ACTA TECHNICA JAURINENSIS
Vol. 18, No. 1, pp. 9-22, 2025
10.14513/actatechjaur.00765

Research Article

Optimization Location Routing Problem (LRP) of Humanitarian Aid Distribution Using HGASA Method in Sigi District

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Submitted: 10/12/2024 Revised: 30/01/2025 Accepted: 31/01/2025 Published online: 26/02/2025

Abstract: Disasters are events that disturb and threaten people's lives caused by nature or/and non-natural factors as well as human factors that cause casualties and economic losses. The polemic of uneven assistance and delays in the event of a natural disaster is the most common thing that occurs during a natural disaster. Location Routing Problem is a continuation of the classical routing problem that combines strategic and operational decisions with the facility location problem and the vehicle routing problem. This study aims to determine the location of the distribution centre construction and the optimal route using the Hybrid Genetic Algorithm and Simulated Annealing methods with the objective function of minimizing total costs and minimizing maximum service time for the distribution of humanitarian aid natural disaster 2018 in Sigi Regency. Optimization is designed into two scenarios, namely the construction of two distribution centres and three distribution centres. The result show that construction of two distribution centres can be designed at locations D3 and D5 with a total cost of IDR405 609 000 and a maximum travel time of 25.921 hours, while the construction of three distribution centres can be done at locations DC1, DC4 and DC 5 or with a total cost of IDR605,778,000 and a maximum service time of 19.634 hours.

Keywords: Disaster, Genetic Algorithm, Simulated Annealing, Optimization, Location Routing Problem.

I. INTRODUCTION

Disaster is an event that disrupts and threatens people's lives caused by nature or/and non-natural factors and human factors that cause loss of life and economic losses. Natural disasters are serious things that threaten the lives and security of people's property around the world caused by natural factors such as earthquakes, landslides, tsunamis, floods and others [1]. Over the past ten years, disaster data from EM-DAT [2] states that the number of natural disasters that occurred during the last ten years from 2003-2023 has increased. The types of natural disasters that occurred include drought, earthquakes, extreme weather, floods, landslides, storms, volcanic activity and fires. As a result of the disaster, the number of individuals affected by the disaster, in 2023, was 93.1 million, below the 2003-2022 annual average of 175.5 million. Economic losses, the reported figure of US$ 202.7 billion, were slightly higher than the EM-DAT 2003-2022 annual average of US$ 196.3 billion. A comparison of the number of natural disasters that occurred during 2023 and those that occurred during 2003-2022 based on their type. The number of occurrences of disasters is shown in the following **Fig. 1**.

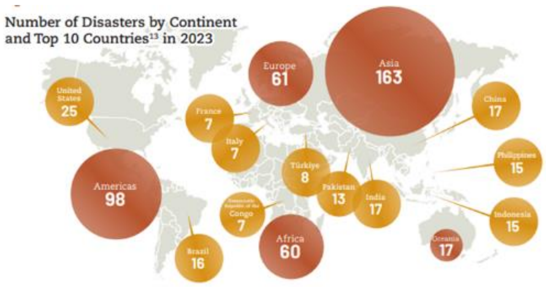

***Figure 1**. Number Occurrence of Disaster 2023 [2]*

From **Fig. 1** shows that in Asia, Indonesia is one of the countries with a moderate frequency of natural disasters, which occurred 15 times during 2023 [2]. This shows that Indonesia is one of the countries prone to natural disasters. Central Sulawesi is one of the provinces in Sulawesi that has a relatively high Indonesian Disaster Risk Index value of 146.07[3]. Sigi Regency is one of the regencies in Central Sulawesi which consists of 15 sub-districts. Most of its areas have a relatively high potential for disasters. The geographical conditions of Sigi Regency, which consists of the Sigi Regency area, is one of the regencies whose areas felt the direct impact of the 2018 natural disaster. According to official data from the Sigi Regency Government, 289 people died and 93,187 people had to evacuate because their homes and residential areas were damaged. Many houses were severely, moderately, or lightly damaged. In addition, various economic facilities such as markets, shops, and other accommodations, as well as public and social facilities, government offices, transportation infrastructure, communications, clean water, and other public services were also disrupted [4]. Seeing the condition of the Republic of Indonesia regarding natural disasters, the government has passed Law No. 24 [1] concerning Disaster Management. This law was issued as a form of government accountability for all Indonesian people. This law also serves as a legal basis for disaster management in Indonesia, which is known as a disaster-prone country. Logistics is one of the important elements in disaster management operations because it affects human survival or life. Logistics assistance that is right on target, at the right time, and benefits many people is the goal of humanitarian aid logistics assistance [5].

Therefore, disaster relief distribution is one of the most important components in the disaster emergency response process. All aid sent from various parties needs to be distributed quickly, accurately and evenly to victims of natural disasters. To save more lives and reduce losses caused by disasters, many researchers have conducted intensive studies on the distribution of emergency supplies [6].

The polemic of uneven assistance and delays in the event of a natural disaster is the most common thing that occurs during a natural disaster. As at the time of the 2018 earthquake, tsunami and liquefaction in Central Sulawesi, showing that until the fifth day after the earthquake, there were still many residents who did not receive logistical assistance such as food and drinks. Limited supply of food and beverages which then causes the picking of goods at stores such as minimarkets [7]. In Sigi Regency, the delay in natural disaster relief was due to the number of refugees reaching thousands of people, damage to many severely affected institutional facilities and public offices that could only operate after the fourth day after the incident and the existence of several locations that are still isolated such as Lindu, Kulawi, South Kulawi and Pipikoro after almost one month after the natural disaster[3]. Even at the beginning of the evacuation period, the community independently made simple tents from materials such as tarpaulins and from used banners/billboards.

