. The iteration is conducted 2,000 times along with some pre-set parameters [19]. Table A2 (see Appendices) shows the results obtained using MATLAB.

Based on the results of the conducted experiment and calculations, the total distance covered by the existing process is 128 km, while the best ACO results cover 93.48 km. The difference in total distance covered is 34.52 km, with an efficiency rate of 26.97%. This difference is because the existing process still relies on conventional methods or employee instincts to determine the next location, resulting in suboptimal distance coverage.

With ACO, the process of determining the location is considered in detail, influenced by the probability obtained through the parameters set in each experiment. Wang and Yang's research [20] suggests that the usual standard combination to produce optimal results is α = 1 and β = 5. According to this research, experiment 5 produces the most optimal results.

However, in this case, ACO with α = 0.1 and β = 5 produces the best route based on nine existing experiments. Experiment 3 requires more iterations than any other experiment, at 1,444 iterations. Experiment 9 only requires 139 iterations. These results illustrate that the effect of pheromone renewal when α = 1 and β = 5, which provides additional pheromone to each point passed, is significant enough to increase interest in subsequent iterations. With an increasing value of pheromone in the *i-j* section, it is more likely that this section will be selected again in the next iteration. This makes experiment 9 require fewer iterations because the accumulated pheromone is significant enough that the ants' interest in finding the optimal route combination is faster.

However, in experiment 3, the parameters used were α = 0.1 and β = 5. The resulting increase in pheromone was not significant enough to cause ants to explore the combination of routes thoroughly. As a result, the level of interest in the edges or points did not decrease significantly. This led to a high number of required iterations, reaching 1,444 iterations, which is far higher than the other nine trials.

```
ACO Algorithm for Jaya Roti
Output : Best Route, Total Distance, Cost generated Penentuan
Initial Parameters
Input  : Number of Ants, Number of cities, Matrix of distance
         between cities, Maximum Iteration, alpha, beta,
         coefficient of Evaporation
Initialization
Generating Visibilty Matrix
  eta = 1./ matrix of distances between cities
Generating Pheromone Matrix
  tau = tau0*ones(Number of City, Number of City)
Probability Calculation
for i=1:Number of Max Iteration
   All ants start from city 1
   for k = 1:Number of Ant
       for l = 2:Number of City
           i = ant(k).Tour(end);
           P = tau(i; : ) .^alpha.*eta(i; : ).^beta
           P = P/sum(P)
        Generate random numbers
        Use roulette wheel selection rules to choose the next city
           C = cumsum(P)
           j = find(r<= C, 1, 'first')
        Calculate the total distance of the route results of all
        ants
        tour = [tour tour(1)]
        L = 0
        for i = 1 : Number of City
            L = L+model.D(tour(i),tour(i+1))
        end
       end
   end
   Updating pheromone
   for k = 1:Number of ant
       for l = i:Number of City
           i = tour(l)
           j = tour(l+1)
           tau(i, j) = tau(i, j)+Q/ant(k).Cost
       end
   end
   For pheromone that ants do not pass through
   tau = (1-rho)*tau
   Get The Best Route
   if ant(k).Cost<BestSol.Cost
       BestSol = ant(k);
   end
end
```

Figure 3. Pseudecode of ACO

The set evaporation level is also instrumental because it allows the potential points that ants did not initially pass through to be selected. The evaporation of pheromone is not significant enough to make the points that the ants did not pass through lose enough pheromone. Therefore, some possible parameters can still produce a more optimal distance. The determination of the parameters above may not apply to certain conditions because it depends on the magnitude of the conditions and problems that need to be resolved. Wang's study also showed that the ACO algorithm could find a shorter path, and the simulation showed faster convergence speed [20].

3.3. Distribution cost calculation

To find out if ACO results are better than existing conditions, a comparison is required through cost and distance aspects. Table A3 (see Appedices) is a comparison of the route and cost of the best ACO results and existing conditions.

