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Integration of AHP and Modified VIKOR Method to Select the Optimum Destination Route

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Abstract: One common approach to rating options is group decision-making using many criteria. Here, we use the same criteria to evaluate each option. Sometimes, decision makers are faced with some situations where they have to choose from a set of alternatives that have several different criteria. Thus, the decision maker cannot use a common method. Therefore, in this research, a modification to a method is carried out. To address the issue of developing alternate routes to Medan City's historical tourism attractions, the AHP and VIKOR approaches have been suggested. When considering options with both specific and broad requirements, this study adapts the VIKOR technique to find a workable solution. In order to demonstrate the suggested model's use and evaluate the efficacy of this approach change, this study offers numerical examples based on case studies. The findings demonstrate that the revised approach is both practical and efficient.

Keywords: AHP; VIKOR; modified VIKOR; network analysis; transportation routes historical destinations

INTRODUCTION

Multi-Criteria Decision-Making (MCDM) is a decision-making process that helps identify better alternatives by adjusting criteria in the decision-making process. Analytic Hierarchy Process (AHP) and VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR) are two methods used in decision-making systems to address various issues, such as resource allocation and waste management. AHP is a decision-making system developed by (Saaty, 2008), while VIKOR is a multicriteria optimization and compromise solution method used to optimize solutions and achieve a compromise that meets multiple criteria.

Combining AHP and VIKOR in decision-making systems allows for the integration of various criteria and alternatives in decision-making processes, enabling decision-making to achieve optimal and compromise solutions by considering various factors and perspectives (Wibawa et al., 2019). Some studies have used AHP and VIKOR in various contexts, such as resource allocation (Eydi et al., 2016; Shahnazari et al., 2021), train system (Demir et al., 2023), and hybrid LiFi/WiFi access (Badeel et al., 2023). Network Analysis is a method used to measure the feasibility of alternative routes in transportation planning.

Network Analysis is a method used to determine the optimal route based on parameters like time. For example, in the case of mass passenger transport in Medan, the Network Analysis method was used to find the best route with the minimum time required. This method is applied to datasets with relevant attributes used in the analysis process.

Medan is known as a major city in Indonesia, known for its diverse population and potential in various fields, including agriculture, human resources, and economics. The study aims to understand the impact of increasing the number of visitors to Medan's tourist attractions, such as museums, art galleries, and educational institutions.

The research will focus on the impact of increasing visitor numbers on the city's economy and the development of tourism infrastructure in Medan. By analyzing the impact of various factors on the city's economy, the study aims to provide valuable insights for future planning and development efforts.

LITERATURE REVIEW

Analitycal Hierarchy Process is a decision-making method developed by (Saaty, 2008). In making decisions, the AHP method uses a comparison between one criterion and another by forming a comparison matrix.

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$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \ldots & a_{nn} \end{bmatrix} \quad (1)$$

where a_{ij} is the relative importance value for each criterion.

In making decisions, the AHP method uses a comparison between one criterion and another by forming a comparison matrix. After getting the comparison matrix value, the following steps will be taken:

1. Sum the values of each column of the matrix.
2. The second step in calculating the matrix normalization value is to divide each column's value by it.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (2)$$

$$B = \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1n} \\ b_{21} & b_{22} & \cdots & b_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \ldots & b_{nn} \end{bmatrix} \quad (3)$$

2. Sum the values of each row and divide them by the number of elements to get the average value or what is commonly called the eigen value. The eigen value will later be used as the weight of each criterion.

$$w_i = \frac{\sum_{j=2}^{n} b_{ij}}{n} \quad (4)$$

One MADM approach to finding good alternatives is VIKOR. The VIKOR procedure consists of the following steps:

1. The matrix is normalized with the following equation:

$$N_{ij} = \frac{(f_j^{+} - f_{ij})}{(f_j^{+} - f_j^{-})} \quad (5)$$

Whether the data for a study variable is higher-the-better (HB) or lower-the-better (LB) dictates how the best and worst values, or costs and benefits, are assessed (Manikanta et al., 2024). The values of (f_j^{+}) and (f_j^{-}) are expressed as follows:

$$f_j^{+} = \max(f_{1j}, f_{2j}, f_{3j}, \ldots, f_{mj}) \quad (6)$$

$$f_j^{-} = \min(f_{1j}, f_{2j}, f_{3j}, \ldots, f_{mj}) \quad (7)$$

2. Calculate the utility measure (S) and regret measure (R) using the equation:

$$S_i = \sum_{j=i}^{n} w_j \left(\frac{f_j^{+} - f_{ij}}{f_j^{+} - f_j^{-}}\right) \quad (8)$$

$$R_i = Max\, j \left[w_j \left(\frac{f_j^{+} - f_{ij}}{f_j^{+} - f_j^{-}}\right)\right] \quad (9)$$

3. Calculate the VIKOR index value Q_i using the formula:

$$Q_i = \left[\frac{S_i - S^{-}}{S^{+} - S^{-}}\right] v + \left[\frac{R_i - R^{-}}{R^{+} - R^{-}}\right](1 - v) \quad (10)$$

The ranking results are the sorting results of S, R, and Q. The smaller the VIKOR index value Q_i, the better the alternative solution.

