Design and Analysis of the Ant Colony Algorithm to Find the Shortest Route to Sibolga Disaster Locations

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Abstract

Determining the shortest route to the disaster location is one of the important aspects in supporting the speed of emergency response. The accuracy in selecting routes can expedite the evacuation process, aid distribution, and the mobilisation of personnel to the disaster site. The city of Sibolga, as an area with a diverse road network, requires a method capable of determining the optimal route effectively and efficiently. This research aims to design and analyse the Ant Colony Optimisation (ACO) algorithm in determining the shortest route to disaster locations in Sibolga. The research methods used include identifying location points and road networks, graph modelling in the form of nodes and weighted edges, designing the Ant Colony algorithm, and testing the route search results based on travel distance. The ACO algorithm works by mimicking the behaviour of ant colonies in finding the best path through pheromone mechanisms and iterative processes. The research results are expected to show that the Ant Colony algorithm is capable of generating the optimal shortest path from the starting point to the disaster location based on the used road network data. Additionally, the analysis of the algorithm's performance provides an overview of the effectiveness of this method in supporting route determination systems in emergency conditions. This research is expected to contribute to the development of decision support systems for disaster management, particularly in accelerating access to disaster locations in the city of Sibolga.

***Keywords**: A*nt Colony Algorithm, Shortest Path, Disaster Location, Route Optimisation, Sibolga

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Introduction

Events known as disasters have the potential to result in large losses in terms of human life, material resources, and the disruption of social and economic activity within the community. One of the key elements that determines the success of emergency management during a disaster is response time. The capacity of rescue teams, disaster officers, and the community to get to the catastrophe site via the quickest and most effective ways is an essential element of response. The likelihood of reducing casualties, accelerating evacuation, and facilitating prompt help distribution increases with the speed at which the catastrophe site is reached.

Sibolga's geographical features as a coastal urban area necessitate prompt and accurate catastrophe management. Determining the route to the catastrophe site is not an easy task due to the state of the road network, the density of towns, and the potential for access hurdles during emergencies. When disturbances, access restrictions, or changes in field conditions occur, a route that is typically thought to be close might not always be the ideal one. Thus, to make the process of determining the shortest path more efficient, a methodical approach is required. This research was conducted using qualitative methods. From the observations, it is evident that in public places/locations, there are three languages used by the community for interaction, namely the National language (Indonesian), Coastal language, and Batak language. However, there is a dominant usage based on the region. For example, in the Sibolga Kota District, the dominant language is Indonesian, except for the Pasar Behind District, where the Coastal language is more dominant. In the Sibolga Utara District, the Batak language is dominant, while in the Sibolga Sambas District and the Sibolga Selatan District, the Coastal language is more dominant [1].

Up to now, estimations, officer expertise, or manual map observations have frequently been used to determine the route to catastrophe regions. That strategy has drawbacks, particularly when dealing with numerous traffic intersections, multiple route options, and the requirement for prompt decision-making. Under such circumstances, the application of optimization algorithms becomes crucial because they can yield more objective, quantifiable, and effective answers than depending only on human intuition.

One of the optimisation methods widely used in solving the shortest path problem is the Ant Colony Optimisation (ACO) Algorithm. This algorithm is inspired by the behaviour of ant colonies in finding the fastest route to a food source through pheromone trails [2]. In the context of computing, this principle can be applied to find the optimal route on a network, including road networks leading to disaster locations. The advantage of the Ant Colony algorithm lies in its ability to explore many possible paths, adapt to search conditions, and generate efficient route solutions through an iterative process [3]

The application of the Ant Colony algorithm in determining the shortest route to disaster locations in Sibolga is relevant because the problems faced are directly related to the route network, location nodes, and the need to optimise travel time. By modelling the road segments as a graph consisting of nodes and weighted edges, the system can be designed to analyse the best route from the starting point to the disaster site. Analysis of the algorithm's performance is also important to determine the level of effectiveness, accuracy, and efficiency of this method in generating the fastest route recommendations.