Therefore, the distribution of disaster assistance is one of the most important components in the overall disaster emergency response process. All aid sent from various parties needs to be distributed quickly, appropriately and evenly for victims of natural disasters. So, to save more lives and reduce losses caused by disasters, many researchers have conducted intensive studies on the distribution of emergency supplies[6]. To effectively reduce the damage caused by the earthquake, aid must be sent to the point of demand in the shortest possible time after the earthquake has occurred. Experts generally believe that the problem of locating emergency facilities (LAP) and the problem of routing emergency vehicles (VRP) in the available transportation network are two of the most challenging issues in the emergency logistics system after an earthquake [8]. The Location-Routing Problem (LRP) is an area that is developing in transportation planning research. LRP covers all three levels of decision-making in supply chain management by planning facilities, vehicles, and supply network routes simultaneously [9]. The important role of distribution centres (DCs) and delivery routes is needed in distributing and transporting aid items [10].

Location Routing Problem is a continuation of the classic routing problem that combines strategic and operational decisions with facility location problems and vehicle routing problems[11]. LRP includes a combination of determining the location of the distribution centre with the selection of the vehicle routing problem. Research on the Location Routing Problem in the distribution of natural disaster relief has been conducted by several researchers ([12], [13], [14], [15], [16], [8], [17]). Meanwhile, research for solving the optimization problem of HGASA method has been used by several researchers [18], [19], [20], [21], [22], [23]).

Through the review of the above literature, it can be found that academics at home and abroad have conducted intensive research on LRP with different disaster backgrounds, and most scholars focus on natural disasters such as earthquakes and floods. Through this study, the researcher will conduct research for the optimization of LRP for the distribution of natural disaster assistance in Sigi Regency Hybrid Genetic Algorithm and Simulated Annealing (HGASA) which is also a method that has been widely used in optimization problem but is still very rarely used in optimization LRP for aid distribution Humanity.

II. LITERATURE REVIEW

1. Distribution of Logistics Assistance

The distribution of logistical assistance is a way of distributing and/or providing logistical assistance for disaster management from the place of origin to the destination area to the intended target. Logistical assistance for disaster victims during the state of emergency must be received by victims in need on time, in the right location, on target, in the right quantity, and with the right quality[3]. One of the main aspects that affects the success of logistics is the role of transportation in distributing humanitarian aid, both the type of mode of transportation and the supporting infrastructure has a great influence [5]. Humanitarian logistics involves a structured approach to overcoming natural disasters and technology. The main stages consist of four phases in the disaster management cycle, namely mitigation, preparation, emergency response, and recovery [14]. Then Hamzani et al. [12] explain the main challenge in the distribution of aid in large-scale disasters is the importance of making decisions quickly and minimizing delays.

2. Location Routing Problem

Location Routing Problem (LRP) is a combination of two NP-hard problems (Facility Location Problem (FLP) and Vehicle Routing Problem (VLP)). The Location Routing Problem (LRP) is a continuation of the classic routing problem that integrates strategic and operational decisions with facility location problems (FLP) and vehicle routing problems (VRP) [11]. Shen et al. [16] addressed the optimization problem in emergency logistics systems, integrates the perspective of environmental protection with a holistic optimization approach to emergency logistics systems. The fuzzy-based low-carbon open route-location problem model (FLCOLRP) in emergency logistics was developed with multi-objective objective functions, which include minimizing delivery time, total cost, and carbon emissions. The problem of location route has a crucial role in supply chain management. In this context, the decision taken involves determining the location of facilities, such as distribution centers, as well as the preparation of vehicle routes [24]. Also, Veysmoradi et al. [17] conducted LRP research for aid distribution with a focus on reducing the fixed cost of building distribution centers (DCs) and travel costs, minimizing the longest travel times, and improving route reliability for all vehicles involved in the process. Yan et al. [25] the research focuses on a two-stage cold chain logistics distribution network, including the optimization of transfer station locations and route planning in two stages. The two-stage location-route model was developed to minimize the total cost by considering the constraints of a tight time window. Various types of vehicles are considered to support distribution activities, and an integrated approach is used in the design of algorithms to guarantee the quality of the resulting solutions. Similarly, the research conducted by Heidari et al. [26] on the Two-Tier Open and Closed Routes (2E-COLRP) problem covers two layers, namely factories, depots, and customers, with a focus on reducing costs and CO2 emissions. This model is designed to identify the best routes, the optimal number of vehicles and facilities, and the determination of the most strategic facility locations.

3. Hybrid Genetic Algorithm and Annealing Simulated (HGASA)

Genetic Algorithm (GA) has effective global search capabilities to quickly find solutions in a solution space. However, it has not been able to conduct local searches that can cause early convergence [20]. GA takes inspiration from the principles of biological evolution and applies a population-based approach by using genetic operators such as crossovers and mutations. On the other hand, simulated annealing (SA) is influenced by the annealing process, and utilizes probability methods for solution space exploration. Although both are used in optimization tasks, they have different mechanisms and advantages. GA is more suitable for global exploration, while SA is effective in avoiding local optimal points through probability measures. Hybrid genetic algorithm and Simulated Annealing (HGASA) is a method that combines GA and SA, which has excellent global search capabilities that can be obtained using GA and the ability to find local optimal using SA [18]. GA is used to get the optimal or near-optimal solution among the solution space, and then SA is used to search for a better one based on the solution. Genetic algorithms have the advantages of strong global optimization capabilities, fast speed, strong versatility, and easy implementation. However, it has the disadvantage of poor local search capabilities, which lowers search efficiency, especially in the late period of optimization. Fortunately, simulated annealing algorithms have strong local search capabilities to make up for the shortcomings of genetic [23].

