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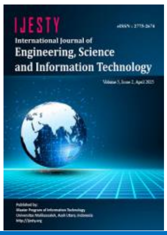

Application of Ant Colony Algorithm to Determine the Shortest Route for Nature and Culinary Tourism in North Aceh

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Abstract

This Research aims to design and implement a shortest route determination system for natural and culinary tourism locations in North Aceh using the Ant Colony Optimization (AntCO) algorithm. The developed system is designed to help tourists plan their trips efficiently by considering the distance and travel time between tourist destinations. The system implementation using the AntCO algorithm successfully displayed optimal routes for 28 tourist destinations in North Aceh. The system successfully implemented filtering features based on tourism categories and route visualization on an interactive map using different markers (green for natural tourism and red for culinary tourism). The research results show that the system successfully optimized tourist travel routes and provided comprehensive information, including automatic location detection, a list of tourist destinations, travel route details, and optimal visit sequences based on selected tourism categories. This system proved effective in helping tourists plan their trips in North Aceh by providing efficient routes according to their preferred tourism category preferences.

Keywords: *Ant Colony Optimization, Geographic Information System, North Aceh, Tourism.*

1. Introduction

In this modern era, information and computing technology development has significantly impacted various aspects of life, including optimizing transportation systems. One of the main challenges in transportation is determining the shortest path that can save time, costs, and resources. This problem is often encountered in everyday applications such as navigation, logistics, and public transportation.

In previous research [1]. in a journal entitled "Application of Ant Colony Optimization Algorithm for Searching the Shortest Route to Tourist Locations" using PHP. This journal has shown the potential of solving the shortest path problem with the Ant Colony Optimization Algorithm (ACO). Based on these results, this study adapts the application of the ACO algorithm. However, this study expects to develop further Research using the process by comparing it with many algorithms using other programming languages to distinguish which algorithm is better for determining the shortest route.

And in the Research of [2]). The journal entitled " In Search of the shortest path "Using the Ant Colony Optimization Algorithm in Gui Matlab to Monitor Sustainable Development Goals" describes how the Ant Colony Optimization method is used to determine the shortest or nearest path in the Traveling Salesman Problem [3] also developed an e-tourism application for Lhokseumawe City and North Aceh Regency which applies the AntCO algorithm in determining the optimal route to tourist locations. This application is designed to help tourists access information about tourist attractions and provide optimal route recommendations to save time and travel costs.

In addition, [4]) developed an Android-based tour guide application for North Sumatra Province using the AntCO algorithm. According to [5], Research uses the ACO algorithm to help tourists choose tourist attractions with the lowest transportation costs. Of course, this takes into account cost and distance variables so that it can increase the efficiency of tourist travel [6]

Referring to the previous journal that solved the TSP problem using ACO, this study aims to expand the application of ACO, especially for the case of determining the closest route between the initial node and the destination node. This experiment will provide new insights into adjusting ACO parameters to obtain optimal solutions on certain graphs.

As an algorithm development tool, PHP is an ideal programming language because it supports various libraries and frameworks for ACO implementation [7]. PHP has advantages in flexibility and ease of integration with databases and web-based systems, making it a suitable

choice for dynamic route optimization implementation[8]. With PHP's capabilities, ACO implementation can be done efficiently and in a structured manner, starting from ant behaviour simulation to final result analysis in web-based applications [9]
This work aims to provide an ACO algorithm-based method to effectively examine the shortest route network to natural and culinary tourism destinations in North Aceh. Using the PHP programming language, this study simplifies the data analysis process and provides a technology-based solution to help tourists determine the optimal travel route [10]. The results of this study are expected to offer practical contributions to improving tourism accessibility in North Aceh and become a reference for the development of technology-based tourism navigation systems in the future.

2. Literature review

2.1. Graf

Graf is a group of people to whom Sisi or Busur frequently connects. Graf G is made up of two hearts: hearts V and hearts E.

1. Vertex (node): V is a set of vertices that is both finite and nonempty.
2. An edge (side or arc) is a collection of arcs that join two vertices.

The nodes in a graph can represent cities, atoms of a substance, parts of technological equipment, different kinds of cars, and so on. On the other hand, the arcs can depict various relationships, including highways, aircraft paths, phone lines, chemical ties, and more. The graph G has V vertices and E arcs, as indicated by the graph notation G(V, E) [2].
Leonhard Euler presented graph theory for the first time in 1736. According to graph theorists, the four-colour problem was first proposed by A.F. Mobius (1790–1868) in one of his lectures in 1840. A. De Morgan's letter is regarded as the first mention of the four-colour problem because he brought it up again with other mathematicians in London ten years later (1806–1871).

