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Optimizing Medan Tourist Routes Using Biogeography-Based Optimization

Fidelis Nofertinus Zai[1]*, Donni Andreas Nainggolan[2], Rian Kurnia[3], Erwin[4]

[1,4] Department of Mathematics, Universitas Sumatera Utara
[2] Department of Mathematics, Universitas HKBP Nommensen Pematangsiantar
[3] Department of Data Science, Institut Teknologi Sumatera

* *Corresponding author: fidelis@usu.ac.id*

Abstract: This study optimizes tourist routes across 14 destinations in the city of Medan using the Biogeography-Based Optimization (BBO) algorithm. The problem is formulated as a closed-path Traveling Salesman Problem (TSP) with an extension allowing for flexibility in freely selecting the starting point. The route is determined based on the distance between two locations, where the distance is assumed to be asymmetric ($d_{i,j} \neq d_{j,i}$) to account for real-world urban road conditions such as one-way systems, while ignoring traffic conditions and other costs. Simulation results show that even though the starting point is freely determined, the BBO algorithm is still able to consistently produce routes that are close to optimal with stable convergence. The main contribution of this study is the provision of an adaptive and realistic route planning model to support tourism information systems in urban areas.

Keywords: tourism route optimization, biogeography-based optimization, TSP, metaheuristic algorithm.

Introduction

Tourism has a significant role in the economic and social development of a region. The satisfaction of tourists is determined by various factors. One of the most important factors is travel route efficiency, particularly when tourists intend to visit multiple destinations within a limited period of time. This problem can be addressed through optimal route planning, which serves to reduce both travel distance and duration while simultaneously minimizing overall costs. However, this optimization only considers distance traveled, ignoring road conditions and travel costs. Consequently, such route optimization has an essential role in enhancing the overall quality of tourist experience [1,2,3].

Mathematically, the problem of optimal route planning has similarities with the Travelling Salesman Problem (TSP), since it falls within the category of combinatorial optimization problems that focus on finding the shortest path through a set of locations exactly once before returning to the starting point [4,5,6,7]. TSP is a fundamental problem in numerous studies on route planning, including tourism routes, due to its NP-hard (Non-deterministic Polynomial time) nature, which made the search for exact solutions inefficient when dealing with large-scale problems [1,4,5,6]. Alternatively, metaheuristic algorithms have become a widely used approach for handling various variants of the TSP with competitive execution times.

Previous studies have specifically focused on developing models for tourism route optimization using several mathematical approaches such as Mixed Integer Linear Programming (MILP) or using heuristic methods. For instance, [8] modeled travel distance and tourist satisfaction by formulating it as an Orienteering Problem (OP). The problem was modeled as an MILP and successfully balanced travel distance and tourist satisfaction. Other studies have also proposed a combination of heuristic and metaheuristic approaches, such as using greedy algorithms to design intelligent tourism routes for enhancing the number of visiting tourists [9].

Various metaheuristic methods have been widely used to solve tourist route optimization problems, including Genetic Algorithms (GA) and Ant Colony Optimization (ACO). Although GA is capable of extensively exploring the solution space, its performance is highly sensitive to the selection of parameters and genetic operators such as crossover and mutation, and it does not guarantee the attainment of a global optimal solution. Furthermore, achieving good results often requires a large number of iterations or a combination of several operators [10]. On the other hand, ACO also has limitations because its performance is highly dependent on the settings of the pheromone parameters and the objective function used, and it often requires integration with additional methods such as dynamic graph modeling or clustering techniques to improve solution quality [11]. These limitations indicate that existing optimization methods still have room for improvement. Therefore, this study explores the use of Biogeography-Based Optimization (BBO) as an alternative method that is expected to provide more stable and efficient solutions for solving tourist route optimization problems . BBO is an optimization method that introduces an approach based on the concepts of habitat migration and mutation, enabling a more adaptive and effective exploration of solutions [12,13,14].