4. Stopping Criteria's

Determining stopping criteria is an important step in the design of genetic algorithms. This criterion will determine when the algorithm should be stopped, either after achieving the desired result or when it meets the predetermined limits. Some commonly used termination criteria in genetic algorithms include [27]: (i) Number of Generations: The algorithm will stop after a certain number of generations have been evaluated. This is a simple approach where the limit on the number of generations is predetermined. (ii) Fitness Level: The algorithm is stopped when one of the individuals in the population reaches a certain level of fitness. For example, when an expected match is reached, the algorithm may stop. (iii) Convergence: Cessation can be done when the population experiences convergence, i.e. when the average value of match or variation in the population becomes stable. If the population reaches convergence quickly, the algorithm may be stopped early. (iv) Execution Time: The algorithm is stopped after reaching a predetermined time limit, which is useful in situations with time constraints. (v) Rate of Change: If there is no significant change in the population match value over several generations, the algorithm can be stopped, indicating that there is no further progress. (vi) Combination Criteria: Multiple criteria can be combined, such as the number of generations along with a specific level of compatibility or time limit.

III. METHODOLOGY

The first step in this research is Designing a Mathematics Model for location routing problem, determine stopping criteria and parameters will using. Then conducting tests on the parameters used, optimize using HGASA for two scenarios namely two or three DC will be open with several simulations. From these result total cost and maximum travelling time will be compared using DIS and conclusion is obtained.

1. Sample

The sample used in this study is Sigi Regency which is one of the districts in Central Sulawesi Province in Indonesia which is classified as a high natural disaster-prone area. Sigi Regency is one of the areas affected by the 2018 natural disaster in Central Sulawesi province. The number of affected villages was 160, and a sample of 72 villages was taken which was classified as experiencing the severe impact of the 2018 natural disaster due to the large number of victims and severe economic damage. Map of the research can be seen in **Fig. 2**.

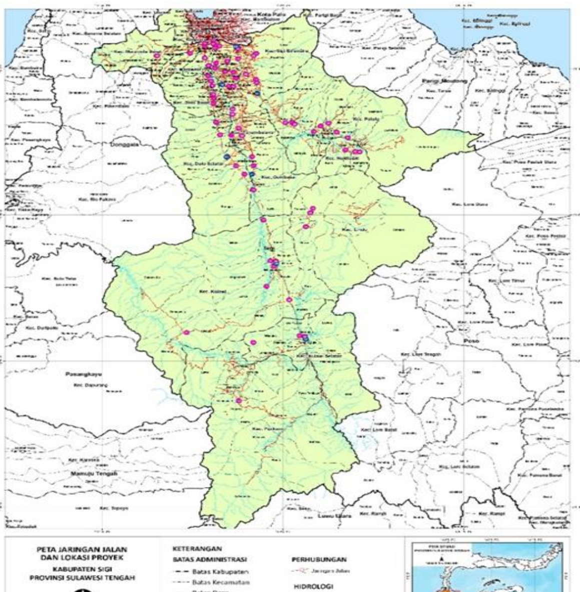

Figure 2. *Sigi Regency Research Map*

2. Mathematical Model

The mathematical model in this study is used to design the program in Mathlab. As for some of the assumptions used in this study: (i) the number of potential distribution centers (DCs) and affected areas or distribution points are known (ii) potential locations to establish distribution centers (DCs) have been identified (iii) the shape of the route between the distribution center (DC) and the distribution point can be represented as a graph (iv) The selection of distribution centers, land routes and air routes are interrelated influenced by the constraints and function of the destination and (v) air routes can only be served by air vehicles.

Here is some consideration of the index set, parameters, dependent variables, decision variables, and objective function used in this research.

Index sets:

I: $Set\ of\ potencial\ locations\ of\ DC\ construction\ sites\ (1,2,3 \ldots i)$

A: $Set\ of\ potencial\ locations\ affected\ by\ the\ diasater\ (1,2,3 \ldots j)$

H: $Set\ of\ available\ terrestrial\ vehicles\ (1,2,3 \ldots h)$

G: $Set\ of\ available\ aerial\ vehicles\ (1,2,3 \ldots g)$

Parameters:

fi: $investment\ cost\ of\ DC\ development\ at\ the\ ith\ location, i \in I$

ch: $variable\ cost\ of\ transportation\ per\ unit\ distance\ for\ terrestrial\ vehicles\ h, for\ h \in H$

cg: $variable\ cost\ of\ transportation\ per\ unit\ distance\ for\ aerial\ vehicles\ g, for\ g \in H$

dij: $The\ distance\ between\ the\ location\ i\ and\ the\ distribution\ point\ j, for\ i \in I, j \in J.$

$vijh$: $number\ of transport\ volume\ from\ location\ i\ to\ distribution\ point\ j\ by\ terrestrial\ vehicle\ h$

$uijg$: $Number\ of\ transport\ volume\ from\ location\ i\ to\ distribution\ point\ j\ by\ aerial\ vehicle\ g$

vh: $The\ speed\ of\ the\ terrestrial\ vehicle\ h, for\ h \in H$

vg: $The\ speed\ of\ the\ aerial\ vehicle\ g, for\ g \in g$

kh: $terrestrial\ vehicle\ capacity$

kh: $aerial\ vehicle\ capacity$

kg: $aerial\ vehicle\ capacity$

Mj: $DC\ capacity$

Objective function:

The first objective function is for minimizing total cost, where LRP simultaneously determines the number and location of distribution centers (DCs) while allocating earthquake-affected areas to DCs and vehicle routes.

Therefore, the total cost consists of the following components: (1) fixed cost for establishing DCs and (2) cost of air and land vehicle travel per km.

$$min\ f_1 = \sum_{i\in I} f_i x_i + \sum_{h\in H}\sum_{(i,j)\in V} c_h d_{ij} Y_{ijh} + \sum_{g\in G}\sum_{(i,j)\in V} c_g d_{ij} z_{ijg} \quad (1)$$

The second objective function minimizing maximum travel time

The objective function aims to reduce the maximum travel time of a vehicle route.

$$Min\ f_2 = \max\left\{\sum_{i,j\in V}\frac{d_{ij}Y_{ijh}}{(v_{h1})},\ \sum_{i,j\in V}\frac{d_{ij}Y_{ijh}}{(v_{h2})},\ \sum_{i,j\in V}\frac{d_{ij}z_{ijg}}{(v_g)}\right\} \quad (2)$$

And there are several constraints that are used in this study.