2.2. Travelling Salesman Problem (TSP)

Finding the shortest path or least distance that a salesperson must travel from one city to an additional town precisely once and then returning to the initial city of departure is known as the Traveling Salesman Problem (TSP). Typically, TSP is applied to a full-weighted graph, representing the distance between two cities by the weight assigned to each edge. The aim is to find a TSP path that visits every vertex on the graph precisely once [11]. Several heuristic functions are considered throughout the TSP optimization process to reduce the search space and identify more effective solutions [1].

2.3. Tourist

Travel, tourist locations, tourists, the tourism business, and other associated factors make up tourism. It encompasses a range of tourism-related activities that are Indonesia's primary source of foreign exchange. From Sabang to Merauke, this nation is renowned for its varied forms of tourism, which include social, cultural, and natural tourism. In addition to its breathtaking natural beauty, Indonesia boasts a rich cultural heritage. The abundance of historical artefacts and the variety of regional arts and civilizations draw domestic and foreign visitors to the area. Indonesia has many promises and is a popular travel destination[12]. The goal of voluntary, short-term nature tourism is to take in the distinctiveness and beauty of the natural world. It is impossible to separate the primary elements of nature tourism, which include[13]

1. Tourist attractions are things of interest to tourists, whether they be natural or artificial.
2. The management's provision of amenities and services to accommodate visitors' needs.
3. In addition to being physically accessible, lodging, food, and beverages must also foster a cosy atmosphere and evoke memories of the regional cuisine and surroundings.
4. Easy access to tourist destinations through roads and other modes of transportation.
5. Additional auxiliary elements include promotion, safety, and security for visitors to the site.

2.4. Ant Colony Optimization

The history of Ant Colony Optimization (ACO) began in 1996, which observed the behaviour of ants to develop an algorithm known as Ant Colony Optimization or Ant Algorithm. ACO is designed as a multiagent simulation that uses the natural metaphor of ants to provide solutions to problems in physical space. Manderick and Moyson introduced the ant algorithm, which Marco Dorigo developed widely. Dorigo utilizes probabilistic techniques to solve computational problems and find the best path. In 2004, Dorigo and Thomas stated that this algorithm was inspired by observations of ant behaviour, resulting in the design of a new algorithm to solve optimization problems. ACO is based on the analogy of ant behaviour that finds a path from the nest to a food source. Ants can use their senses to explore complex environments, find food, and return to their nests by leaving pheromone trails along their path. Ant Colony Optimization is one of the practical heuristic approaches to solving optimization problems by finding reasonable solutions. This approach uses a distributed computation to avoid getting stuck in a local optimum and applying a greedy algorithm that can produce pretty good solutions in the early stages of the search [14].

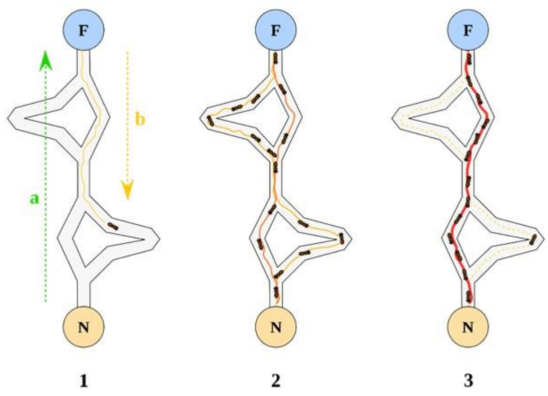


Fig 1. An example of the AntCO algorithm

Ant Colony Optimization (ACO) began in 1996 by studying the behaviour of ants to create an algorithm known as Ant Colony Optimization or Ant Algorithm. With the help of the natural metaphor of ants, ACO, a multiagent simulation, solves problems in real space. After being first introduced by Manderick and Moyson, Marco Dorigo expanded the use of the ant algorithm. Dorigo uses probabilistic methods to determine optimal actions and solve computational problems.

2.5. Ant System

The Ant System (AS) Algorithm is one of the variants of Ant Colony Optimization used to solve the Traveling Salesman Problem. This algorithm involves several ants (m) that work together and communicate via pheromones. The stages of this algorithm include each and starting its journey from its respective starting location. The ants travel by repeatedly visiting locations one by one. The following location is selected using a state transition rule called the random proportional rule, which is based on a probability that considers the inverse of the distance and the amount of pheromone between two locations. Ants tend to choose shorter paths and have high pheromone levels. Each ant has a memory called a tabu list, which records all the locations it has visited during its journey. This tabu list ensures that ants do not see the exact location more than once so that a solution close to optimal can be obtained. The tabu list will be full when the ant has completed its journey.