This study aims to formulate an objective function for determining tourism routes with the goal of minimizing travel distance across 14 tourist destinations in the city of Medan, North Sumatra. The optimization is performed purely based on travel distance, so road conditions and other costs are ignored. This problem is formulated as a closed-path TSP (Traveling Salesman Problem) to accommodate the reality of urban routes where the distance between two points may differ due to one-way street systems (the distance from location A to location B is not always the same as the distance from location B to location A). The novelty of this research lies in the modification of the initialization mechanism and solution structure in the BBO algorithm, designed to be adaptive to arbitrary starting point selection. The main contributions of this research include the development of a modified BBO algorithm for near-optimal route search, the implementation of a dynamic starting point feature that provides practical flexibility for tourists without compromising distance efficiency, and the provision of a scalable route planning model as a framework for tourism information systems. The results of this research are expected to make a tangible contribution to the development of more adaptive and realistic tourism route planning systems.

Research Methods

Problem Formulation

The problem of determining the shortest route for visiting a set of tourist destinations is a combinatorial optimization problem. In the context of this problem, the starting point also serves as the final location, and the objective is to identify an optimal sequence of locations such that the overall route distance is minimized.

Such problem is known as the Travelling Salesman Problem (TSP), which is modeled as a problem for weighted undirected complete graphs $G = (V, E)$ where $V = \{v_0, v_1, v_2, \dots, v_n\}$ is a set of vertices that represent tourist destinations in Medan city. The set E contains all edges that link every pair of vertices (v_i, v_j), with each edge assigned a weight $d_{i,j}$ corresponding to the distance between v_i and v_j.

Let $R = [r_0, r_1, r_2, \dots, r_n]$ is a vector representing the order of visits, where $r_0 = 0$ (starting point) and $r_i \in \{1, 2, \dots, n\}$. Based on the preceding problem description, the primary objective of the optimization process is to determine a permutation of the vertices in R, with the exception of the starting point, that minimizes the following objective function.

$$f(R) = d_{0,r_1} + \sum_{i=1}^{n-1} d_{r_i,r_{i+1}} + d_{r_n,0} \quad (1)$$

where:

$d_{i,j}$: distance between location i and j, where the distance is asymmetric ($d_{i,j} \neq d_{j,i}$).

R : set representing tourist destinations

n : number of tourist destinations to visit (in this study $n = 13$)

r_i : an index of unique locations visited in a specific order without repetition (permutation constraint).

Biogeography Based Optimization (BBO)

The Biogeography Based Optimization (BBO) method is a heuristic optimization approach inspired by biogeography theory [12]. In BBO, each solution is considered a habitat, denoted as H_i [15]. A habitat is characterized by a life-supporting capacity, measured in terms of a high habitat suitability index (HSI) [16]. Factors such as the availability of drinking water, which affect HSI, are referred to as suitability index variables (SIVs) [17].

Each habitat has an emigration rate, denoted by μ and an immigration rate denoted by λ [18]. The number of species within a habitat varies from one habitat to another. The maximum number of species that a habitat can accommodate is represented as S_{max}. A similar convention applies to migration rates: the maximum immigration rate is denoted as I, which occurs when the number of species in the habitat is zero. Similarly, the maximum of emigration rate is denoted as E, which occurs when the number of species in the habitat reaches S_{max} [12]. The relationship between the number of species and the corresponding immigration and emigration rates is illustrated in Figure 1 [19].

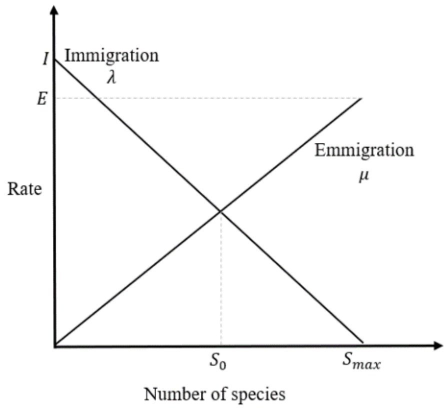

Figure 1. Model of immigration and emigration based on Biogeography theory.

