Highway route selection using GIS and analytical hierarchy process case study Ramadi Heet rural highway

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Abstract: An appropriate road network imposes on planners take into account factors such as land use, slope, soil type, hydrology, and agricultural area. Due to various considerations and desires, the planning process is difficult hence there may be confusion in interest in the decision-making process. The use of a geographic information system (GIS) and Multi-Criteria Decision Analysis (MCDA) assist planners in achieving more detailed and desirable results. Thus, reducing the complexity of the planning process and helping various stakeholders for drawing to general conclusion. The study site was chosen on an area between the cities of Ramadi and Heet in Anbar Province, western Iraq, where it suffers from congestion and traffic accidents. This research aims to integrate a set of evaluation criteria using the Analytical Hierarchy Process (AHP) and a spatial multicriteria model to find the optimal path in the study area. In this study, two alternate paths were proposed and compared with the current path to find the best path. Finally, the results indicated that the first alternative is 36% better. This research succeeded in proving that it is possible to decide a rural highway route between two cities using GIS and MCDA.

Keywords: spatial analysis; Highway route selection; GIS; MCD; AHP.

1. INTRODUCTION

The method of planning and building roads is known as one of the most complex tasks in achieving a combination of technological, economic, and environmental factors. Furthermore, the technique for deciding the best route is one of the stages that are dependent upon some location criteria that requires a harmony between them, to limit losses due to natural resource depletion and reduce the initial survey to determine the best route [1].

The challenge of choosing and constructing new roads between cities is a popular one in transportation engineering, and several papers have been published to solve it using various techniques such as geometry, optimization, and logic. The basic highway design challenge is to determine the most cost-effective route between two defined end points, taking into account topography, socioeconomic conditions, and environmental effects, while also...
meeting a collection of design and operational constraints [2]. The traditional method of finding the best highway route is a tedious, costly process and time-consuming because of the many factors that must be considered. Moreover, the paths of roads are often influenced by social, economic, environmental, political, and restrictive factors [3].

The selection process may be difficult and time-consuming when all these factors are taken into consideration. Therefore, new techniques are needed that can save time and money in planning [4].

GIS is widely used in civil engineering applications. Transport and highway engineering is one of these fields that has been affected by developments in aspects of geographic information systems. Because of their capacity to consider a large number of spatial variables at the same time [5]. GIS are powerful spatial analysis tools that allow you to collect, store, query, evaluate, view, and output geographic data.

GIS can facilitate the route selection process during the early stages of highway planning. Use of GIS selections gives the ability for prioritization by displaying spatial gauges from different areas and points of view, and finally aids in making broad decisions. The required data depends on the nature of a spatial decision problem [6][26].

A few qualities of spatial decision-making issues have been assessed dependent on various criteria. Spatial multi-standards decision-making (SMCDM) includes the investigation of model qualities upheld by geographic events, so the decision maker’s preference for a set of analysis criteria [7]. An enormous number of important components settle on it hard to settle on spatial choices, and it is hard to attempt to acquire and process data to obtain decision-makers. Accordingly, the utilization of GIS and MCDM technology to support decision-makers can obtain more effectively and efficiently to solve spatial decision-making problems GIS and multi-criteria research have supported planners in acquiring ideal and more reliable outcomes, subsequently diminishing the intricacy of the arranging interaction just as urging assorted gatherings to arrive at an overall resolution[25] [8].

This research aims to find the optimal route between the cities of Ramadi and Heet, the path that complies with the requirements of government regulations and that saves the cost and travel time between the two cities.

The methodology is based on using GIS data and remote sensing to perform spatial analysis and to develop a methodology for choosing the best route based on certain criteria using GIS as an implementation platform. The improvement is based on several criteria such: slope, land use, hydrology, soil type, and agricultural land.

**METHODOLOGY AND MATERIAL**

**1.1 Study Area**

The study area is locating in Al-Anbar province, in western Iraq, between Ramadi and Heet cities which includes the extent of latitude between (33°40’00” - 33°20’00”) N and longitude between (42°40’00” - 42°20’00”) E according to UTM metric unit. This area includes various villages. The existing road is about 62 km. Since the Euphrates River flows through the study area, farming is the primary land use practice of the people in the area. The population density in villages varies and differs from one village to other, but it is usually not dense.