a. Vehicle Functions

$$v_{ijh}Y_{ijh} \le K_h \quad \forall (i,j)\in V, \forall h\in H \quad (3)$$

$$u_{ijg}z_{ijg} \le K_g \quad \forall (i,j)\in V, \forall g\in G \quad (4)$$

b. Distribution center capacity

$$\sum_{i\in I} v_{ijh}Y_{ijh} + \sum_{i\in I} u_{ijg}z_{ijg} \le M_j \quad (5)$$

c. Distribution center opening restrictions

$$\sum_{i\in I} x_i \ge 1 \quad (6)$$

d. Assignment

$$\sum_{i\in I} y_{ijh} + \sum_{i\in I} z_{ijg} = 1 \quad \forall j\in J, \forall i \in I \quad (7)$$

e. Vehicle Type

$$\sum_{h\in H} y_{ijh} + \sum_{g\in G} z_{ijg} \le 1 \quad \forall i \in \mathrm{I}\ ;\ \forall j \in \mathrm{J};\ i\ne j \quad (8)$$

f. Travel Time

$$\sum_{i,j\in V}\frac{d_{ij}Y_{ijh}}{(v_h)} \le t_{max,terrestrial}\ \forall h \in H \quad (9)$$

$$\sum_{i,j\in V}\frac{d_{ij}z_{ijg}}{(v_g)} \le t_{max,aerial}\ \forall g\in G \quad (10)$$

g. Decision Variables

$$x_i \in \{0,1\} \quad \forall i\in I;\ \forall j\in J; \forall\in K \quad (11)$$

$$y_{ijh} \in \{0,1\} \quad \forall\ (i,j)\in V; h\in H; \quad (12)$$

$$z_{ijg} \in \{0,1\} \quad \forall i\in V; g\in G \quad (13)$$

The objective function (1) for total cost minimization includes a fixed cost component for DC establishments and air and ground vehicle travel costs per km. Objective function (2) minimizing the maximum travel time of a vehicle route. Obstacle function (3-4) The number of goods transported by a vehicle does not exceed the capacity of the vehicle; (5) the transport volume of land and air vehicles does not exceed the DC capacity; (6) the number of DCs to be opened is at least one; (7) Each affected location can only be served by one DC; (8) each route is served by only one type of vehicle (land or air), and not by both; (9-10) the maximum travel time for ground and air vehicles shall comply with the established time limits; and (11-13) Decision and non-negative variables

3. Hybrid Genetic Algorithm and Annealing Simulated (HGASA)

The Hybrid Genetic Algorithm and Simulated Annealing (HGASA) is a technique that integrates the strengths of Genetic Algorithms (GA) and Simulated Annealing (SA). This approach leverages the robust global search capabilities of GA to explore the solution space for an optimal or near-optimal solution, followed by SA's proficiency in refining the solution to find a better local optimum ([18]. The stages of HGASA are shown in **Fig. 3**.