Based on the biogeography theory described above, let i denote the number of species in a habitat, then the emigration rate (μ) and immigration rate (λ) correspond to the number of species defined as follows.

$$\mu_i = \left(\frac{E}{S_{max}}\right) \cdot i. \quad (2)$$

$$\lambda_i = \left(-\frac{I}{S_{max}}\right) \cdot i + I. \quad (3)$$

The process of finding optimal values in BBO involves the above two operators, migration and mutation.

Migration

The migration strategy in BBO is analogous to the global recombination approach in genetic algorithms [20] and evolution strategy[21], in which multiple parents may contribute to a single offspring, although the resulting offspring differs in certain aspects from each parent. In evolutionary strategy, global recombination is employed to generate new solutions, whereas in BBO migration is utilized to modify existing solutions.

Similar to other population-based optimization algorithms, BBO incorporates a form of elitism to preserve a subset of the best solutions within the population. This mechanism prevents the best solutions from being changed by the immigration effect [12].

The algorithm of the BBO migration operator is given as follows [17],

For $d = 1$ **to** D **do**
    If $rand < \lambda_i$ **then**
        Select another habitat (H_j) with probability $\sim\mu_j$
        Define $H_i(d) = H_j(d)$
    End If
End For

where d represents the variable being discussed and D represents the size of the problem being discussed.

Algorithm 1. Migration in Biogeography-Based Optimization

Mutation

In nature, certain catastrophic events (catalysts) can drastically alter habitats, hence producing significant effects on the species within them [17]. Each element in the population is associated with a probability that indicates the likelihood of a mutation event taking place. Solutions with either very low or very high Habitat Suitability Index (HSI) values are unlikely to undergo mutation, while solutions with moderate HSI values are relatively more likely to undergo mutation. If a solution S has a low probability P_i, its likelihood of mutation is high. Conversely, solutions with high probability values have lower likelihood to mutate. This mechanism can be implemented using the following formula [16]:

$$\boldsymbol{m_i = m_{max}\left(\frac{1-P_i}{P_{max}}\right)} \tag{4}$$

$$P = \frac{w}{\sum_{i=1}^{n} w_i} \tag{5}$$

where $w = [w_1, w_2, \ldots, w_n]$ and $w_i = C_i^n$ [12].

The algorithm of the BBO mutation algorithm is given as follows [17],

```
For d = 1 to D do
        If rand < m_i then
                Define H_i(d) = H_new
        End If
End For
```

Algorithm 2. Mutation in Biogeography-Based Optimization

Results and Discussions

This section presents the results of optimizing tourism routes in Medan using the Biogeography-Based Optimization (BBO) algorithm. The optimization process begins with collecting distance data between locations. This distance data is then used to construct a complete directed graph. Next, using all the data obtained, the optimization is performed using BBO.

Data Acquisition

In this study, the data consist of the distances between the selected tourist destinations in Medan city. The dataset comprised of 14 tourist destinations, which are listed as follows.

v_0 : Lapangan Merdeka Medan
v_1 : Taman Wisata Danau Siombak Marelan
v_2 : Istana Maimun
v_3 : Taman Sri Deli
v_4 : Rumah Adat Karo GARISTA
v_5 : Taman Cadika Pramuka
v_6 : Museum Tjong A Fie Mansion

v_7 : Gedung London Sumatera
v_8 : Pos Bloc Medan
v_9 : Masjid Raya Al-Mashun
v_{10} : Tjong Yong Hian Gallery
v_{11} : Maha Vihara Maitreya Cemara Asri
v_{12} : The Le Hu Garden
v_{13} : Ucok Durian

The distance data between locations ($d_{i,j}$) was acquired from Google Maps in March 2026 using the motorcycle routing option. This mode of transport was selected to reflect the urban mobility characteristics in Medan, where motorcycles are a primary choice for navigating city traffic efficiently. Due to the prevalence of one-way traffic systems in Medan's road network, the resulting distance matrix is asymmetric ($d_{i,j} \neq d_{j,i}$). The data acquisition protocol utilized the "avoid tolls" setting to represent realistic urban tourism paths. The resulting travel distances, expressed in kilometers (km), are presented in Table 1.