Jaya Roti incurred distribution costs of IDR 233,856 using existing routes, covering a total distance of 128 Km. However, the best ACO result from experiment 3 resulted in a distribution cost of IDR 170,795, covering a total distance of 94.48 Km. Although the ACO result obtained a distribution cost that is more than the minimum distribution cost obtained by using the existing route, the efficiency level obtained was 36.92%, with a minimum cost of IDR 63,061 per shipment. The increasing distance will result in higher distribution costs, so it needs to be considered since the suboptimal route will affect the cost of distribution produced.

4. Conclusions

The total shortest route distance obtained by using ant colony optimization (ACO) was 93.48 Km, resulting in an efficiency rate of 26.97% and a cost of IDR 170,795 for one delivery. The minimum cost for one delivery was IDR 63,061.

The route sequence line follows the main road through Jl. Raya Warung Gunung, Jl. Raya Petir, Jl. Syeikh Nawawi Al Bantani, Jl. Cijaku Raya, Jl. Kedaton, Jl. Raya Petir Serang, Jl. Kejaksaan 1, Jl. Pangeran Dipenogoro, Jl. Samaun Bhakti, Jl. Magelaran, and back to the original location through Jl. K.H Abdul Latif.

Declaration statement

Yusraini Muharni: Conceptualization, Methodology, Software. **Febby Chandra Adipradana:** Data curation, Writing- Original draft preparation. **Evi Febianti**: Visualization, Investigation. **Muhammad Adha Ilhami**: Software, Validation. **Ade Irman:** Software, Validation. **Kulsum:** Writing-Reviewing, Editing. **Lely Herlina:** Writing-Reviewing **Anting Wulandari**: Editing. **Hartono**: Data curation and Reviewing.

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Disclosure statement

The author declares that we have no relevant or material financial interests that relate to the research described in this paper".

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Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

References

[1] B.-Y. Cheng, J. Y.-T. Leung, and K. Li, "Integrated scheduling of production and distribution to minimize total cost using an improved ant colony optimization method," *Comput. Ind. Eng.*, vol. 83, pp. 217–225, May 2015, doi: 10.1016/j.cie.2015.02.017.

[2] A. Swarnkar, N. Gupta, and K. R. Niazi, "Adapted ant colony optimization for efficient reconfiguration of balanced and unbalanced distribution systems for loss minimization," *Swarm Evol. Comput.*, vol. 1, no. 3, pp. 129–137, Sep. 2011, doi: 10.1016/j.swevo.2011.05.004.

[3] D. Liu, X. Hu, and Q. Jiang, "Design and optimization of logistics distribution route based on improved ant colony algorithm," *Optik*, vol. 273, p. 170405, Feb. 2023, doi: 10.1016/j.ijleo.2022.170405.

[4] D. Zhang, S. Cai, F. Ye, Y.-W. Si, and T. T. Nguyen, "A hybrid algorithm for a vehicle routing problem with realistic constraints," *Inf. Sci.*, vol. 394–395, pp. 167–182, Jul. 2017, doi: 10.1016/j.ins.2017.02.028.

[5] Q. Zhang and S. Xiong, "Routing optimization of emergency grain distribution vehicles using the immune ant colony optimization algorithm," *Appl. Soft Comput.*, vol. 71, pp. 917–925, Oct. 2018, doi: 10.1016/j.asoc.2018.07.050.

[6] Y. meng Yue and X. Wang, "An Improved Ant Colony Optimization Algorithm for Solving TSP," *Int. J. Multimed. Ubiquitous Eng.*, vol. 10, no. 12, pp. 153–164, Dec. 2015, doi: 10.14257/ijmue.2015.10.12.16.

[7] P. Stodola, P. Otřísal, and K. Hasilová, "Adaptive Ant Colony Optimization with node clustering applied to the Travelling Salesman Problem," *Swarm Evol. Comput.*, vol. 70, p. 101056, Apr. 2022, doi: 10.1016/j.swevo.2022.101056.

[8] R. Skinderowicz, "Improving Ant Colony Optimization efficiency for solving large TSP instances," *Appl. Soft Comput.*, vol. 120, p. 108653, May 2022, doi: 10.1016/j.asoc.2022.108653.

[9] J. B. Mach, K. K. Ronoh, and K. Langat, "Improved spectrum allocation scheme for TV white space networks using a hybrid of firefly, genetic, and ant colony optimization algorithms," *Heliyon*, vol. 9, no. 3, p. e13752, Mar. 2023, doi: 10.1016/j.heliyon.2023.e13752.