The road construction materials availability near the Euphrates River are the main property of the area, which will reduce the cost of road construction. The main climatic characteristics of the study area include rain of varying amounts and low, temperature variation, presence of strong winds, and dust storms. The annual rainfall recorded is about 115 mm. The weather is also characterized by its coldness in the winter season, high temperatures and drought in the summer. The average temperature in summer is (43°C), while it decreases in the winter to reach about( 2.6°C). Humidity also rises between October and May[9]. The surface of the
study area is generally characterized by flatness, but the height increases as we head towards the west, as its height ranges between 60 to 120 MASL. [27].

Figure 1. Study area

1.2 Methods

This research aims to design a model that explains the possibility of finding the optimal route for a rural highway connecting the cities of Ramadi and Hit. Figure (2) briefly illustrates the methodology steps. The following steps explain the methodology for choosing the best path:
1: Define criteria and prepare data
2: criteria weights
3: suitability map creation for the route
4: generating alternatives and select the best route.

The operations were carried out using ESRI's ArcGIS 10.8 Spatial Analyst as shown in the fig(2):

**Figure 2.** The flow-chart of different procedures to select the optimal path between Ramadi and Heet cities.
1.3 Data sources and modeling procedure

Remote sensing is an effective method for collecting data without direct communication, and it is particularly useful for obtaining information about land uses such as agricultural land, water bodies, urban areas, and slopes are obtained by analyzing and interpreting satellite images and maps covering the entire study area at various scales as shown in Table (1).

| Sources                          | Data used           | The Derived Layers |
|---------------------------------|---------------------|--------------------|
| USGS\(^1\)                      | Satellite image     | Land use           |
|                                 |                     | Agriculture lands  |
| NASA\(^2\)                      | ASTER DEM           | Slope              |
|                                 |                     | Hydrology          |
| FAO\(^3\)                       | Soil type map       | Soil type          |

1. United States Geological Survey. Landsat 8 image of 2020 downloaded from [https://earthexplorer.usgs.gov/](https://earthexplorer.usgs.gov/)
2. National Aeronautics and Space Administration. AASTER DEM downloaded from [http://search.earthdata.nasa.gov/search](http://search.earthdata.nasa.gov/search)
3. [http://www.fao.org/](http://www.fao.org/)

All parameter were extracted from ArcGIS 10.8 package. All of the data’s coordinate systems were combined using the UTM-WGS84 Zone 38 N projection.

1.4 Criteria Selection

The first stage of any highway location study is to check all existing data for the area where the road is to be built. This stage is normally carried out in the office before any field or photogrammetric investigation. All available data is gathered and analyzed. These data can be gathered from maps, existing engineering reports, and charts that are normally available in one or more of the state’s departments of transportation, agriculture, hydrology, geology, and mining departments. The amount and type of data gathered and checked depends on the type of highway considered [10].

The criteria that are relevant in deciding the best road route in rural areas are briefly described below:

i. **Slope**: The slope map is created using the study area’s Digital Elevation Model (DEM). The slope is divided into 5 categories as shown in Fig. (3b). If the slope percentage increases, so do the amount of earthwork required. As a result, fields with a low slope are given a high suitability rating, whereas fields with a high slope are given the lowest [11][12][18].

ii. **Soil type**: The soil properties are important in determining the route selection process. Soil surveys for highway construction include examining soil properties along the highway and identification of soil suitable for use as fill and subsoil. Due to soil conditions that can have a significant impact on the location of the roadways, a detailed study of the land at the road end location is always carried out. Fig.(3d) shows a soil map for the study area, as it is divided into four categories: The first is (silty loam) represents 34%, the second (clay loam) represents 49%, the third (loamy sand) represents 12%, and finally (sandy clay) represents 5% From the total area. [10][19][2]

iii. **Earthwork**: Earthwork involves cutting and filling volumes, and the price per unit volume varies depending on soil type. As a result, the excavation costs for hard rocks and comparatively soft soils will differ greatly. Cut and fill volumes that will be
calculated using the design surface, created in the CADD program, which will be imported into ArcView. It is preferable that the cut quantities are close to the filling quantities to avoid increasing the cost, and that any increase in the quantities of cut and filling will be accompanied by an increase in the cost [13][14][15].

iv. **Length:** The length of the road decides the total construction time. The shorter the distance, the shorter construction period and disruption for the public and local businesses. Using GIS, the length of each candidate route in kilometers was estimated. the route with the longest value will be less suitable [8][16][17].

v. **Hydrology:** The valley’s location is obtained from a DEM map. Valleys are classified according to their cross-section. While type 1 realized as a smaller cross-section And therefore the best appropriate,type7 realized as a larger cross-section And therefore the less appropriate, as shown in Fig. (3c) [1][3][28] [20].

vi. **Land use land cover (LULC):** LULC is important to show the socio-economic and environmental effects of a road project. LULC was extracted from Landsat 8 satellite imagery taken in June 2020 as a result of the controlled classification used. A signature file for controlled classification is created, training samples are taken and classification is carried out with maximum probability, this divides the study area into four major groups of land cover groups: barren land (50%), grass, and vegetation (34%), built-up area (10%), and water (6%) as shown in Fig. (3a) [8][19][21].