After this stage, each ant performs a global pheromone update using the global pheromone updating rule. This involves evaporating pheromones from all paths and then, based on the length of the tour taken by each ant, leaving a certain amount of pheromone on each edge that is part of their tour, proportional to the quality of the resulting solution. As the resulting tour becomes shorter, the amount of pheromone left on each edge that is passed increases. As a result, edges on the shortest tours will have a more significant amount of pheromone. This makes ants more likely to pass by these edges on subsequent tours. Conversely, edges that are not given a pheromone will be avoided by ants[15].

Ants In subsequent tours, the tabu list will be emptied. This pheromone evaporation process aims to prevent stagnation, where ants tend to do the same tour repeatedly. This process is repeated until the maximum number of tours or the system reaches stagnation, where no better alternative solutions are found [16].

The following are the steps to determine the shortest route using the Ant Colony Optimization algorithm:

Step 1 :

a. Initialization of the prices of the algorithm parameters, including :
    1. Ant or pheromone distance intensity between locations (τ_ij)
    2. Number of locations (n) and distance between locations (dij)
    3. Ant cycle constant (Q)
    4. Ant trail intensity control constant (a), value a > 0
    5. Visibility control constant (β), value β > 0
    6. Visibility between locations n_ij=1/d_ij
    7. Number of ants (m)
    8. Ant trail or pheromone evaporation constant (ρ), value 0 < ρ < 1
    9. The maximum number of cycles ($NCmax$) is fixed during the algorithm. At the same time, τij will constantly be updated in each algorithm cycle starting from the first cycle (NC = 1) until the maximum number of cycles is reached (NC = $NCmax$) or until convergence occurs.

b. Initialize the original location, namely placing m ants at their respective initial locations randomly.

Step 2 :

Next, the initialization result of each ant's initial location is recorded into the tabu list as the first element. Each ant's tabu list will contain the first element with a specific location index, which means that each $tabuk(i)$ can include a location index between 1 and n with $tabuk(i)$ denoting the ith element of $tabuk$ (tabu list for ant k). This means that $tabuk(i)$ denotes the ith location visited by ant k on a tour.

Step 3 :

Arrangement of travel routes for each ant to all destination locations. Ants that have been at their initial locations will each travel to other locations as destination locations. Ants travel to destination locations that are not in $tabuk$. To determine the following destination location, the probability of each location is calculated using the following probability function:

....(1)

$$p\frac{k}{ij} = \begin{Bmatrix} \frac{[\tau_{ij}]^{\alpha}[n_{ij}]^{\beta}}{\sum_{u \in j_i^k}[\tau_{ij}]^{\alpha}[n_{ij}]^{\beta}}, for\ s\ \in j_i^k \\ 0\ for\ other\ s \end{Bmatrix}$$

The probability at each location that has been obtained will then be calculated as the cumulative probability using the equation:

....(2)

$$kumulatif_n = p_{ij}^k + kumulatif_{n-1}$$

After the cumulative probability of each location is obtained, a random number (q) will be generated with $0 < q < 1$. Then, the ant from the previous location will walk to the area where $q \le kumulatifn$.

Step 4:

a. Calculating the length of each ant's travel path. After one cycle is completed by all ants, the length of the closed path or Lk of each ant will be calculated. The calculation of the length of the closed path is based on the $tabuk$ of each ant through the following equation:

....(3)

$$L_k = d_{tabu_{k(n)}, tabu_k(1)} + \sum_{s=1}^{n-1} d_{tabu_k(s), tabu_k(s+1)}$$

b. After calculating the Lk of each ant, the minimum closed path length for each cycle or $LminNC$ and the minimum closed path length overall or $Lmin$ will be obtained.

c. Ant colonies leave pheromones on the paths between locations they have passed. Changes in pheromones between locations can occur due to evaporation and differences in the number of ants passing through. Therefore, the calculation of pheromone changes is carried out through the following equation:

....(4)

$$\Delta\tau_{ij} = \sum_{k-1}^{m} \Delta\tau_{ij}^k$$

Where 〖Δτ〗 _ij is calculated based on the equation:

....(5)

$$\Delta\tau\frac{k}{ij} = \begin{Bmatrix} \frac{Q}{L_k}, (i,j) \in tabu_k \\ 0, (i,j) lainnya \end{Bmatrix}$$

Step 5:

Calculating the intensity value of ant trails or pheromones between locations for the next cycle using the equation:

....(6)

$$\tau_{ij} = (1-\rho)\tau_{ij} + \sum_{k=1}^{m} \Delta\tau_{ij}^k$$

Step 6:

Empty the tabu list so that it can be filled out again in the next cycle. Suppose the maximum number of cycles has not been reached or convergence has not occurred. In that case, the same process is carried out from step two with the updated pheromone intensity parameter price between locations.