[10] L. Xu, K. Huang, J. Liu, D. Li, and Y. F. Chen, "Intelligent planning of fire evacuation routes using an improved ant colony optimization algorithm," *J. Build. Eng.*, vol. 61, p. 105208, Dec. 2022, doi: 10.1016/j.jobe.2022.105208.

[11] X. Yang, H. Dong, and X. Yao, "Passenger distribution modelling at the subway platform based on ant colony optimization algorithm," *Simul. Model. Pract. Theory*, vol. 77, pp. 228–244, Sep. 2017, doi: 10.1016/j.simpat.2017.03.005.

[12] X. Du, C. Du, J. Chen, and Y. Liu, "An energy-aware resource allocation method for avionics systems based on improved ant colony optimization algorithm," *Comput. Electr. Eng.*, vol. 105, p. 108515, Jan. 2023, doi: 10.1016/j.compeleceng.2022.108515.

[13] P. González, R. R. Osorio, X. C. Pardo, J. R. Banga, and R. Doallo, "An efficient ant colony optimization framework for HPC environments," *Appl. Soft Comput.*, vol. 114, p. 108058, Jan. 2022, doi: 10.1016/j.asoc.2021.108058.

[14] M. Dorigo, V. Maniezzo, and A. Colorni, "Ant system: optimization by a colony of cooperating agents," *IEEE Trans. Syst. Man Cybern. Part B Cybern.*, vol. 26, no. 1, pp. 29–41, Feb. 1996, doi: 10.1109/3477.484436.

[15] Y. Wang and Z. Han, "Ant colony optimization for traveling salesman problem based on parameters optimization," *Appl. Soft Comput.*, vol. 107, p. 107439, Aug. 2021, doi: 10.1016/j.asoc.2021.107439.

[16] M. Das, A. Roy, S. Maity, and S. Kar, “A Quantum-inspired Ant Colony Optimization for solving a sustainable four-dimensional traveling salesman problem under type-2 fuzzy variable,” *Adv. Eng. Inform.*, vol. 55, p. 101816, Jan. 2023, doi: 10.1016/j.aei.2022.101816.

[17] P. Balaprakash, M. Birattari, T. Stützle, and M. Dorigo, “Estimation-based metaheuristics for the single vehicle routing problem with stochastic demands and customers,” *Comput. Optim. Appl.*, vol. 61, no. 2, pp. 463–487, Jun. 2015, doi: 10.1007/s10589-014-9719-z.

[18] H. Zhao and C. Zhang, “An ant colony optimization algorithm with evolutionary experience-guided pheromone updating strategies for multi-objective optimization,” *Expert Syst. Appl.*, vol. 201, p. 117151, Sep. 2022, doi: 10.1016/j.eswa.2022.117151.

[19] Zhou, H. Ma, J. Gu, H. Chen, and W. Deng, “Parameter adaptation-based ant colony optimization with dynamic hybrid mechanism,” *Eng. Appl. Artif. Intell.*, vol. 114, p. 105139, Sep. 2022, doi: 10.1016/j.engappai.2022.105139.

[20] Q. Wang *et al.*, “A Dual-Robot Cooperative Welding Path Planning Algorithm Based on Improved Ant Colony Optimization,” *IFAC-Pap.*, vol. 55, no. 8, pp. 7–12, 2022, doi: 10.1016/j.ifacol.2022.08.002.