Most of the time, the VIKOR technique will have a set of criteria for each option and will rank them according to those criteria (San Cristóbal, 2011). In other words, each alternative is used with the same criteria, or sometimes only one criterion. Each alternative has unique criteria, as the set for each alternative is not fixed. As a result, some alternatives may have a fixed set of common criteria, while others do not. To overcome this, a modification of VIKOR is suggested. The steps used in the modified VIKOR method are as follows:

1. Determine the best f_j^{+} and worst f_j^{-} values in the decision matrix. It is not possible to determine the ideal and non-ideal points, as in the VIKOR method, where $f_j^{+} = \max\ (f_{ij}, j = 1, \ldots, n)$; and $f_j^{-} = \min\ (f_{ij}, j = 1, \ldots, n)$, because the criteria are used to rate the alternatives. Hence, according to each criteria of each option, the benefits or costs need to be rearranged, with the highest level being the best and the lowest level being the worst. The new method's first ranking matrix looks like this: With i=1, 2,…,m, Ai is the i-th alternative, C_j is the j-th criteria, and f_ij is the performance of the alternative (Ai) according to the j-th criterion.
2. In the normalized weight matrix, w_j^{i} is the weight of alternative $i\ (1, 2, \ldots, m)$ and criterion $j\ (1, 2, \ldots, n)$, and the normalization (r_{ij}) is expressed as follows:

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$$r_{ij} = \frac{\left(f_{ij}^{+} - f_{ij}\right)}{\left(f_{ij}^{+} - f_{ij}^{-}\right)} \tag{11}$$

3. Determine the most suitable solution. The best value of f_{ij}^{+} and the worst value of f_{ij}^{-} (each alternative has unique criteria)
4. Calculate the values of S_i (utility measure) and R_i (regret measure):
5.

$$S_i = \sum_{j=1}^{n} w_j r_{ij}, \quad S_i = \sum_{j=1}^{n} w_j \left(f_{ij}^{+} - f_{ij}\right) / \left(f_{ij}^{+} - f_{ij}^{-}\right) \tag{12}$$

$$R_i = \max\left[w_j r_{ij}\right], R_i = \max\left[w_j \left(f_{ij}^{+} - f_{ij}\right) / \left(f_{ij}^{+} - f_{ij}^{-}\right)\right] \tag{13}$$

5. Calculating the Q_i index value, $i\ (1, 2, \ldots, m)$; VIKOR index as follows:
6.

$$Q_i = \left[v(S_i - S^{-})/(S^{+} - S^{-})\right] + \left[(1 - v)(R_i - R^{-})/(R^{+} - R^{-})\right] \tag{14}$$

7. Sort the alternatives based on the values of $\{S_i, R_i, Q_i\}$. For example, propose alternative (A_1), which is ranked first based on the calculation of $\min\{R_i | i = 1, 2, \ldots, m\}$ if the following two conditions are met:
8.

$$Q(A_2) - Q(A_1) \geq \left(1/(n-1)\right)$$

$$Q(A_m) - Q(A_1) < \left(1/(n-1)\right) \tag{15}$$

Only if the stability condition is not met, the set of possible solutions consists of alternatives A_1 and A_2 if one condition is not met. If the profit condition is not met, options A_1, A_2, ..., and A_m are available. For m, when the positions of the two alternatives are close to each other, A_m is determined by the relationship $Q(A_m) - Q(A_1) < \left(1/(n-1)\right)$.

Geographic Information System (GIS) has the potential to facilitate spatial analysis and develop model data for transportation planning and assessment in local areas (Fischer & Nijkamp, 1992). Model networks, such as road networks, are crucial for studying human mobility and determining travel distances. GIS Network Analysis requires good data network and attribute information. Model networks can be multi-layer, using train and bus systems. The combination of internet technology and GIS allows for interactive network analysis, enabling timely spatial decision-making for local residents and city planning.

METHOD

The steps of this research are shown in Fig. 1:

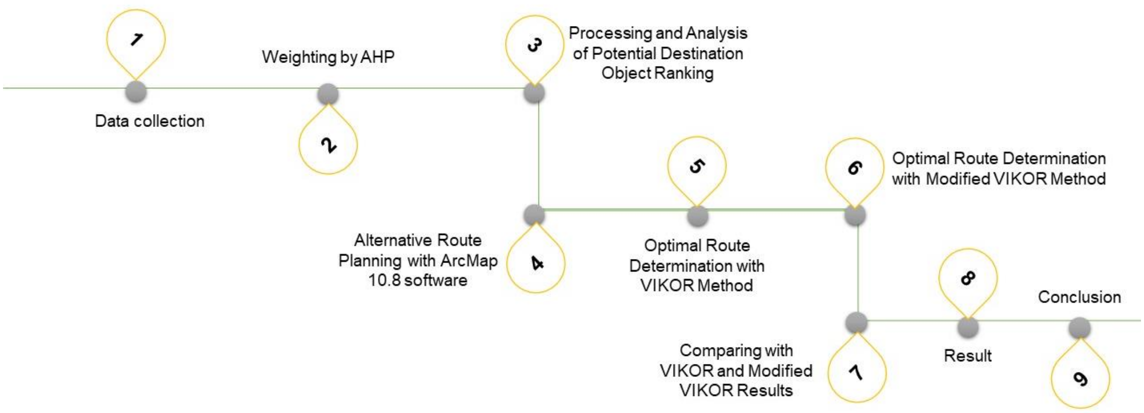

Fig. 1 Research Method Diagram

The data used in this research are AHP pairwise comparison questionnaires based on expert assessments with respondents referring to related agencies, shapefile of Medan City administrative boundaries, shapefile of Medan City transportation roads, shapefile of Medan City public facilities distribution, shapefile of Medan City historical destination objects distribution, statistical data on the number of visitors to Medan City historical destination objects in 2023, statistical data on the reputation of Medan City historical destination objects based on the distribution of questionnaires to the general public, quantitative data on the number of attraction facilities in Medan City historical destination objects in 2023.

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RESULT

Weighting Criteria and Sub-Criteria for Ranking Historical Destinations

The weights of each criterion and sub-criteria were derived from the parameters using calculations based on the answers provided by the three expert respondents on the AHP questionnaire. The weights of the three criteria such as, attractions, amenities, and accessibility are displayed in Table 1; the weights of the accessibility sub-criteria are displayed in Table 2; the weight values of the amenities sub-criteria are displayed in Table 3; and the weights of each attractions sub-criteria are displayed in Table 4.