One type of pertemuan is a combination of sumber daya (ruangan, orang, and so on), of which some are determined by a problem and some may be considered a component of pemecahan [4]. According to [5] and [6], Algoritma Ant is one of the most effective techniques in the field of penjadwalan, particularly when applied to TSP (travelling salesman problem). The first computer-based problem-solving tool was developed in the early 1960s with the goal of reducing administrative work, [7]. This research not only focuses on algorithm design but also on analysing the results of its application in the real context of the Sibolga region. Thus, this research is expected to contribute to the development of decision support systems in the field of disaster mitigation and emergency response. The research results can serve as a consideration for related agencies, such as the BPBD, the transportation department, and other parties involved in disaster management, to improve the quality of response and mobilisation of assistance in the field.

Based on the description, research on the Design and Analysis of the Ant Colony Algorithm for Determining the Shortest Path to Disaster Locations in Sibolga is important to conduct. This research is expected to produce a route search model that is effective, efficient, and adaptive in supporting decision-making during disasters, so that emergency response processes can be carried out more quickly and accurately.

Literature Review

2.1 Definition of Optimisation

Optimisation is one of the disciplines in Mathematics that focuses on systematically obtaining minimum or maximum values from a function, probability, or other value searches in various cases. Optimisation is very useful in almost all fields to conduct efforts effectively and efficiently to achieve the desired outcome. Of course, this will be very much in line with the economic principle that aims to consistently reduce expenses to produce maximum output. (Nasution, 2015),

The optimal value is the value obtained through a process and is considered the best solution among all existing solutions. The optimal value can be found in two ways: (Waliprana, 2003).

1. The first method is the conventional way, which involves trying all possible options and recording the obtained values. This method is less effective because it requires a lot of time for checking, making it suboptimal.
2. The second method is to use a formula or media such as images or graphs so that the optimal value can be estimated quickly and accurately.

Examples of problems that require optimisation include:

1. Determining the shortest path from one place to another.
2. Determining the minimum number of workers needed to carry out a production process with minimal labour costs and maximal production output.
3. Organising public transportation routes to reach all locations.
4. Organising the routing of telephone cable networks so that the installation costs are not too high and their usage is not wasteful.

2.2 Understanding Disaster

The definition of Disaster according to Law Number 24 of 2007 on Disaster Management explains that a Disaster is an event or series of events that threaten and disrupt the lives of the community caused by natural factors and/or non-natural factors as well as human factors, resulting in loss of human life, environmental damage, property loss, and psychological impact. According to the Asian Disaster Reduction Center [8], a disaster is a disturbance to society that causes widespread losses and is felt by the community, various materials, and the environment (natural) where the impact exceeds the ability of humans to cope with it using existing resources.

According to [9]. Disasters can also be defined as events that damage and disrupt the functions of a community, rendering it abnormal, causing ecological disturbances or emergencies of such severity that they result in death, injury, illness, property damage that cannot be effectively managed using procedures, and require external assistance [10].

2.3 Analysis

Analysis is observing something in depth, distinguishing, and selecting its constituent parts for further investigation. Analytical research is the study of something to understand what is actually happening. Nana Sudjana in [11] stated that selecting the integrity of something into components or parts to create a clear arrangement or hierarchy is known as analysis. In general, analysis is defined as a process that encompasses various actions, such as breaking down, distinguishing, selecting, classifying, and grouping according to certain standards, as well as discovering relationships and interpreting their meanings [12]. Analysis not only involves searching for patterns but also developing a way of thinking by conducting in-depth tests to identify components, interactions between components, and their relationship to the whole.

Sugiyono (2018) analysis is the process of searching for patterns. Additionally, analysis is also a method of thinking that involves an in-depth examination of an object to identify its components, the relationships between components, and their connection to the whole. It can be concluded that analysis is the investigation of an event to understand the actual situation. The essence of Analysis is the ability to dissect and solve an object in depth by breaking down its components or assembling a part for further study [12].

2.4 Basic Concept of Ant Colony Optimisation (ACO)

The behaviour of ants that is very interesting is when they search for food, where they can find the shortest path between the food source and their nest. When walking from the food source to the nest and vice versa, ants lay down a substance called pheromone. Pheromone can be defined as "hormone carriers," which are hormones produced by the endocrine glands that can provide chemical signals. When these hormones are secreted as signals by one ant, other ants can recognise them.