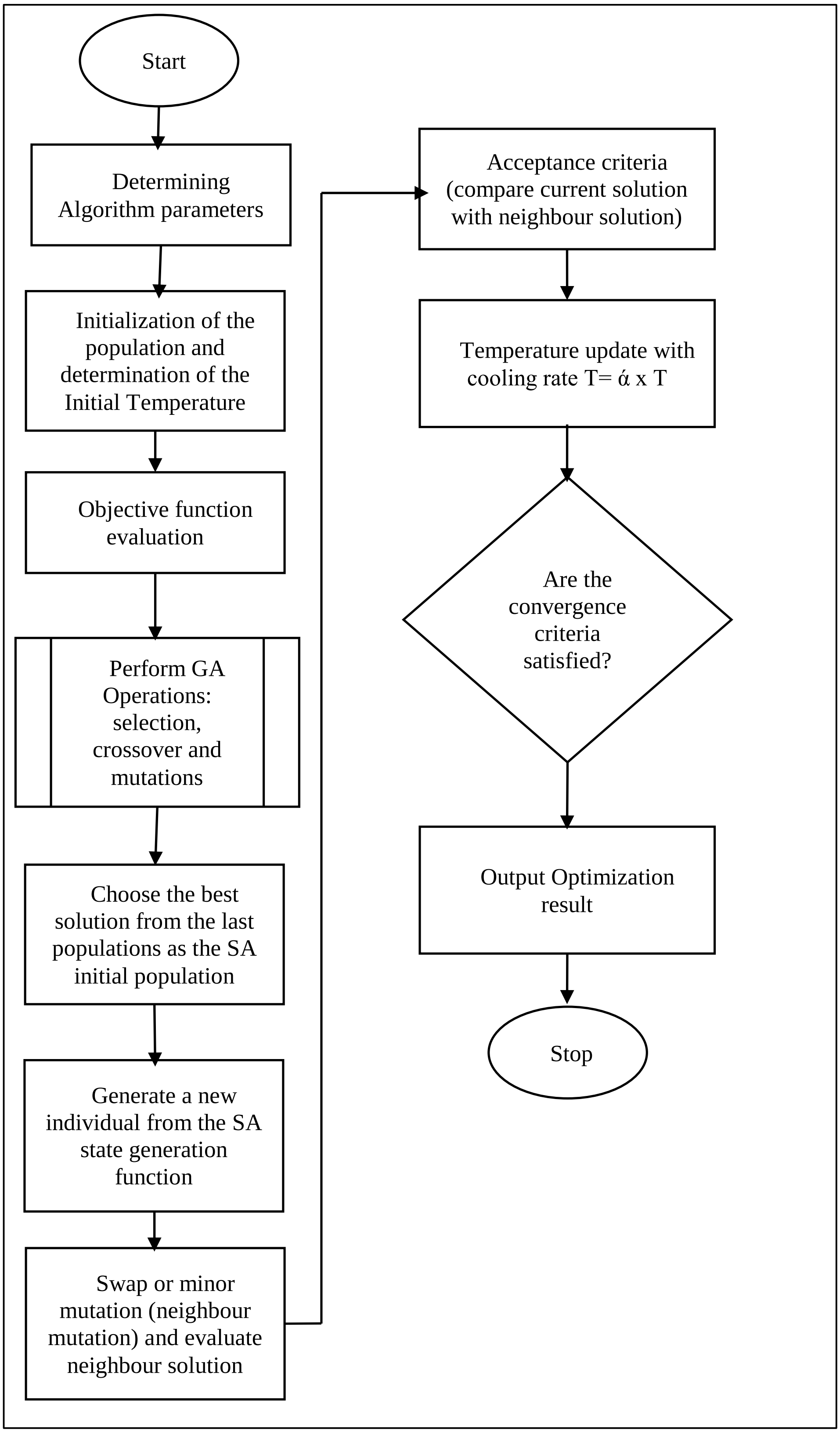

***Figure 3**. HGASA Process [28]*

4. Stopping Criteria

Determining stopping criteria is an important step in the design of genetic algorithms. This criterion will determine when the algorithm should be stopped, either after achieving the desired result or when it meets the predetermined limits. In this study the discontinuation criterion is carried out if it has met the specified maximum number of iterations and If there is no significant change in the population match value over several generations, the algorithm can be stopped, indicating that there is no further progress. The determination of the parameters to be used is carried out by testing the number of populations, crossover probabilities, mutation probabilities, cooling factor and Initial temperature in the HGASA algorithm before conducting simulations in case studies.

IV. RESULT

1. Figures Overview of Distribution Cases in 2018 Natural Disasters in Sigi Regency

When a natural disaster occurs, Sigi Regency uses two locations as shelters for aid items before being distributed to natural disaster locations. The two locations namely the Sigi Regency BPBD Office in Bora and the Sigi Regency BAPPEDA office in Mpanau. Based on this, the total cost and maximum travel time carried out during natural disasters are then calculated. The result show in **Table 1**.

Number Shelter	*Total Cost (IDR)*	*Maximum Travel Time (hr)*
2	409531721	27.575

Table 1. Results of Calculatin of Total Cost and Maximum Travel Time

The results of the calculation were obtained with the provision that the distribution was carried out in accordance with the request from the disaster-affected areas or distribution points and deliveries using pickups, trucks and helicopters for several points that could not or were difficult to reach by land. Deliveries of aid items to distribution points are delivered according to the availability of aid items and one-way or adjacent lanes will be delivered at the same time, if aid items are available. The following relief routes in the event of a natural disaster by two shelters are shown in **Fig. 4** and **5** below.

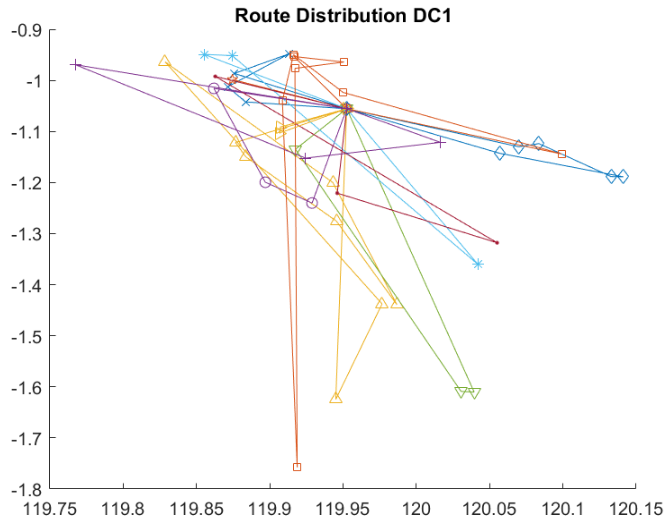

Figure 4. *Distribution Route of Natural Disaster Assistance in Sigi Regency by shelter 1*

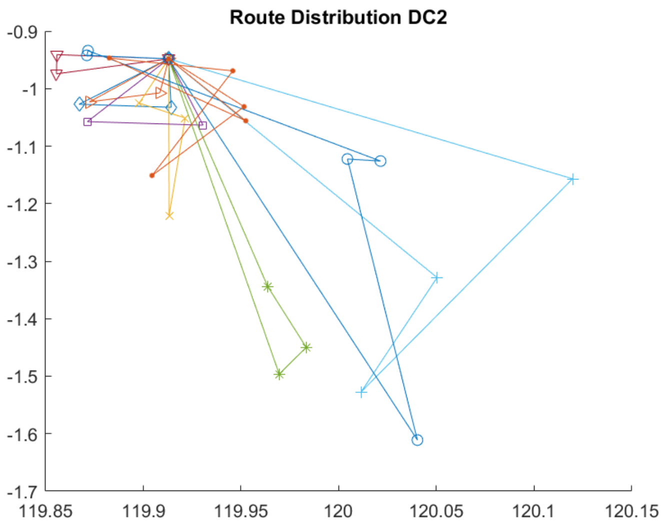

Figure 5. *Distribution Route of Natural Disaster Assistance in Sigi Regency by shelter 2*

2. Application Hybrid GASA Method

There are two scenarios for opening the number of open DCs, namely two DCs and three DCs. The simulation was carried out 56 times, of which 21 times for a combination of two DCs were opened and 35 times for a combination of three DCs were opened. The following are the results of the HGASA algorithm simulation shown in **Fig. 6**.