Table 1
Weight of Expert Respondent Assessment Criteria

Criteria	Code	Weight
Accessibility	A1	0.153
Amenities	A2	0.562
Attractions	A3	0.285

Table 2
Weight of Accessibility Sub-Criteria Assessment of Expert Respondents

Sub-Criteria	Code	Weight
Main Road Access	B1	0.192
Public Facility Access	B2	0.365
Information & Guidance	B3	0.443

Table 3
Weight of Amenities Sub-Criteria Assessment of Expert Respondents

Sub-Criteria	Code	Weight
Public Facilities	C1	0.397
Destination Reputation	C2	0.5
Supporting Facilities	C3	0.103

Table 4
Weight of Attractions Sub-Criteria Assessment of Expert Respondents

Sub-Criteria	Code	Weight
Number of Visitors	D1	0.796
Number of Attractions	D2	0.102
Cultural & Historical Value	D3	0.102

The weight can be used to rate the potential of historical tourism objects using the weighted overlay method since the inconsistency ratio value is less than 0.1, indicating that the comparison matrix is acceptable.

Processing Criteria for Ranking Potential Historical Destination Objects

1. **Accessibility Criteria**
   Data processing for accessibility criteria using Euclidean Distance and then classified using the weighted overlay method in ArcMap 10.8 software. The processing results can be seen in Fig. 2. Colors are used to indicate accessibility criteria, each color indicating the distance of each area. As stated in class 1, areas with the lightest blue color are known to be closest to main roads and public facilities, while areas with the darkest blue color (class 5) are known to be farthest from these locations. The following are the classes and distances of the locations in Fig. 2:
   - Class 1: 0 to 346.39 meters
   - Class 2: 346.39 to 692.77 meters
   - Class 3: 692.77 to 1,039.16 meters
   - Class 4: 1,039.16 to 1,385.54 meters
   - Class 5: 1,385.54 to 1,731.93 meters

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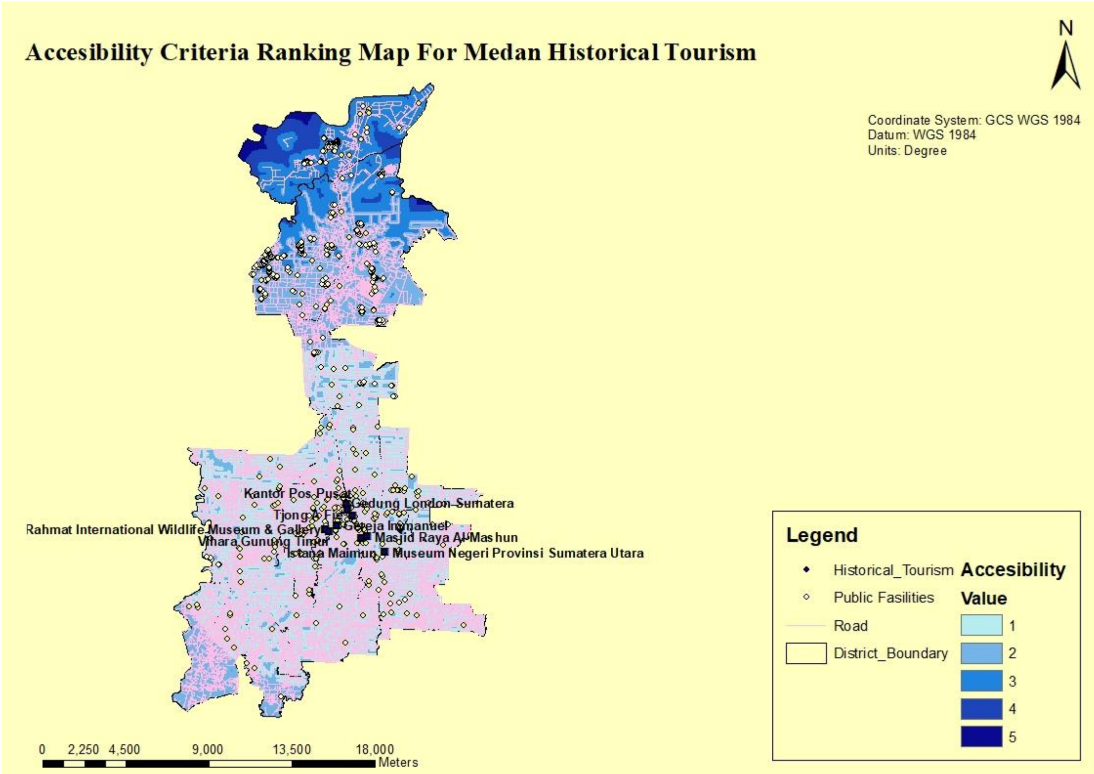

Fig. 2 Accessibility Criteria Ranking Map for Medan Historical Tourism

2. **Amenities Criteria**

The weighted overlay results were used to rank the nine historical tourism destinations in order of preference. The ranking is divided into three sections. Based on the amenities criteria, the best-ranked historical tourism is represented in blue, and the lowest-ranked educational tourism is represented in yellow. The ranking of educational tourism based on amenities is shown in Fig. 4.