Table 1. Distance Matrix between Tourist Destinations in Medan (km)

$d_{i,j}$	v_0	v_1	v_2	v_3	v_4	v_5	v_6	v_7	v_8	v_9	v_{10}	v_{11}	v_{12}	v_{13}
v_0	0	19	3	2.8	12	12	2.1	1.2	0.18	2.9	2	7.9	14	3.6
v_1	20	0	21	21	29	29	22	20	20	21	20	18	34	21
v_2	2.1	21	0	0.65	11	9.2	1.3	1.8	2.1	0.5	3	9.6	12	4.4
v_3	2.3	22	1.1	0	11	9.5	1.5	1.9	2.5	0.35	3.1	9.4	12	5.1
v_4	11	29	11	11	0	6.2	11	11	11	11	9.8	19	15	8.5
v_5	11	28	9.4	9.8	6.8	0	10	11	11	9.7	9.5	19	9.5	8.3
v_6	0.65	19	1.9	1.7	11	11	0	0.45	0.8	1.8	1.5	8.8	13	3.2
v_7	0.16	19	2.1	2.4	11	11	1.3	0	0.35	2.4	1.2	8	14	3.2
v_8	1.2	18	2.8	2.6	12	11	2.5	1.4	0	2.7	2.2	7.7	14	3.4
v_9	2.3	22	0.75	0.15	11	9.2	1.5	2	2.5	0	3.2	9.5	12	4.8
v_{10}	2.2	20	3.7	4.1	10	9.8	2.7	2.5	1.5	3.9	0	9.3	15	2.1
v_{11}	8.1	18	11	10	19	18	9.5	8.4	8.3	9.7	9.3	0	20	10
v_{12}	15	33	12	12	15	9.3	13	14	14	12	15	21	0	17
v_{13}	4.1	21	4.4	5	8.9	8.5	4.3	4.3	3.3	4.9	2	10	16	0

Source: *Data extracted from Google Maps (March 2026) using "Motorcycle Driving Mode". The distances are asymmetric due to one-way traffic systems in Medan City.*

The data in Table 1 will be used in the optimization process. The optimization aims to determine a route with the minimum possible travel distance. The first location in the route also serves as the final location, as every tourist is assumed to return to the starting point. For instance, if a tourist wishes to begin the journey at the destination closest to their residence, they may freely select it as the first location. This optimization framework represents a well-designed itinerary for tourists, as it is adaptive to the preferences of tourists.

Graph Construction

In this section, a complete directed graph will be constructed, where each location is represented as a point or node in the graph, and the connecting lines between points represent direction and distance. Since all roads follow a one-way system, each connecting line has an arrow pointing in a different direction. Furthermore, each arrow on the connecting line has a number indicating the distance between the two locations in that direction. In the resulting graph, there are several connecting lines that are nearly overlapping due to the density of nodes in the graph. However, information that is not clearly visible in the graph can be found in Table 1. A visualization of the graph can be seen in Figure 2.