Appendices

Table A1.
Location data

No	Init. Locatrion	Latitude	Longitude	Address	Demand (Unit)
1	Jaya Roti	-6.344842	106,25159	Serang Regency	0
2	L1	-6.167172	106,178440	Serang Regency	50
3	L2	-6.166809	106,175382	Serang Regency	50
4	L3	-6.166793	106,175054	Serang Regency	50
5	L4	-6.168131	106,171782	Serang Regency	50
6	L5	-6.170475	106,170997	Serang Regency	130
7	L6	-6.171076	106,171007	Serang Regency	130
8	L7	-6.171952	106,172310	Serang Regency	130
9	L8	-6.171835	106,172557	Serang Regency	130
10	L9	-6,172085	106,170240	Serang Regency	50
11	L10	-6,169392	106,171663	Serang Regency	50
12	L11	-6,169358	106,172956	Serang Regency	50
13	L12	-6,167066	106,172016	Serang Regency	50
14	L13	-6,166548	106,175070	Serang Regency	50
15	L14	-6,17480	106,161538	Serang Regency	50
16	L15	-6,175451	106,160732	Serang Regency	50
17	L16	-6,176157	106,155909	Serang Regency	50
18	L17	-6,173816	106,164676	Serang Regency	50
19	L18	-6,170222	106,166759	Serang Regency	60
20	L19	-6,169936	106,166962	Serang Regency	60
21	L20	-6,169399	106,166976	Serang Regency	50
22	L21	-6,169060	106,166970	Serang Regency	50
23	L22	-6,168934	106,167750	Serang Regency	50
24	L23	-6,168829	106,167614	Serang Regency	50
25	L24	-6,169380	106,167698	Serang Regency	50
26	L25	-6,169672	106,167741	Serang Regency	50
27	L26	-6,170117	106,167591	Serang Regency	50
28	L27	-6,165671	106,173331	Serang Regency	50
29	L28	-6,165300	106,173776	Serang Regency	20
30	L29	-6,164892	106,173660	Serang Regency	50
31	L30	-6,161161	106,174119	Serang Regency	130
32	L31	-6,158401	106,175932	Serang Regency	50
33	L32	-6,156247	106,176625	Serang Regency	50
34	L33	-6,156559	106,175715	Serang Regency	50
35	L34	-6,156306	106,177625	Serang Regency	50
36	L35	-6,155966	106,179227	Serang City	50
37	L36	-6,151212	106,178245	Serang City	50
38	L37	-6,146969	106,176762	Serang City	50
39	L38	-6,136444	106,170148	Serang City	60
40	L39	-6,12561	106,163961	Serang City	60
41	L40	-6,123001	106,164296	Serang City	130
42	L41	-6,119308	106,165043	Serang City	130
43	L42	-6,133799	106,166756	Serang City	150
44	L43	-6,154794	106,179171	Serang City	130
45	L44	-6,094145	106,175917	Serang City	150
46	L45	-6,112422	106,153917	Serang City	130
47	L46	-6,110363	106,163976	Serang City	130

Table A2.
Location data

Condition	Parameter value				Total Distance (Km)	Number of Iterations	Efficiency (%)
	τ	α	β	ρ			
Existing	-	-	-	-	128	-	-
1	1	0.1	1	0.05	94.93	1.198	25.84
2	1	0.1	2	0.05	93.79	1.668	26.73
3	1	0.1	5	0.05	93.48	1.444	26.97
4	1	0.5	1	0.05	95.54	274	25.36
5	1	0.5	2	0.05	94.33	208	26.31
6	1	0.5	5	0.05	93.99	404	26.57
7	1	1	1	0.05	97,54	83	23.80
8	1	1	2	0.05	94.50	88	26.17
9	1	1	5	0.05	93.69	139	26.80

Table A3.
Location data

Condition	Parameter value				Total Distance (Km)	Total Cost	Route
	τ	α	β	ρ			
Existing	-	-	-	-	128	Rp. 233.856	L1-L2-L3_L4-L5-L6-L7-L8-L9-L10-L11-L12-L13-L14-L15-L16-L17-L18-L19-L20-L21-L22-L23-L24-L25-L26-L27-L27-L28-L29-L30-L31-L32-L33-L34-L35-L36-L37-L38-L39-L40-L41-L42-L43-L44-L45-L46-L47-L1
Trial 3	1	0,1	5	0,05	93.48	Rp. 170.795	L1-L2-L3_L4-L13-L5-L11-L12-L6-L7-L8-L9-L10-L15-L16-L17-L18-L19-L27 L26-L25-L24-L23-L22-L21-L20-L14-L29-L30-L28-L31-L32-L34-L33-L35-L44-L38-39-L43-L40-L41-L42-L46-L47-L45-L37-L36-L1