When foraging for food, initially, ants will wander randomly around the area near their nest. Once they detect food, the ants will analyse the quality and quantity of the food and bring some parts back to their nest. On their way, they leave a trail of a chemical substance called pheromone. This pheromone will guide other ants to the food source. The amount of pheromone left by the ants depends on the amount of food found. The more food that is obtained, the more pheromones are left behind. Thus, the more pheromone trails accumulate on that path. [4].

2.5 Algoritma Ant Colony Optimization

Experts have proposed various different Ant Colony Optimisation algorithms. Here are the variants of Ant Colony Optimisation chronologically from 1991 to 2001. The most successful algorithms among these 9 ACO variants are Ant System (AS), MAX-MIN AS, and Ant Colony System (ACS). [13].

2.5.1 Ant System

This algorithm was introduced by Dorigo, Maniezzo, and Colorni in 1991. The artificial ants in this algorithm are different from real ants. The ants in this algorithm have memory, are not completely blind, and operate in an environment where time is discrete. TSP can be stated as a problem of finding the minimum distance of a closed tour through a number of n cities where each city is visited only once. TSP is represented by a complete graph, meaning all its nodes are interconnected. So, if there are n nodes, the graph has (n!/((n-2)! 2!)) edges, according to the combination formula, and also has (n-1)!/2 possible tours that each ant can take. The graph is also symmetric, meaning the distance from city r to city s is the same as the distance from city s to city r (δ(r,s) = δ(s,r)).

The main role of pheromone evaporation is to prevent stagnation, which is a situation where all ants end up taking the same tour. This process is repeated until the number of tours performed reaches a maximum. The transition rule used by the Ant System is called random proportional, where city r chooses to move to city s by determining visibility with the formula:

$$\eta = 1/\delta \quad (1)$$

Choosing the next city using the status transition rule with the formula:

$$P_k(r,s) = \left\{ \frac{[\tau rs] . [\eta rs]}{\sum [\tau ru \; u \epsilon Jr \; k \; 0 \;\;] . [\eta ru] \beta} \right.^{\beta} \quad (2)$$

Where r is the pheromone, η = 1/δ is visibility (the inverse of the distance δ(r,s) = [(xr – xs)^2 + (yr – ys)^2], Jk (r) is the set of cities to be visited by ant k currently at city r (to make the solution feasible), and β is a parameter that controls the relative weight of pheromone against distance (β>0). In equation 2.2, we multiply the pheromone on the segment (r,s) by the corresponding visibility value, $\eta = (r,s)$.

In this way, we prefer shorter paths that have a greater amount of pheromone. In the ant system, the global pheromone update rule is implemented as follows, after the ants make their tour, the pheromone present on all segments is updated according to the equation

$$\tau(r,s) \leftarrow (1-\alpha).\tau(r,s) + \sum m\ i{=}1\ \Delta\tau k\ r,s) \quad (3)$$

Where $0<\alpha<1$ is a pheromone decay parameter, L is the length of the tour performed by ant k, and m is the number of ants. Ant System is useful in finding optimal or good solutions for TSP with a small number of cities, but the time required to obtain these results makes it impractical for larger problems. To improve the performance of AS, the Ant Colony System was developed (Dorigo & Gambardella, 1997).

2.5.2 Ant Colony System

Ant Colony System (ACS) is an improvement over the original AS. ACS was introduced by Gambardella and Dorigo. In ACS, a pheromone update procedure is performed at the end of constructing a complete solution or tour. The local pheromone update is performed by all ants after each step of the solution construction. (Euis Nurlaelasari 2018) Informally, ACS works as follows: a number of ants are placed on a number of n cities based on several initialisation rules (for example, randomly). Each ant creates a tour (i.e., a possible TSP solution) by repeatedly applying a state transition rule.

While building its tour, an ant also modifies the amount of pheromone on the segments it visits by applying the local pheromone update rule. After all the ants finish their tour, the amount of pheromone on the segments is modified again (by applying the global pheromone update rule). As in the ant system, when creating a tour, ants are 'guided' by heuristic information (they prefer shorter segments) and by pheromone information: A segment with a high amount of pheromone is a highly desirable choice.