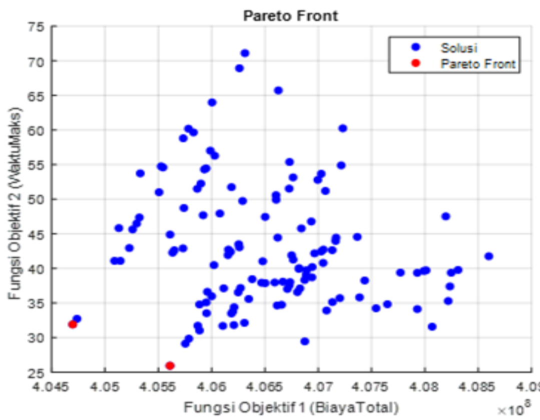

Figure 6. *HGASA Results for 2 DC*

Fig. 6 shows the distribution of solution results for the two distribution centres that were opened. The blue dots on the graph represent all the solutions generated by the HGASA algorithm, where each dot is a single solution that satisfies some combination of both objective functions. The red dot indicates the Pareto Front. The value range of objective function 1 ranges from Rp404,697,000 to Rp408,600,000 and the value range of the injective function 2 ranges from 25,921 hours to 71,124 hours. The solutions are scattered randomly on the chart, with some Pareto solutions prominent in the bottom left of the chart. There are two pareto front solutions that are produced as the optimal solution, namely the combination of distribution centres 1,3 and 3,5.

Furthermore, the results of HGASA in the simulation for three DCs were opened, as shown in **Fig. 7**.

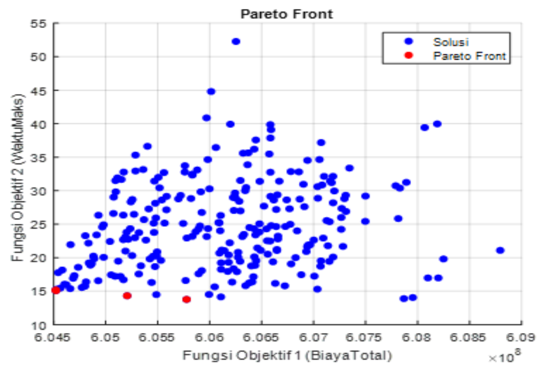

Figure 7. *HGASA Results for 3 DC*

Fig. 7 is a distribution of the solution results for the three distribution centers that were opened. The blue dots on the graph represent all the solutions generated by the HGASA algorithm, where each dot is a single solution that satisfies some combination of both objective functions. The red dot indicates the Pareto Front. The value range of objective function 1 ranges from IDR 604,519,000 to IDR 608,795,000 while the value range of objective function 2 ranges from 13,763 hours to 52.28 hours. The solution is spread out in a higher density around the middle value of Objective Function 1, with some Pareto solutions prominent in the bottom left of the graph. There are three pareto front solutions that are produced as optimal solutions, namely 1, 4 and 5, 3.4 and 5, 3.5 and 6.

From the results of the simulation, then the location of the DC to be selected was determined. Decision making uses the Displaced Ideal Solution (DIS). The DIS method selects the best solution (W*) from each existing solution (Wy), then the normalization process is carried out according to the equation that has been determined in the previous chapter. The normalization value can be negative if the solution being compared has a value greater than its ideal value. However, when calculating the direct distance, use the absolute value of the normalized result to ensure the distance remains positive. The selection of the best decision is based on the smallest direct distance. The following are the results of the solution generated using the HGASA method shown in **Table 2.**

Table 2. *HGASA optimization results*

Number DC	*DC Opened*	*Distribution Point*	*Route*	*Total Cost (IDR)*	*Max. travel time (hours)*
2	3,5	D3: 1-2-3-5-7-8-10-11-12-13-14-17-20-21-22-24-25-27-29-33-34-35-36-38-39-40-41-42-44-45-48-49-53-54-56-57-59-60-61-62-63-66-67-70	Heli: 35-35-33 Truck: 56-59-1-54-60-36-21 Pickup: 53-12-14-67-62-41-20-7-24-38-48-39-49-10-22-57-13-17-61-5-25-3-42-63-29-66-8-70-44-40-2-27-11-45	405,609.300	25.921
		D5: 4-6-9-15-16-18-19-23-26-28-30-31-32-37-43-46-47-50-51-52-55-58-64-65-68-69-71-72	Heli: 30-72-52 Truck: 4-37-55-19-28-23-26-6-15-58-18-16-69-64-65-47-51-43-50-68-71-31-9-32-46 Pickup: -		
3	1,4,5	D1: 3-4-12-18-21-26-27-29-31-32-33-34-35-36-38-44-47-49-59-61-63-64-65-66-69-71	Heli: 34-35-33 Truck: 59-36-4-18-12-38-26-21-3-69-63-66 Pickup: 29-64-49-65-61-44-71-47-27-31-32	605,777,600	19.634
		D4: 1-2-7-8-11-14-15-16-19-23-24-25-28-39-40-41-42-45-46-53-54-55-57-60-70	Heli: - Truck: 54-60-53-1-14-41-7-24-19 Pickup: 55-39-46-57-28-15-42-16-8-23-25-70-40-2-11-45		
		D5: 5-6-9-10-13-17-20-22-30-37-43-48-50-51-52-56-58-62-67-68-72	Heli:30-72-52 Truck: 56-67-62-17-20-37-10-6-5-58-51-43-50-68-48-22-13-9 Pickup: -		

The results of **Table 2.** show the opening of two DCs (DC3 and DC5), the total cost incurred is Rp 405,609,300 with a maximum distribution time of 25,921 hours. Although this cost is slightly lower compared to the two-DC scenario of NSGA II, the maximum distribution time is much higher, indicating a significant trade-off between cost and time efficiency. In DC3, heli routes are used to reach hard-to-reach distribution points, while trucks and pickups are optimized to reach areas with better accessibility. In contrast, the DC5 demonstrates the effective use of heli and truck without the need to use pickups, indicating a simpler and more focused route.

In the scenario of three DCs (DC1, DC4, and DC5), the total cost incurred is IDR 605,777,600 with a maximum distribution time of 19,634 hours. This scenario combines the strategic use of helicopters, trucks, and pickups, where helicopters are used at specific distribution points in DC1 and

DC5 to optimize time. DC4, which does not use a heli, utilizes trucks and pickups to reach distribution points in more detail, demonstrating flexibility in addressing complex distribution challenges.