2.6. Effectiveness Value

The effectiveness value indicates whether the route resulting from a calculation is relatively longer or shorter when compared to the route results on Google Maps. Based on the distance travelled from the calculation and Google Maps, the effectiveness value can be obtained through the equation:

....(7)

$$Nilai\ Efektifitas = \frac{|JM - JP|}{JM} \times 100\%$$

2.7. PHP

PHP is a scripting language integrated with HTML and runs on the server side. All commands given will be executed entirely on the server, and only the results are sent to the browser[17]. In website development, PHP is a crucial programming language to learn because of its ability to make websites dynamic. With PHP, whether running on a local server or online, you can create a website structure with HTML. This HTML structure is generally used with CSS for an attractive display design [18].

2.8. MySQL

MySQL is one of the most popular types of database servers. MySQL is included in the RDBMS (Relational Database Management System) category. MySQL supports the PHP programming language and SQL, a structured query language[19]. SQL in MySQL follows the standards set by an association called ANSI. As an RDBMS server, MySQL allows database users to create, manage, and use data in a relational model. This means that tables in a database can have relationships between one table and another [20].

3. Research Methods

A few strategies were used in this Research. The first step in data collection is to gather information pertinent to the study's topic, which will almost certainly be used as input at the data collection stage. Finally, the observation process is carried out by using Google Earth and making a long-term trip to the designated sea location. In addition, this study examines literature by using various journals, both national and local, as well as websites related to the study title as references.

3.1. System Scheme

The system scheme is a scheme that describes the system process from the start to the end. The following is the system scheme in this study.

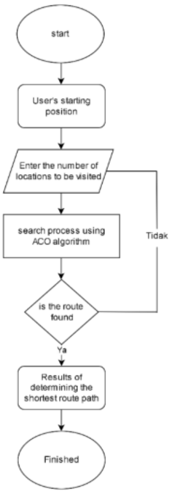


Fig 2. System Scheme

Description of the system schema:

1. Starting the Process
   The system starts searching for travel routes.
2. Determining the User's Starting Position.
   The system receives or detects the user's starting location as the trip's starting point.
3. Entering the Number of Locations to Visit
   The user provides input for the number and list of tourist destinations they want to visit.
4. Searching for Routes with the ACO Algorithm
   The system uses the Ant Colony Optimization (ACO) Algorithm to calculate and determine the most optimal travel route.
5. Verifying Route Availability
   The process continues to the next stage if the route is successfully found.
   If the route is not found, this flowchart does not yet show alternative solutions (for example, asking the user to re-enter data or providing an error notification).
6. Displaying the Shortest Route Results
   The system presents search results in the shortest travel route based on algorithm calculations.
7. Ending the Process
   The route search process is complete after the optimal route is found and displayed.

3.2. Ancolony Method Scheme

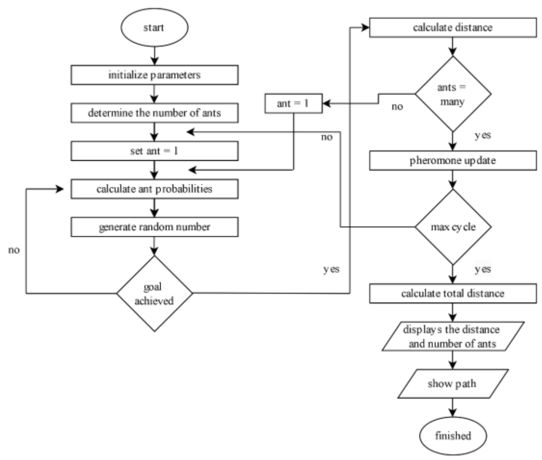


Fig 3. An colony Method Scheme

Description of the method scheme, namely :