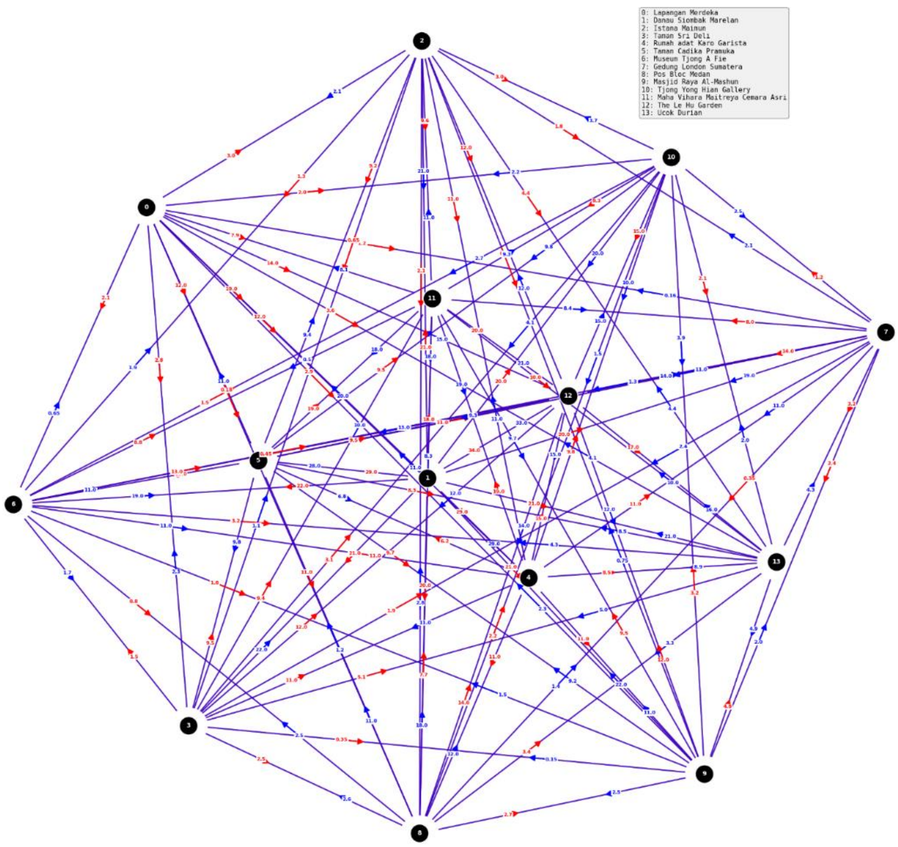

Figure 2. A weighted directed graph representation of 14 tourist destinations in Medan. The red and blue arrows indicate asymmetric distances ($d_{i,j} \neq d_{j,i}$) between nodes.

Results of Tourist Route Optimization

Tour route optimization was performed by varying the starting points of the visits to generate several route scenarios. In this optimization process, the selected starting points include Medan's Merdeka Square, Maimun Palace, Al-Mashun Grand Mosque, Maha Vihara Maitreya Cemara Asri, and the London Sumatera Building. The optimization was implemented using Python, where the program allows users to freely select the starting point, as illustrated in the following figure.

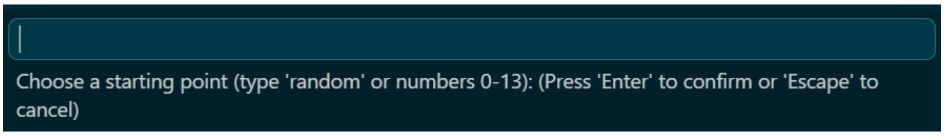

Figure 3. Start point selection display

Figure 3 is a screenshot from Python, which serves as a menu for flexibly entering the starting location index. The index is selected from 0 to 13 according to the location in the Data Acquisition section.

The optimization was performed using the following parameters: the maximum mutation rate was set to 0.001 to maintain population diversity while preventing premature convergence; the number of generations (iterations) was set to 1000; the population size or number of habitats per generation is set to 100, elitism is set to 1 so that the best solution in each generation is retained without undergoing migration or mutation, and the number of independent trials is set to 100 with different random seeds to ensure the statistical reliability of the results obtained. The algorithm was run 100 times with independent trials using different seeds (seeds 0 through 99) for each initial location scenario; the best result from all trials was then selected as the final solution to be reported. Based on these parameter values, the results obtained are as follows.

1. Starting location: Lapangan Merdeka Medan

The best route, with Lapangan Merdeka Medan as both the starting and final location is as follows.