The use of vehicle routes shows significant adjustments to improve efficiency and reduce costs. The use of helicopters has remained consistent for certain areas that are inaccessible or difficult to reach by land, while trucks are used effectively to reach large areas with more focused routes. Pickups, which are used extensively in some DCs, allow for distribution handling in denser areas or with more limited access.

3. Comparison of Overview of Distribution Cases in 2018 with the application of the HGASA Method

The results of the calculation of the overview of distribution case in Natural disaster 2018 in Sigi Regency and the application of HGASA is shown in **Table 3.**

Table 3. *Result Overview of Distribution Cases in 2018 with the application of the HGASA Method*

	Number DC Opened	***Total Cost (IIDR)***	***Maximum time travel (hours)***
Distribution in Sigi (Natural Disaster 2018)	2	409,531,721	27.572
HGASA	2	405,609.300	25.921
	3	605,777,600	19.634

The calculation results presented in **Table 3** highlight significant differences between the humanitarian aid distribution in Sigi Regency in 2018 and the application of the HGASA method for varying numbers of distribution centres (DCs). In the 2018 humanitarian aid distribution in Sigi Regency, which did not utilize an optimization method, two shelters were opened, total cost reaches IDR409,531,721 and the maximum travel time is 27,572 hours. Meanwhile, using the HGASA method for two DCs that are opened, the total cost is IDR 405,609,300 and the maximum travel time is 25,921 hours, and for the opening of three DCs, the total cost is IDR 605,777,600 and the maximum travel time is 19,634 hours.

HGASA with 2 DCs offers cost savings over distribution in 2018. However, the addition of DC to 3 led to a significant increase in cost. HGASA, both with 2 DC and 3 DC, improves travel time efficiency. The addition of DC to 3 provides a greater reduction in maximum travel time. If the main goal is to reduce the maximum travel time for a faster response, especially in emergency situations, opening 3 DCs with HGASA is more recommended. Hybrid Approach in HGASA Although HGASA uses a combination of genetic algorithms and simulated annealing, which in theory can provide an advantage in the exploration of solutions, some studies have shown that hybrid methods often have weaknesses in maintaining population diversity. Coello (2010) stated that hybrid algorithms can lose important solution diversity, making them more susceptible to convergence on local solutions. The following **Fig. 8** and **9** show route drawing for HGASA method Scenario 2 DC's. Then **Fig. 10** are route drawing for HGASA method scenario 3 DC's.

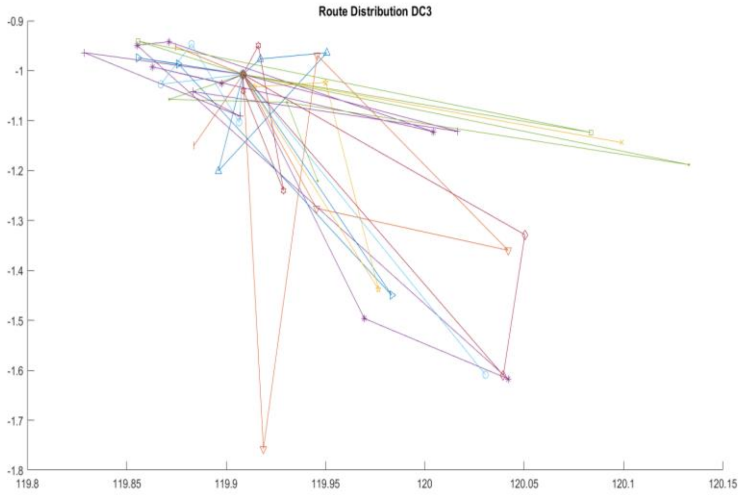

Figure 8. *Distribution Route of HGASA Method Scenario 2 DC's by DC3*

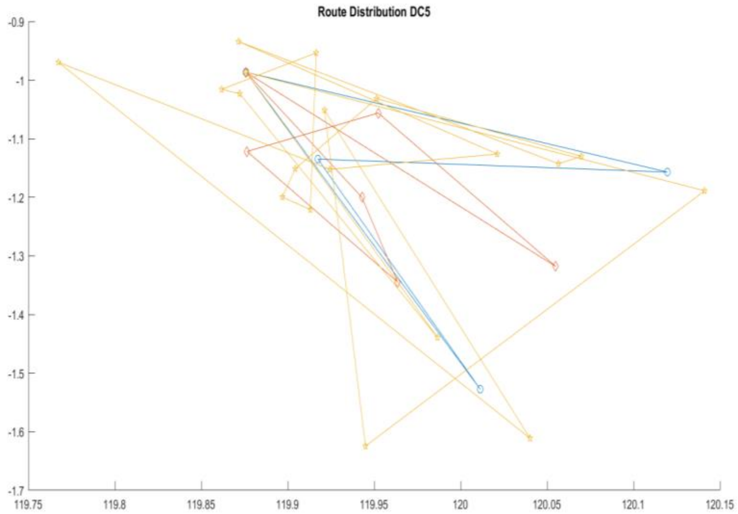

Figure 9. *Distribution Route of HGASA Method Scenario 2 DC's by DC 5*

Based on **Fig. 8** and **9** show that the distribution route is more centralized at two distribution centre points (DCs). Most routes have a more complex distribution pattern with some longer routes. The route network appears denser and overlaps each other, indicating that multiple receiving locations rely on a single DC, thus increasing the mileage. even some locations that are far from DC still must be served by one of the two DCs, thus increasing travel time. **Fig. 10** shows that the opening of the three DCs results in more spread routes, reducing the average length of the routes and creating a more efficient distribution. Route networks look more segmented with better load sharing, reducing route overlap. locations that were far away from the previous two DCs can now be more easily reached by the third DC, reducing the average distance for distribution.

HGASA combines the global search capabilities of genetic algorithms (GA) and the local search capabilities of simulated annealing (SA). In this case, GA helps explore the solution space to find the optimal DC configuration (e.g., 2 DC or 3 DC), while SA fines out the solution by finding the best distribution route around the selected configuration.