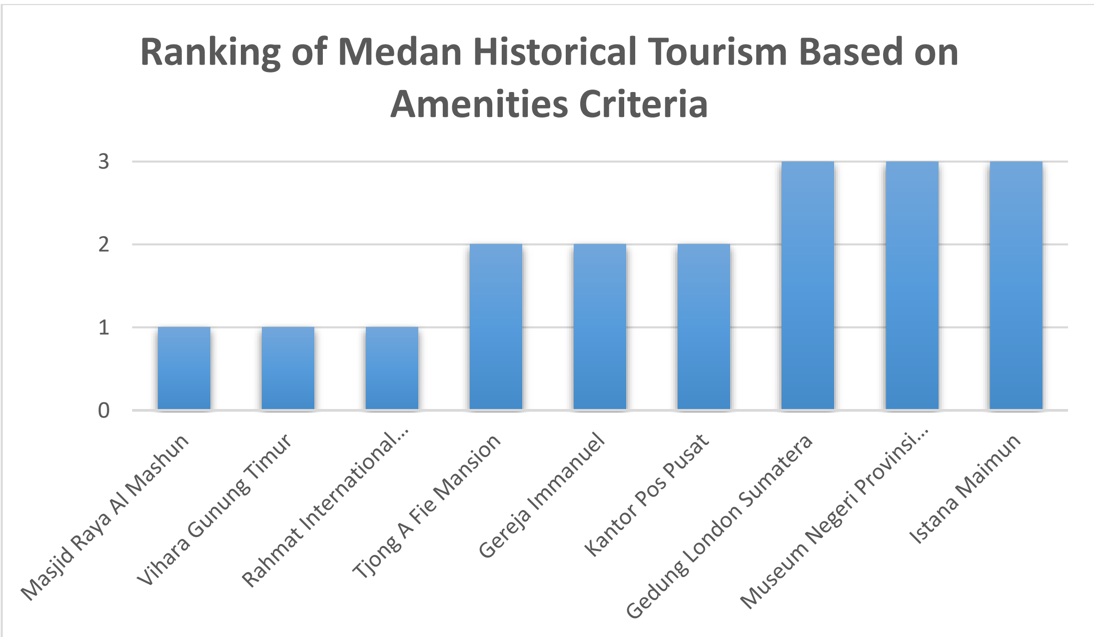

Fig. 3 Ranking of Medan Historical Tourism Based on Amenities Criteria

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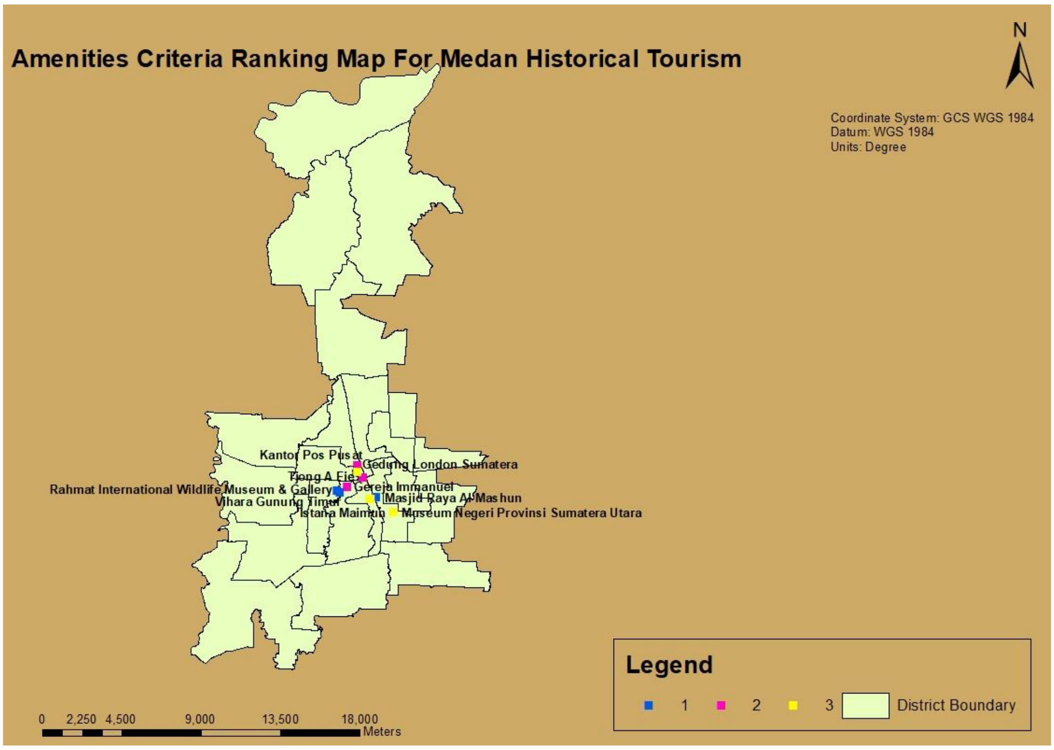

Fig. 4 Amenities Criteria Ranking Map For Medan Historical Tourism

3. Attractions Criteria

The weighted overlay results of the attractions criteria, which are based on the weights from the AHP calculation, are then shown in Fig. 5.

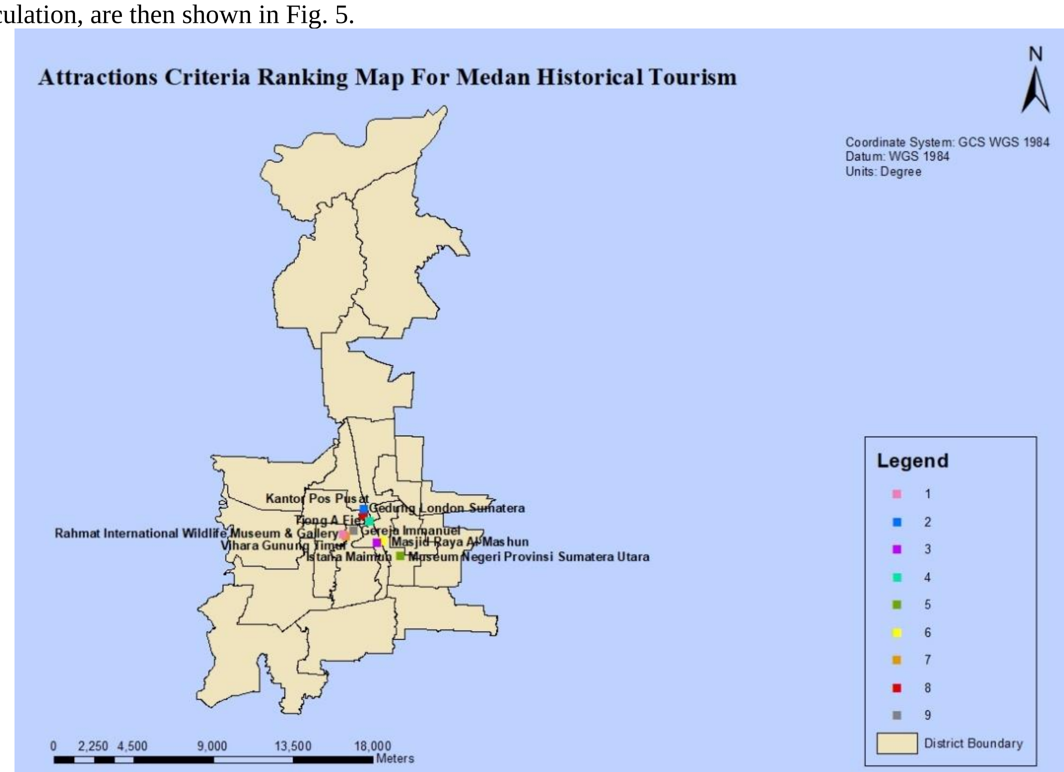

Fig. 5 Attractions Criteria Ranking Map For Medan Historical Tourism

The pink color indicates the highest ranked historical tourism, while the gray color indicates the lowest ranked historical tourism. The comprehensive ranking of historical tourism according to the attractions criteria is shown in Fig. 6.