The transition status rule applicable in ACS is as follows: an ant placed in city r chooses to move to city s by applying the rule, where q is a random fraction between [0..1], q0 is a parameter for comparing random numbers ($0 \leq q0 \leq 1$), and S is a random variable selected based on a probability distribution. The status transition rule derived from equations 2.4 and 2.2 is called the pseudo-random-proportional rule. This status transition rule directs ants to transition to cities connected by short paths and with a large amount of pheromone. Every time an ant at city r chooses city s as the next destination, it generates a random number between [0..1] where ($0 \leq q0 \leq 1$). If $q \leq q0$, then the ant will utilise the existing knowledge regarding the problem.

While touring to find a solution to the TSP, ants visit the edges and change the pheromone levels on those edges by applying the local pheromone update rule shown by the following equation: (Dorigo & Gambardella, 1997)

$$\tau\ (r,s) = (1-\rho) * \tau\ (r,s) + \rho * \Delta\tau\ (r,s) \quad (4)$$

$$\tau(r,s) \leftarrow (1-\alpha).\tau\ (r,s) + \alpha.\Delta\tau(r,s). \quad (5)$$

Research Methodology

This research uses a quantitative research method with a computational experiment approach. The research focuses on the design, implementation, and performance analysis of the Ant Colony Optimisation (ACO) algorithm in determining the shortest path to disaster locations in the Sibolga area. This approach is used because the research aims to produce an algorithmic model that can be tested based on road network data and certain parameters.

The data collection techniques used in this research include: Observation conducted to identify important locations, disaster points, road nodes, and paths that can be used as routes, Literature study conducted by reviewing books, journals, and previous research related to shortest path optimisation, graph theory, and the Ant Colony algorithm, and Documentation conducted by collecting map data, road segment lists, and other supporting information relevant to the research.

The variables used in this study are:

1. Input variables, namely the starting point, destination point, distance between nodes, number of ants, initial pheromone value, alpha and beta parameters, and evaporation rate.
2. Process variables, namely the iteration process of the Ant Colony algorithm in exploring all possible routes.
3. Output variables, namely the shortest path and the total distance travelled to the disaster location.

In this study, the road network is modelled in the form of a graph, namely:

1. nodes represent intersections, starting points, or disaster locations;
2. edges represent road segments connecting the nodes;
3. weights on each edge indicate the distance between nodes.

This graph model serves as the basis for applying the Ant Colony algorithm to find the shortest path.

Results

Ant Colony Algorithm is an algorithm used to determine the shortest path from one area (point) to another while considering time efficiency. For this reason, in this research, a Shortest Path Determination using the Ant Colony Algorithm was designed.