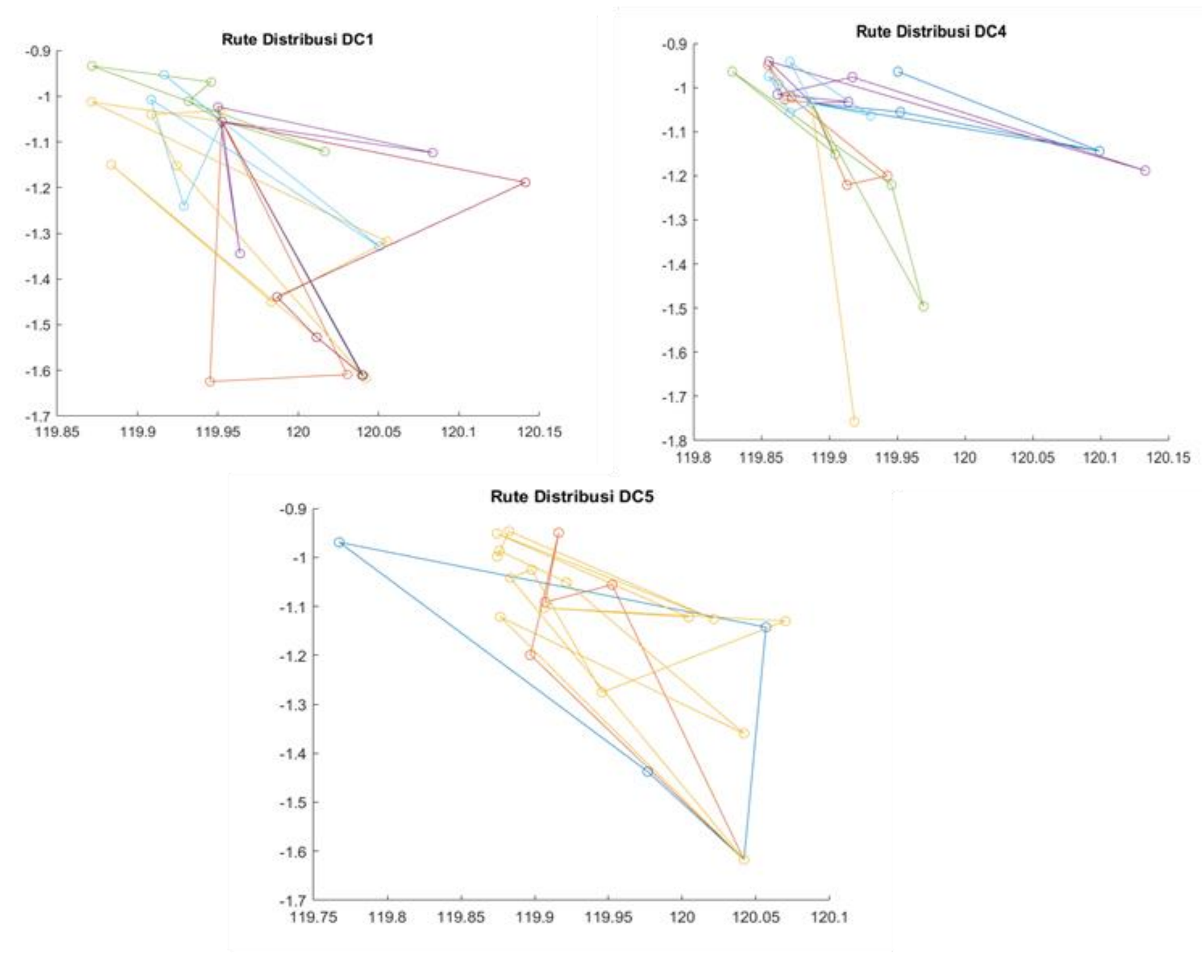

Figure 10. *Distribution Route of HGASA Method Scenario 3 DC*

V. CONCLUSION

Based on the results of research that has been carried out in the use of the HGASA method for the distribution of humanitarian aid using historical data of natural disasters in 2018 in Sigi district. The optimization of HGASA obtained two distribution centers can be carried out at the location of D3 and D5 or the location of the South Dolo Health Center in Balluase and the South Kulawi Sub-district Office in Tompi Bugis with a total cost of IDR 405,609,300 and a maximum service time of 25,921 hours while the construction of three distribution centers can be carried out at the location of DC1, DC4 and DC 5 or the location of the Sigi Bora BPBD Office, PUSDALOPS Maku Office and South Kulawi Sub-district Office in Tompi Bugis with a total cost of IDR 605,777,600 and a maximum service time of 19,634 hours.

The opening of three DCs by HGASA drastically reduces the maximum travel time, which can be a critical factor in emergency situations. If reducing travel time is a top priority (for example, for disaster emergency response), opening three DCs with HGASA is more effective. However, if cost control is the primary focus, HGASA with two DCs is more optimal than the previous distribution.

Professional contributions from this publication namely (i) utilization of the HGASA method for disaster logistics management: this publication provides an innovative approach in optimizing the distribution of humanitarian aid by integrating historical data of disasters. This can help professionals in the field of logistics and disaster management in more effective and efficient strategic planning; (ii) reduced response time in emergency situations: this study provides a framework that government agencies and non-governmental organizations can apply to accelerate the delivery of aid, which is crucial in saving lives in emergency situations; and (iii) contribution to the academic literature: this research has become one of the important references in the application of the HGASA method for disaster logistics management, providing new insights for further research in this field.

Further research may focus on the development of more complex algorithms, testing in a variety of real-world conditions, and integration with modern technologies such as IoT and decision support systems. This will ensure that the HGASA method not only provides an optimal theoretical solution but is also relevant for practical applications in a variety of disaster and logistics distribution scenarios.

AUTHOR CONTRIBUTIONS

S. Bombang: Conceptualization, Experiments, Theoretical analysis and writing.

B. P. Icthiarto: Supervision and Review.

H. H. Purba: Review and editing.

DISCLOSURE STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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