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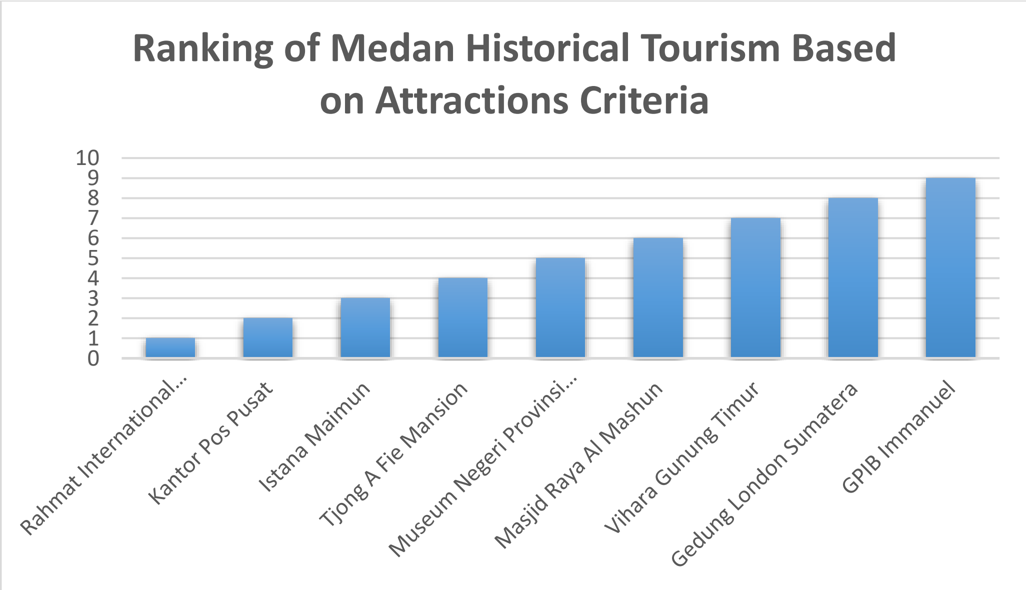

Fig. 6 Ranking of Medan Historical Tourism Based on Attractions Criteria

Ranking Analysis of Potential Historical Destination Objects

The AHP findings for each criterion are used to carry out weighted overlay processing. Figure 7 displays a ranking map of possible historical sites in Medan City according to accessibility, amenities, and attractions, using the weights from the AHP Questionnaire.

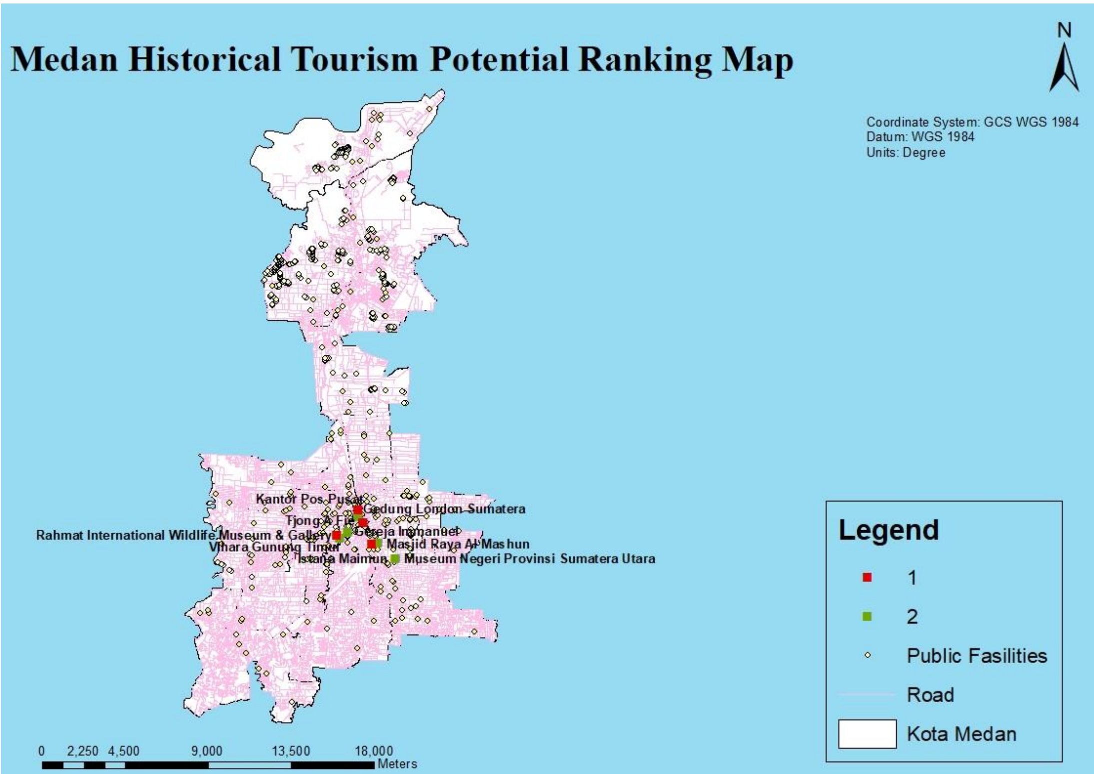

Fig. 7 Medan Historical Tourism Potential Ranking Map

Numbers 1 and 2 indicate the possible rankings for historical destinations. Historical tourism destinations with high potential at rank 1 are shown in red, while destinations with low potential at rank 2 are shown in green. The comprehensive ranking of historical destinations according to the criteria of accessibility, amenities, and attractions is shown in Fig. 8.