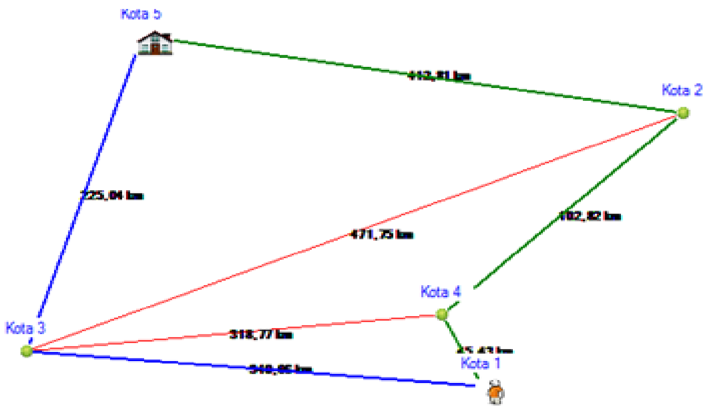

Figure 1. Ant Colony Search Step 1

The calculation of the shortest path determination results from figure 1 is as follows:
Siklus 1
Semut 1 = 1->4->3->5 = 45,43 + 318,77 + 225,04 = 589,24 = 589,24
Semut 2 = 1->3->5 = 349,96 + 225,04 = 575
Semut 3 = 1->3->4->2->5 = 349,96 + 318,77 + 102,82 + 412,81 = 1184,36
Semut 5 = 1->3->4->2->5 = 349,96 + 318,77 + 102,82 + 412,81 = 1184,36
Siklus2
Semut 1 = 1->4->3->2->5 = 45,43 + 318,77 + 471,75 = 1248,76
Semut 3 = 1->3->5 = 349,96 + 225,04 = 575
Semut 4 = 1->3->2->5 = 349,96 + 471,75 + 412,81 = 1234,52
Semut 5 = 1->4->3->2->5 = 45,43 + 318,77 + 471,75 +412,81 = 12348, 76
From the completion of the 2 cycles of the shortest path search, the shortest path obtained is 1->3->5 = 575

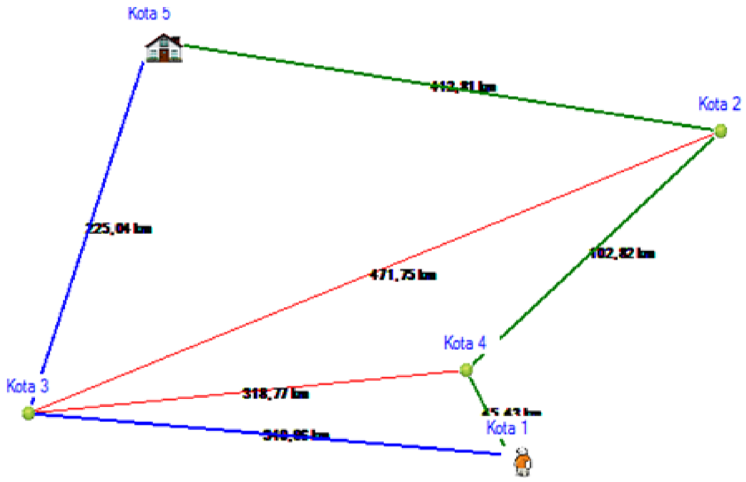

Figure 2. Ant Colony Search Step 2

The calculation of the shortest path determination from figure 2 is as follows:
The calculation of the weight/distance above is obtained from:

1->4->3->5 = 45,43 + 318,77 + 225,04 = 589,24
1->3->4->2->5 = 349,96 + 318,77 + 102,82 + 412.81 = 1184,36
1->4->2->5 = 45,43 + 102,82 + 412,81 = 561,06
1->3->5 = 349,96 + 225,04 = 575

Create a city map by clicking on the map, or the map can be created automatically by pressing the "Generate Random City" button, which will display a dialogue to enter the number of cities you want to create. In images 1 and 2, the city map is depicted using the "Draw Random City" button. The red lines connecting the cities indicate that those cities are connected to each other. The blue and green lines represent the shortest paths from the search results. In the search parameter section, the default search value for a city can be seen. This value can be changed according to the user's preference. In figures 1 and 2, the search results for a city consisting of 5 interconnected cities on the city map are shown. The origin city of the search is city 1 and the destination city is city 5. The Ant Colony search results show the shortest path with the route: City1->City3->City5

Conclusion

Based on the design and analysis conducted, the Ant Colony Optimisation (ACO) algorithm can be used as a method to determine the shortest route to disaster locations in the city of Sibolga. This algorithm works by utilising the pheromone trail mechanism and iterative search processes, enabling it to find the optimal route from the starting point to the destination. The application of the ACO algorithm on road networks modelled in the form of graphs shows that this method is effective in solving the shortest path search problem. By considering the weight of the distance between nodes, the algorithm is able to select several alternative paths and generate more efficient routes to support the mobilisation of personnel, evacuation of victims, and distribution of aid during a disaster.

The analysis results also show that the use of the Ant Colony algorithm provides a systematic and measurable approach compared to manual path determination. Through the processes of iteration, pheromone updating, and path evaluation, this algorithm can assist in making decisions more quickly and accurately in emergency situations. Thus, this research proves that the design and analysis of the Ant Colony algorithm have good potential to be applied in the disaster route determination decision support system in Sibolga. This research is expected to serve as a foundation for the development of a more adaptive, efficient, and beneficial disaster navigation system for relevant agencies in improving disaster response speed.

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