Lapangan Merdeka → Pos Bloc Medan → Danau Siombak Marelan → Maha Vihara Maitreya Cemara Asri → Museum Tjong A Fie → Tjong Yong Hian Gallery → Ucok Durian → Rumah adat Karo Garista → Taman Cadika Pramuka → The Le Hu Garden → Istana Maimun → Masjid Raya Al-Mashun → Taman Sri Deli → Gedung London Sumatera → Lapangan Merdeka

This route yielded the best total distance of 79.59 km, obtained from the best trial among 100 independent trials that were run. The convergence process of the BBO algorithm can be observed in the graph of the objective function versus generation shown in Figure 4.

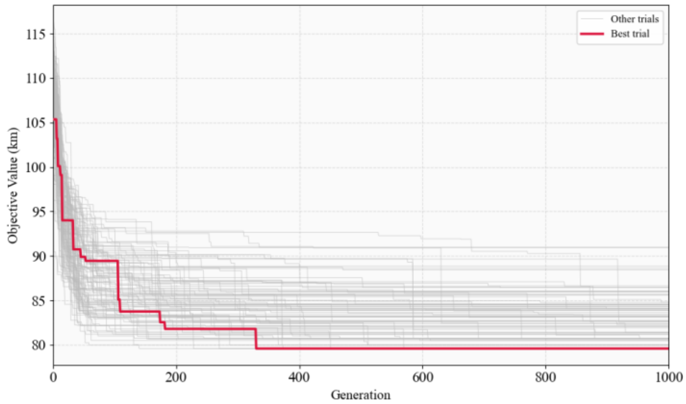

Figure 4. The objective function values of the BBO algorithm for each generation across 100 independent trials, starting from Lapangan Merdeka Medan algorithm for each generation across 100 independent trials, starting from

Figure 4 shows that all experiments exhibited a significant decrease in the objective function value during the early generations, then gradually stabilized at a lower value as the number of generations increased. The best experiment (indicated by the red line) successfully achieved an objective function value of 79.59 km and began to converge around the 330th generation, while most of the other experiments converged within the range of 80 to 92 km. The differences in final values among the experiments reflect the stochastic nature of the BBO algorithm, where the quality of the obtained solutions depends on the initial population conditions, which are influenced by the random seed of each experiment.

2. Starting location: Istana Maimun

The best route with Istana Maimun as both the starting and final location is given as follows.

Istana Maimun → Masjid Raya Al-Mashun → Taman Sri Deli → Gedung London Sumatera → Lapangan Merdeka → Pos Bloc Medan → Danau Siombak Marelan → Maha Vihara Maitreya Cemara Asri → Museum Tjong A Fie → Tjong Yong Hian Gallery → Ucok Durian → Rumah adat Karo Garista → Taman Cadika Pramuka → The Le Hu Garden → Istana Maimun

This route yielded the best total distance of 79.59 km, matching the result obtained for the scenario starting at Merdeka Square in Medan. This similarity in total distance indicates that both routes essentially follow the same sequence of visits but start from different points, which is a natural mathematical property of the TSP: the total distance of a cycle does not depend on the chosen starting point. The evolution of the objective function value over generations for this scenario is shown in Figure 5. Compared to the previous scenario, the best trial in this scenario required more generations to reach a stable value around the 440th generation, but still succeeded in producing the same final objective function value.

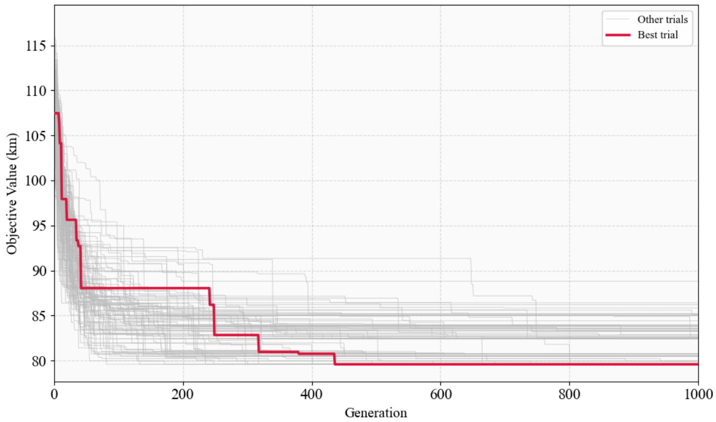

Figure 5. The objective function values of the BBO algorithm for each generation across 100 independent trials, starting from Istana Maimun.