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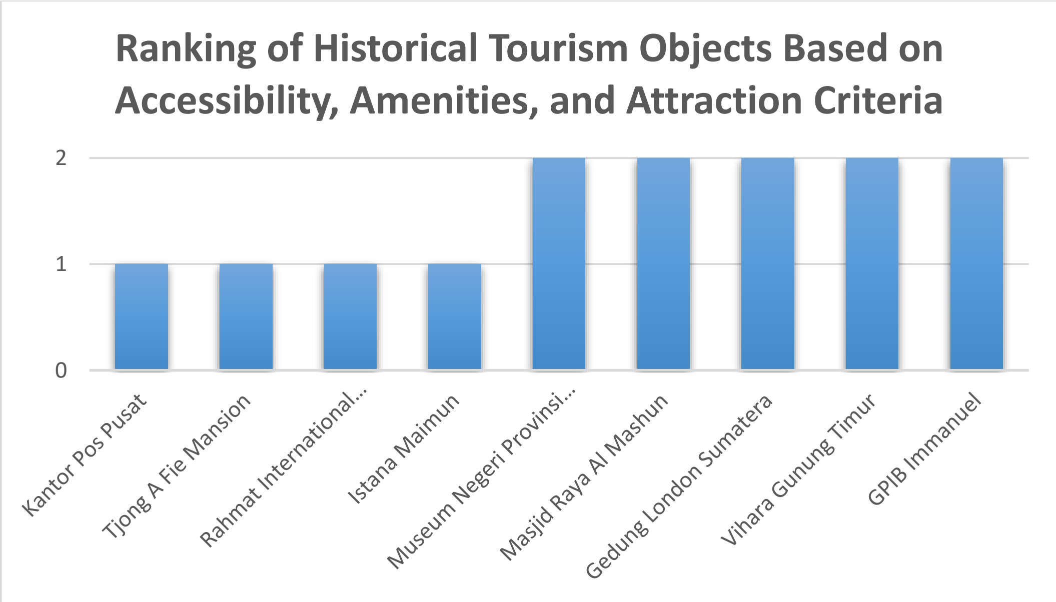

Fig. 8 Ranking of Historical Tourism Objects Based on Accessibility, Amenities, and Attraction Criteria

Planning Alternative Tourist Transportation Routes with Network Analysis

This study used network analysis to plan three alternative tourist transportation routes, each passing through four different historical destinations with high and low potential ratings.

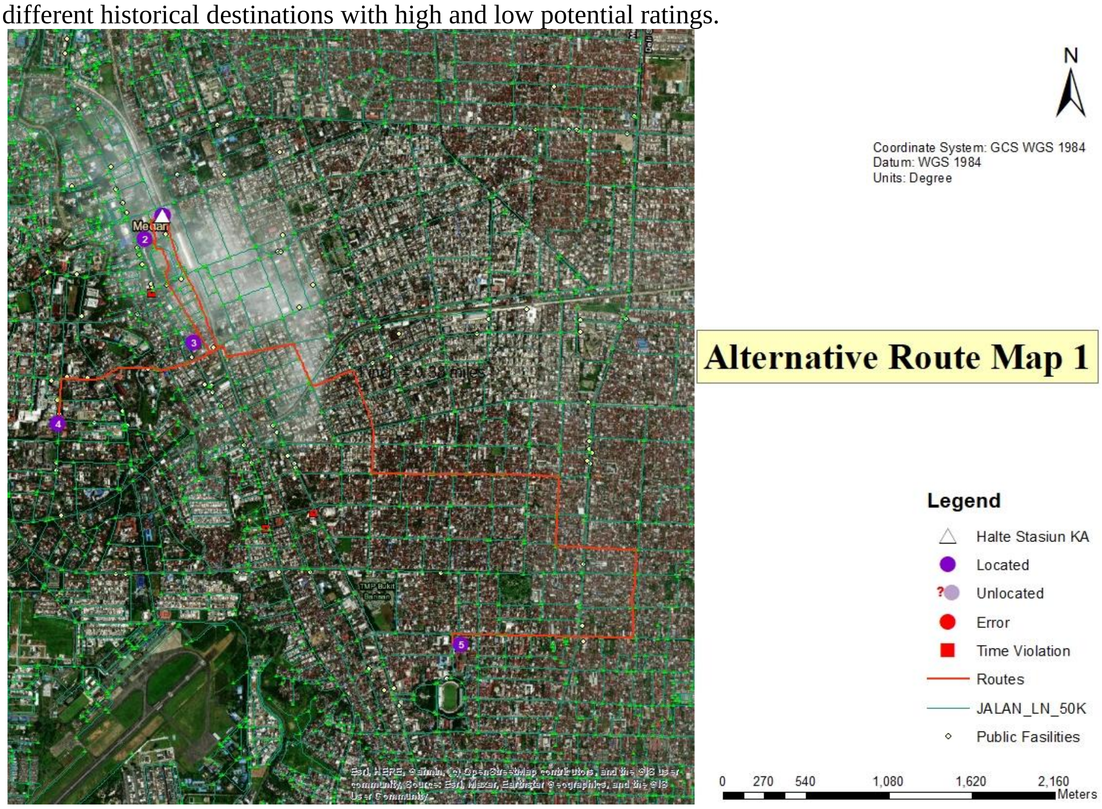

Fig. 9 Alternative Route Map 1 Medan Historical Tourism Transport

Fig. 9 illustrates the first alternative transportation route where there are four historical tourist destinations in Medan City:

- Kantor Pos Pusat
- Tjong A Fie Mansion
- GPIB Immanuel
- Museum Negeri Province Sumatera Utara