1. Starting the Process
2. Initializing Parameters
3. Determining the Number of Ants
4. Setting the Initial Value of Ants = 1
5. Calculating the Probability of Path Selection
6. Generating Random Numbers
7. Verifying Goal Achievement
8. Calculating the Distance Traveled
9. Ensuring All Ants Have Walked
10. Updating Pheromone Levels
11. Determining Whether the Maximum Cycle Has Been Reached
12. Calculating the Total Distance
13. Displaying the Distance and Number of Ants
14. Presenting the Best Path
15. Ending the Process (Done)

4. Results and Discussion

This project aims to use the Ant Colony Optimization (AntCO) algorithm to find the quickest routes to North Aceh's natural and gastronomic tourism destinations. The developed system makes use of geographic data and distances between tourist spots, including both culinary tourism (Mie Bing Apa Noh Lancok and Martabak Durian Samudera Pasee) and nature tourism (Ujong Blang Beach, Blang Kolam Waterfall, and Mount Salak). Field research and associated sources gathered information on routes and distances between places.

4.1. Descriptive Data

The data used in this study includes information about 23 tourist destinations in North Aceh, consisting of 16 natural and 11 culinary tourist locations. Each area is equipped with data on the name of the tourist attraction, address, and geographical coordinates in the form of latitude and longitude. The registered natural tourist destinations include Ujong Blang Beach, Blang Kolam Waterfall, and Mount Salak, which are spread across various sub-districts such as Banda Sakti, Kuta Makmur, and Nisam Antara. Meanwhile, culinary tourist locations include Mie Bing Apa Noh Lancok, Martabak Durian Samudera Pasee, and Kari Kambing Simpang Ektren, spread across various North Aceh Regency areas.

Table 1. Location Data and Tourist Spots

T	Name of Tour	Tourist Address	*Latitude*	*Longitude*
T1	Ujong Blang Beach	West Hagu. Sea, District. Banda Sakti, Lhokseumawe City, Aceh	5.203290 91805482	97.136349 00756172
T2	Blang Kolam Waterfall	Sido Muliyo, District. Kuta Makmur, North Aceh Regency	5.058489 078381101	97.012224 12290393
T3	Seven Angels Waterfall	Pulo Meuria, District. Geureudong Pase, North Aceh Regency	4.985878 71861532	97.04448 855173925
T4	Lhok Buloh River baths	Saweuk, Kuta Makmur District, North Aceh Regency	5.119122 845980779	97.036547 32290418
T5	Mount Salak	Forest, Nisam Antara District, North Aceh Regency, Aceh	9584619 83448543	96.937842 94724092
T6	Termite Waterfall	Sido Mulyo, Panton Rayeuk I, District. Kuta Makmur, North Aceh Regency	5.094050 91059578	97.011806 97872547
T7	Bantayan Beach	Bantayan, Jl, Ulee Rubek Tim., North Aceh Regency	5.223100 7219385726	97.427155 33639755
T8	Lancok Beach	Lancok, Syamtalira Bayu District, North Aceh Regency, Aceh	5.141579 922228592	97.185529 63824716
T9	Krueng Sawang baths	Babah Krueng, District. Sawang, North Aceh Regency, Aceh	5.150939 784898044	96.907438 76318636