3. Starting location: Masjid Raya Al-Mashun

The best route, with Masjid Raya Al-Mashun as both the starting and final location is as follows, Masjid Raya Al-Mashun → Taman Sri Deli → Gedung London Sumatera → Lapangan Merdeka → Pos Bloc Medan → Danau Siombak Marelan → Maha Vihara Maitreya Cemara Asri → Museum Tjong A Fie → Tjong Yong Hian Gallery → Ucok Durian → Rumah adat Karo Garista → Taman Cadika Pramuka → The Le Hu Garden → Istana Maimun → Masjid Raya Al-Mashun.

This route yields the best total distance of 79.59 km. This result is consistent with the two previous scenarios, which reaffirm that all five scenarios essentially produce the same route structure mathematically due to the cyclic nature of the Traveling Salesman Problem, where the total distance of a closed cycle is not affected by the choice of starting point. The evolution of the objective function value over generations for this scenario is not shown because the pattern is similar to Figures 4 and 5.

4. Starting location: Maha Vihara Maitreya Cemara Asri

The best route with Maha Vihara Maitreya Cemara Asri as both the starting and final location is given as follows.

Maha Vihara Maitreya Cemara Asri → Museum Tjong A Fie → Tjong Yong Hian Gallery → Ucok Durian → Rumah adat Karo Garista → Taman Cadika Pramuka → The Le Hu Garden → Istana Maimun → Masjid Raya Al-Mashun → Taman Sri Deli → Gedung London Sumatera → Lapangan Merdeka → Pos Bloc Medan → Danau Siombak Marelan → Maha Vihara Maitreya Cemara Asri

That route yielded the best total distance of 79.59 km. The evolution of the objective function values across generations follows a pattern similar to that shown in Figures 4 and 5.

5. Starting location: Gedung London Sumatera

The best route with Gedung London Sumatera as both the starting and final location is given as follows.

Gedung London Sumatera → Lapangan Merdeka → Pos Bloc Medan → Danau Siombak Marelan → Maha Vihara Maitreya Cemara Asri → Museum Tjong A Fie → Tjong Yong Hian Gallery → Ucok Durian → Rumah adat Karo Garista → Taman Cadika Pramuka → The Le Hu Garden → Istana Maimun → Masjid Raya Al-Mashun → Taman Sri Deli → Gedung London Sumatera

The resulting route has an approximate total travel distance of 79.59 km. The optimization process obtained is the same as Figures 4 and 5.

Conclusion

In this study, the Biogeography-Based Optimization (BBO) algorithm was implemented to solve the tourist route optimization problem in the city of Medan. The tourist route optimization problem was formulated as a Traveling Salesman Problem (TSP) with the additional feature of flexibility in the selection of the starting point of the trip by tourists. The results show that the BBO algorithm is capable of generating routes with more efficient total travel distances through migration and mutation mechanisms that allow for exploration of a broader solution space. Out of the five scenarios tested, the BBO algorithm produced the best total travel distance of 79.59 km. One of the strengths of this study is its ability to accommodate starting points based on tourist preferences. However, this study has several limitations that must be acknowledged. The developed model only optimizes travel distance and does not yet account for real-world factors such as travel time variability due to traffic conditions, visit duration at each location, operating hours of tourist attractions, and more complex tourist preferences. Additionally, the testing was conducted on a small agency with 14 tourist locations in the city of Medan using static distance data; therefore, generalizing the results of this study to other regions or larger agencies still requires further validation. Therefore, this study can be viewed as a baseline that opens opportunities for further development, such as incorporating time constraints and tourist preferences, testing on a larger scale, and developing an adaptive route optimization mobile application that allows tourists to dynamically determine the shortest travel route.

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