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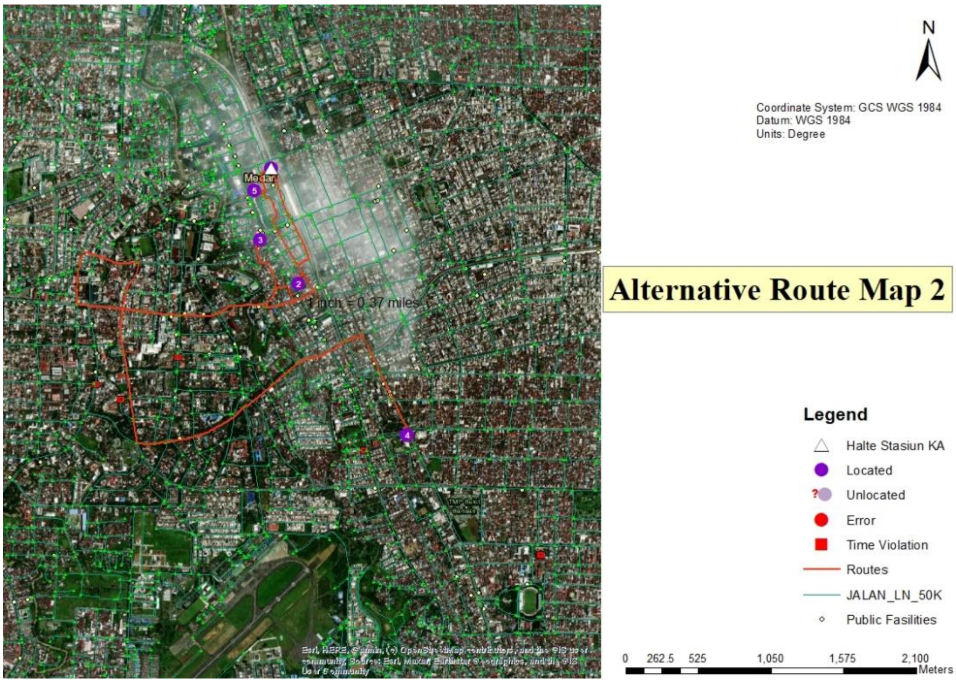

Fig. 10 Alternative Route Map 2 Medan Historical Tourism Transport

Fig. 10 illustrates the second alternative transportation route where there are four historical tourist destinations in Medan City:

- Gedung London Sumatera
- Tjong A Fie Mansion
- Masjid Raya Al Mashun
- Kantor Pos Pusat

Fig. 11 illustrates the third alternative transportation route where there are four historical tourist destinations in Medan City:

- Rahmat International Wildlife Museum & Gallery
- Vihara Gunung Timur
- Istana Maimun
- Gedung London Sumatera

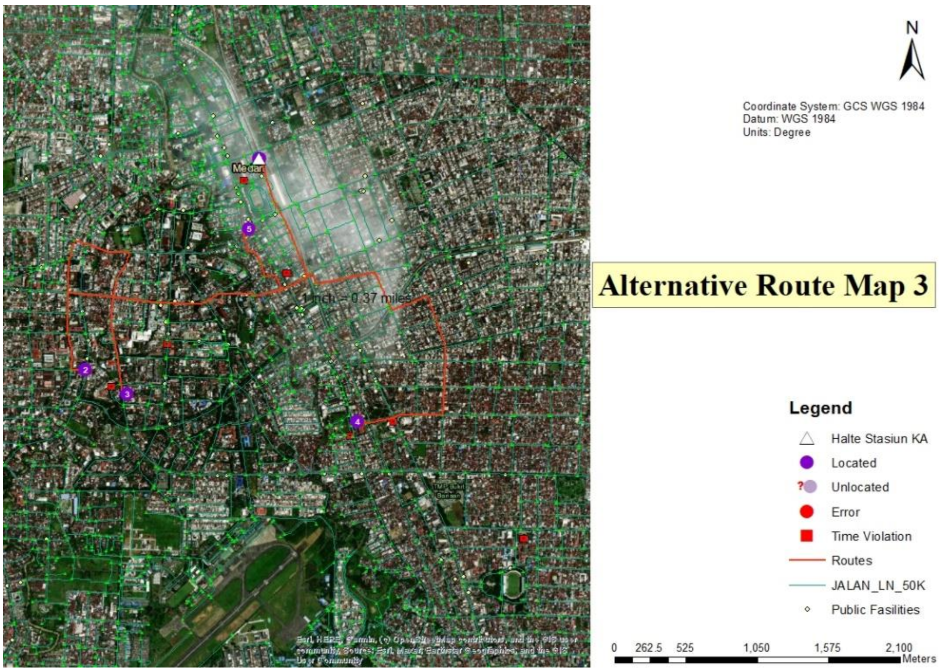

Fig. 11 Alternative Route Map 3 Medan Historical Tourism Transport

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Determination of Alternative Tourist Transportation Routes

VIKOR Method

In this study there are three alternative routes (route 1, route 2, route 3) and two criteria to be analyzed (distance and travel time). Table 5 will present the criteria value of each route alternative:

Table 5
Criteria Values for Each Route

Route	Distance (km)	Travel Time (minute)
1	15,8	55
2	7,6	35
3	10,2	34

Based on Table 5, normalization of alternative values is carried out on each cost criterion (lower is better). The normalization results are shown in Table 6 below:

Table 6
Normalized Decision Matrix

Route	Distance	Travel Time
1	0	0
2	1	0,9
3	0,7	1

Next, calculate the S and R values of each route alternative. Thus, the calculation for each alternative route is obtained as follows:

- Route 1
  $S_1 = 0{,}6(0) + 0{,}4(0) = 0$
  $R_1 = \max[0{,}6(0); 0{,}4(0)] = 0$

- Route 2
  $S_2 = 0{,}6(1) + 0{,}4(0{,}9) = 0{,}96$
  $R_2 = \max[0{,}6(1); 0{,}4(0{,}9)] = 0{,}6$
- Route 3
  $S_3 = 0{,}6(0{,}7) + 0{,}4(1) = 0{,}82$
  $R_3 = \max[0{,}6(0{,}7); 0{,}4(1)] = 0{,}42$

Based on the calculation results above, the largest value for $S = 0{,}96$ and the smallest value for $S = 0$. While the largest value for $R = 0{,}6$ and the smallest value for $R = 0$. Next, the VIKOR index value is calculated, the smallest Q value is the best alternative. The value of $v = 0{,}5$ is assumed. Here are the calculations:

- Route 1
  $$Q_1 = 0{,}5\frac{(0-0)}{(0{,}96-0)} + 0{,}5\frac{(0-0)}{(0{,}6-0)} = 0$$
- Route 2
  $$Q_2 = 0{,}5\frac{(0{,}96-0)}{(0{,}96-0)} + 0{,}5\frac{(0{,}6-0)}{(0{,}6-0)} = 0{,}5 + 0{,}5 = 1$$
- Route 3
  $$Q_3 = 0{,}5\frac{(0{,}82-0)}{(0{,}96-0)} + 0{,}5\frac{(0{,}42-0)}{(0{,}6-0)} = 0{,}43 + 0{,}35 = 0{,}78$$

Based on the results of the VIKOR method calculation, the best alternative route is route 1.

Modified VIKOR Method

This method will use different criteria for each route. This is because the traditional VIKOR method cannot perform calculations if each alternative has different criteria. Therefore, Modified VIKOR will be used for calculations with different criteria for each route. The criteria that will be used for each route are as follows:

- Route 1: distance, travel time, safety
- Route 2: distance, travel time, scenic value
- Route 3: distance, travel time, cost

Table 7 will present the criteria value of each route alternative:

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Table 7. Decision Matrix

Route 1	Distance (km)	Travel Time (min)	Safety (score)
Route 1	15,8	55	8
Route 2	**Distance (km)**	**Travel Time (min)**	**Scenic Value (score)**
Route 2	7,6	35	7
Route 3	**Distance (km)**	**Travel Time (min)**	**Cost (currency)**
Route 3	10,2	34	15

Furthermore, the results for normalization are all shown in Table 8 below:

Table 8. Normalized Decision Matrix

Route 1	Distance	Travel Time	Safety
Route 1	0	0	0
Route 2	**Distance**	**Travel Time**	**Scenic Value**
Route 2	1	0,95	0
Route 3	**Distance**	**Travel Time**	**Cost**
Route 3	0,68	1	0

Furthermore, the calculation of S and R values is done using the same equation as the traditional VIKOR method.

- Route 1
  $S = 0{,}4(0) + 0{,}4(0) + 0{,}2(0) = 0$
  $R = \max[0{,}4(0); 0{,}4(0); 0{,}2(0)] = 0$
- Route 2
  $S = 0{,}4(1) + 0{,}4(0{,}95) + 0{,}2(0) = 0{,}78$
  $R = \max[0{,}4(1); 0{,}4(0{,}95); 0{,}2(0)] = 0{,}4$
- Route 3
  $S = 0{,}4(0{,}68) + 0{,}4(1) + 0{,}2(0) = 0{,}67$
  $R = \max[0{,}4(0{,}68); 0{,}4(1); 0{,}2(0)] = 0{,}4$

Based on the calculation results above, the largest value for $S = 0{,}78$ and the smallest value for $S = 0$. While the largest value for $R = 0{,}4$ and the smallest value for $R = 0$. It is assumed that the value of $v = 0{,}5$ so the calculation is as follows:

- Route 1
  $$Q = 0{,}5\left(\frac{0-0}{0{,}78-0}\right) + 0{,}5\left(\frac{0-0}{0{,}4-0}\right) = 0$$
- Route 2
  $$Q = 0{,}5\left(\frac{0{,}78-0}{0{,}78-0}\right) + 0{,}5\left(\frac{0{,}4-0}{0{,}4-0}\right) = 1$$
- Route 3
  $$Q = 0{,}5\left(\frac{0{,}67-0}{0{,}78-0}\right) + 0{,}5\left(\frac{0{,}4-0}{0{,}4-0}\right) = 0{,}43 + 0{,}5 = 0{,}93$$

Based on the above calculations, the ranking for alternative routes can be given as follows:

- Route 1: $Q = 0$ (The best)
- Route 3: $Q = 0{,}93$

Route 2: $Q = 1$

DISCUSSIONS

Despite having different criteria, the Modified VIKOR method can be adapted to handle different sets of criteria for each route by normalizing and aggregating each criterion appropriately. Route 1 remains the best option according to the Modified VIKOR method, considering the given weights and normalization. Route 1, which was selected as the optimum route is presented in Table 9 below.

*name of corresponding author

Table 9
Optimum Route for Historical Tourism Destination in Medan City

Route	Destinations	Distance	Travel Time
1	Stasiun Kereta Api	0	0
	Kantor Pos Pusat	0,9 km	3 min
	Tjong A Fie Mansion	2,4 km	10 min
	GPIB Immanuel	2,6 km	8 min
	Museum Provinsi Sumut	4,4 km	14 min
	Stasiun Kereta Api	5,5 km	20 min
	Total	15,8 km	55 min

CONCLUSION

This study focuses on the effectiveness of the AHP-VIKOR method and the VIKOR method modified with AHP, which incorporates network analysis, to determine optimal route selection. The conclusions that can be drawn are as follows:

1. AHP-VIKOR Analysis:
   - The weight for each criterion is calculated using AHP, to ensure a structured and objective weighting process.
   - Traditional VIKOR is applied to evaluate and rank routes based on overall performance by considering all criteria uniformly across all routes.
2. AHP-Modified VIKOR Analysis:
   - The weights determined by AHP are used in the modified VIKOR method, which handles different criteria for each route.
   - This method provides a more customized evaluation by considering additional criteria specific to each route, resulting in a more accurate and relevant ranking.
3. Network Analysis:
   - Network Analysis is used to understand the interrelationships and influences among various criteria and routes.
   - This view helps in identifying important factors and their impact on the overall decision-making process.
4. Results and comparison:
   - Both the AHP-VIKOR method and VIKOR modified with AHP provide a systematic approach to route selection.
   - AHP-modified VIKOR offers greater flexibility and accuracy by accommodating different criteria for each route, making it more adaptable to complex decision-making scenarios.

AHP-VIKOR, although robust, lacks flexibility in handling route-specific criteria.

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