T	Name of Tour	Tourist Address	*Latitude*	*Longitude*
T10	Sawang Geudong Beach	Sawang, Samudera District, North Aceh Regency, Aceh	5.154831 287323158	97.244187 2210543
T11	Bangka Jaya Beach	Keude Krueng Geukueh, District. Dewantara, North Aceh Regency, Aceh	5.252206 400228825	97.024095 29406914
T12	Purple Beach	Lhok Puuk, District. Seunuddon, North Aceh Regency, Aceh	5.201441 865221206	97.369932 86523314
T13	Alue Meuh Sawang Waterfall	Alue Meuh, District. Sawang, North Aceh Regency	5.061454 108977039	96.849887 09776825
T14	Kreung Saweuk	Saweuk, Kuta Makmur District, North Aceh Regency	5.131689 539862158	97.044713 65729013
T15	Lhok Seulayang	Lhok Jok, District. Kuta Makmur, North Aceh Regency	5.089312 514460729	97.077002 82749391
T16	The Tomb of Sultan Malikussaleh	Beuringen, Samudera District, North Aceh Regency, Aceh	5.132484 6679782485	97.203970 92051167
T17	Mie Bing Apa Noh Lancok	Jl. Lancok - Meuraksa, Jambo Timu, Kec. Blang Mangat, Lhokseumawe City	5.141964 9080772825	97.176744 4149616
T18	Durian Martabak Samudera Pasee	Uteun Geulinggang, Dewantara District, North Aceh Regency	5.256731 106447393	97.085157 07987901
T19	Waroeng Bamboe	North Aceh Regency, Tambon Baroh, Jl. Medan-Banda Aceh, and Kec. Dewantara	5.236225 2799472335	97.027440 7013075
T20	Simpang Ektren Goat Curry	Simpang Ektren, Pusong, Kec. Samudera, North Aceh Regency	5.117003 413896121	97.225963 58612576
T21	Rujak Nibong	Sumbok Rayek, District. Nibong, North Aceh Regency	5.070048 037230277	97.254481 8289966
T22	Sate yah roh Geurugok	Paloh Igeuh, District. Dewantara, North Aceh Regency	5.226198 783793209	96.991172 44108011
T23	Durian Martabak Samudra Pasee Gedong	Jl. Medan - Banda Aceh No.1, Keude Geudong, Kec. Samudera, North Aceh Regency	5.121163 176250978	97.23720 869118121
T24	Pujasera Pim	Jl. Lkr. Comp. PIM, Tambon Tunong, District. Dewantara, North Aceh Regency	5.221768 379680458	97.031889 3787261
T25	Bakso Asean Krueng Geukueh	Jl. Railway, Bangka Jaya, District. Dewantara, North Aceh Regency	5.244422 783560418	97.018734 72983934
T26	Assembly Point	Hagu Sel., Banda Sakti District, Lhokseumawe City, Aceh	5.192486 3145405515	97.1483225 6931423
T27	Rumoh Tuha Roastery	Simpang Empat, Banda Sakti District, Lhokseumawe City.	5.182188 122353645	97.144224 17856447

The geographic coordinates of each tourist destination, including latitude and longitude, are key information for determining the distance and travel time between locations. For example, Ujong Blang Beach has coordinates of 5.203290° N, 97.136349° E, while Blang Kolam Waterfall is located at coordinates of 5.058489° N, 97.012224° E. This data allows for a more in-depth analysis of the distance between tourist destinations, which will be used to calculate the shortest route using the Ant Colony Optimization (AntCO) algorithm. Presenting data in the form of coordinates is very important to ensure the accuracy of route calculations and provide a clearer picture for tourists who want to plan a trip to tourist destinations in North Aceh.

4.2. Example of Ant Colony Optimization (ACO) Calculated by Hand

Before discussing the full implementation of the ACO algorithm on the developed system, a manual calculation is done using a simple example of a selected tourist location. This manual calculation serves as a summary of the processes in the algorithm that solve the shortest route problem. The process begins by mapping the available tourist locations as points to be visited and then calculating the distance between the locations. Each step in the ACO algorithm, such as determining probability, calculating pheromones, and selecting the best route, is applied manually to obtain the optimal path that connects all the tourist locations.

This manual calculation is critical for understanding and verifying how the ACO algorithm can be adapted to concrete problems like this. In addition, manual calculations allow researchers to identify potential constraints or logical errors that may occur during coding during the implementation of the algorithm. The following is a complete explanation of Ant Colony Optimization (ACO) implementation to determine the shortest route. This explanation includes steps from start to finish, complete with calculations at each stage.

1. Determining the Starting Point and Locations to be Visited

Suppose we have the Unimal Bukit Indah Campus (T1) as the starting point. Then, the user selects five tourist locations to be visited (for example, T2: Blang Kolam Waterfall, T3: Tujuh Bidadari Waterfall, T4: Lhok Buloh River Baths, and T5: Mount Salak.

Starting Point:

a. T1 (Unimal Bukit Indah Campus)

Locations you want to visit:

a. T2: Blang Kolam Waterfall

b. T3: Tujuh Bidadari Waterfall

c. T4: Lhok Buloh River Baths

d. T5: Mount Salak

2. Using the Haversine Formula to Determine Distances Between Places

To calculate the distance between two points (based on latitude and longitude), we use the Haversine formula :

$$d = 2R \times arcsin\left(\sqrt{sin^2\left(\frac{\Delta\emptyset}{2}\right) + cos(\emptyset_1)\cdot cos(\emptyset_2)\cdot sin^2\left(\frac{\Delta\lambda}{2}\right)}\right)$$

Where:

R : is the radius of the earth, about 6371 km.

$\Delta\emptyset$: is the difference in latitude between two points (in radians).

$\Delta\lambda$: is the difference in longitude between two points (in radians).

∅_1 and ∅_2 : are the latitudes of point 1 and point 2 (in radians).

Example Calculation:

Suppose we calculate the distance between T1 (Bukit Indah Unimal Campus) and T2 (Blang Kolam Waterfall):

a) T1 (Bukit Indah Unimal Campus): Latitude = 5.203290, Longitude = 97.136349

b) T2 (Blang Kolam Waterfall): Latitude = 5.058489, Longitude = 97.012224

First step, convert latitude and longitude into radians:

$$\emptyset_1 = 5.203290 \times \frac{\pi}{180} = 0.090707$$

$$\lambda_1 = 97.136349 \times \frac{\pi}{180} = 1.695465$$

$$\emptyset_2 = 5.058489 \times \frac{\pi}{180} = 0.088305$$

$$\lambda_2 = 97.012224 \times \frac{\pi}{180} = 1.694581$$

Difference between Latitude and Longitude :

a)

$$\Delta\emptyset = \emptyset_2 - \emptyset_1 = 0.088305 - 0.090707 = -0.002402$$

b)

$$\Delta\lambda = \lambda_2 - \lambda_1 = 1.694581 - 1.695465 = -0.000884$$

Calculating Distance:

$$a = sin^2\left(\frac{\Delta\emptyset}{2}\right) + cos(\emptyset_1)\cdot cos(\emptyset_2)\cdot sin^2\left(\frac{\Delta\lambda}{2}\right)$$

$$a = sin^2(-0.001201) + cos(0.090707)\cdot cos(0.088305)\cdot sin^2(-0.000442)$$

$$a = 1.4416 \times 10^{-6} + 0.995939 \times 0.995588 \times 1.7527 \times 10^{-7}$$

$a = 1.6160 \times 10^{-6}$

$c = 2 \times arcsin\left(\sqrt{1.6160 \times 10^{-6}}\right) = 0.002544\ rad$

$d = 2 \times 6371 \times 0.002544 = 32.35$ km

So, the distance between the Unimal Bukit Indah Campus (T1) and Blang Kolam Waterfall (T2) is 32.35 km.

3. Distance Matrix for All Locations

After calculating the distance between locations, we will build a distance matrix that shows the distance between all tourist points.

Table 2. Distance Matrix

	T1	T2	T3	T4	T5
T1	0	32.35 km	45.25 km	50.12 km	65.00 km
T2	32.35 km	0	25.00 km	30.10 km	40.00 km
T3	45.25 km	25.00 km	0	35.00 km	55.00 km
T4	50.12 km	30.10 km	35.00 km	0	40.00 km
T5	65.00 km	40.00 km	55.00 km	40.00 km	0

4. Running Ant Colony Optimization (ACO) with Concrete Calculation

Let's take an example with 5 locations to visit and Bukit Indah Unimal Campus (T1) as the starting point. We will randomly select other locations from your dataset (for example, T2: Blang Kolam Waterfall, T3: Tujuh Bidadari Waterfall, T4: Lhok Buloh River Bath, T5: Mount Salak). The Distance Matrix (already calculated using the Haversine formula).

Initially, we initialize the pheromone with a small value (for example, 0.1) for all paths, and visibility is calculated as the inverse of the distance between points (1/distance). Here is an example of visibility and pheromone:

Table 3. Pheromone Initialization and Visibility

	T1	T2	T3	T4	T5
T1	0.1	0.0309	0.0221	0.0199	0.0154
T2	0.0309	0.1	0.04	0.0332	0.025
T3	0.0221	0.04	0.1	0.0286	0.0182
T4	0.0199	0.0332	0.0286	0.1	0.025
T5	0.0154	0.025	0.0182	0.025	0.1

Alpha (α) and Beta (β) control the influence of pheromones and visibility on the probability of path selection. For example, let's choose α = 1 and β = 2. The ants will choose a path based on the probability calculated using the formula :

....(8)

$$P_{ij} = \frac{(T_{ij})^{\alpha} \cdot (\eta_{ij})^{\beta}}{\sum_{k \in N_i} (T_{ik})^{\alpha} \cdot (\eta_{ik})^{\beta}}$$

Let us determine the probability of choosing the first ant path, for example, from T1 → T2:

$$P_{T1 \to T2} = \frac{(0.1)^1 \cdot (0.0309)^2}{(0.1)^1 \cdot (0.0309)^2 + (0.1)^1 \cdot (0.0221)^2 + (0.1)^1 \cdot (0.0199)^2 + (0.1)^1 \cdot (0.0154)^2}$$

$$P_{T1 \to T2} = \frac{(0.1) \cdot (0.000955)}{(0.1) \cdot (0.000955) + (0.1) \cdot (0.000488) + (0.1) \cdot (0.000396) + (0.1) \cdot (0.000237)}$$

$$P_{T1 \to T2} = \frac{0.0000955}{0.0000955 + 0.0000488 + 0.0000396 + 0.0000237} = \frac{0.0000955}{0.0002076} \approx 0.46$$

So, the probability of the ant choosing the path T1 → T2 is 46%. The likelihood of choosing the other path will be calculated similarly, and the ant will choose the path based on this probability.

5. Pheromone Update

After all ants have completed their journey, we will update the pheromone-based on the path found. For example, after one iteration, if the path T1 → T2 → T3 → T4 → T5 is found with a total distance of 145 km, we will add a pheromone to this path. The pheromone update is done with the formula :

....(9)

$$T_{ij} \leftarrow (1 - \rho) \cdot T_{ij} + \Delta T_{ij}$$

$$\Delta T_{ij} = \frac{Q}{d}$$

For example, for path T1 → T2 :

$$\Delta T_{T1\rightarrow T2} = \frac{Q}{145} = \frac{1}{145} = 0.0069$$

If ρ = 0.5, then the pheromone update becomes :

$$\Delta T_{T1\rightarrow T2} = (1 - 0.5) \cdot 0.1 + 0.0069 = 0.05 + 0.0069 = 0.0569$$

The pheromone on the T1 → T2 path will be updated to 0.0569. Similar updates are made for other paths found by the ants. After several iterations, ACO will produce the best path connecting the Bukit Indah Unimal Campus (T1) with five other locations with the shortest total distance. Finally, we will get the optimal location sequence and distance, which is the total distance the ants travel. For example:

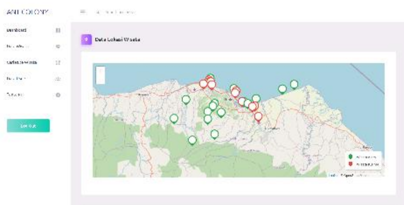
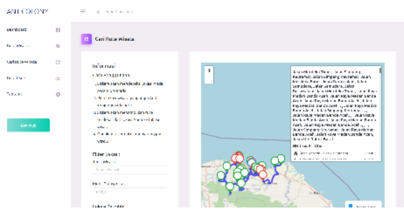
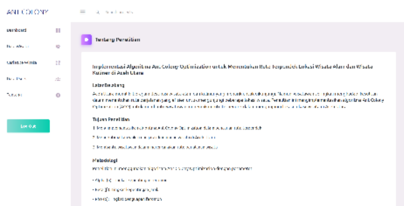
a. Unimal Bukit Indah Campus → Blang Kolam Waterfall → Tujuh Bidadari Waterfall → Lhok Buloh River Baths → Mount Salak

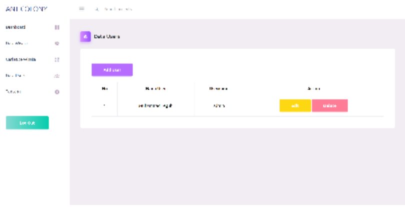
b. Total distance: 145 km

4.3. White Box Testing

At this stage, the White Box Testing method ensures that each component in the system runs according to the previously determined design. This testing focuses on testing the program's internal structure and logic flow, including checking conditions, loops, and code paths to detect possible errors or anomalies not detected by other testing methods. This approach thoroughly tests each function and subroutine to ensure no mistakes can affect the system's overall performance. Thus, White Box Testing helps ensure the developed system operates efficiently and according to the expected specifications.

Table 4. White Box Testing

No	Action	Testing	Output	Results
1	Open the system	Displaying the login page	Valid	
2	Press the travel data menu	Displaying the travel data page	Valid	
3	Press the search menu for tourist routes	Displaying the tourist route search page	Valid	
4	Press the about menu	Showing the about page	Valid	

No	Action	Testing	Output	Results
5	Press the user data menu	Displaying the user data page	Valid	

5. Conclusion

This study aims to design and implement a system for determining the shortest route between natural and culinary tourist locations in North Aceh using the Ant Colony Optimization (AntCO) algorithm. The developed system can optimize tourist trips by considering the distance and travel time between tourist destinations. The system implementation results show that the AntCO algorithm effectively calculates the shortest route, which can help tourists plan their trips more efficiently and reduce the time and distance needed to visit several tourist locations in one trip.

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