1.5 **Criteria weights**
A specific weight must be determined between all the criteria factors in each alternative because they have different priorities according to the goals and objectives. Because the criteria factors in each alternative have different priorities depending on the aims and objectives, special weight must be assigned to each of them. The AHP method is a powerful method for calculating weights by comparing each factor to its corresponding factor, which is preferable to giving absolute weight without any comparison [4],[23].

The AHP evaluation was created in three stages:

The first stage is to develop a comparative matrix of the matrices. The Saaty scale was used for determining the relative significance of the chosen criteria by the study's expert team (and questionnaire). The advanced pairing matrix from the earlier comparisons is then normalized in the second step; The final step is to calculate each factor's weight, which is used to calculate the comparison matrix's eigenvectors.

| Table 2. AHP Saaty scale [23] |
|--------------------------------|
| Definition                  | Preference |
| Equal importance            | 1          |
| moderately importance       | 3          |
| Strongly importance         | 5          |
| very strongly importance    | 7          |
| extremely importance        | 9          |
| intermediate values         | 2, 4, 6, 8 |

The weighting method can be calculated as follows:

First, the factors are compared to each other. The next step is to determine the weight of each attribute factor. This factor is the primary Eigenvectors of the resulting matrices obtained by multiplying the pairwise matrix itself. Following that, each row sum will be
calculated and normalized by the sum of all rows, yielding the real factor weight for each attribute. Based on [4, 23] each column is summed:

\[
C_{ij} = \sum_{i=1}^{n} C_{ij}
\]

(1)

and then each cell is divided by the column sum:

\[
X_{ij} = \frac{C_{ij}}{\sum_{i=1}^{n} C_{ij}}
\]

(2)

To construct a weighted matrix, divide the sum of the matrix’s normalized column by the number of parameters (n).

\[
W_{ij} = \frac{\sum_{n=1}^{n} X_{ij}}{n}
\]

(3)

The decision maker’s preferences must be tested for consistency before using the weights. Through multiplying each layer’s weights by the original decision matrix then summing the results around the rows, the eigenvector of the evaluation matrix is computed, then dividing each row’s sum by the corresponding layer’s weight.

\[
\lambda = \sum_{i=1}^{n} C_{v_{i1}}
\]

(5)

\[
CI = \frac{\lambda - n}{n-1}
\]

(6)
Table 3. Random Index (RI) values depending on the number of the criteria[23].

| No. of criteria | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|-----------------|------|------|------|------|------|------|------|------|------|------|
| RI              | 0.00 | 0.00 | 0.58 | 0.9  | 1.12 | 1.24 | 1.32 | 1.41 | 1.46 | 1.49 |

\[
CR = \frac{CI}{RI} \tag{7}
\]

In the hierarchy developed for this study, four main criteria under the objective (selection of the best highway route), are adopted. Pair comparison matrices were generated for each of these four groups. As shown in Table (4), where the generated pairwise comparison matrix is displayed. After that, the AHP method is used to determine each parameter’s weights.

Table 4. Pairwise Comparison Matrix

| criteria     | Soil type | LU/C | Hydrology | Slope | weights |
|--------------|-----------|------|-----------|-------|---------|
| Soil type    | 1         | 1/6  | 1         | 1/2   | 10.25%  |
| LU/C         | 6         | 1    | 8         | 1     | 48.8%   |
| Hydrology    | 1         | 1/8  | 1         | 1/5   | 7.3%    |
| Slope        | 2         | 1/6  | 5         | 1     | 33.6%   |
| Sum          | 10        | 1.45 | 15        | 2.7   | 100%    |

![Image a](attachment:image1.png)

![Image b](attachment:image2.png)
2. Results and Discussion

2.1 Suitability map creation for route selection by GIS

After collecting and preparing the data, these data are reclassified on a proportional scale from 1 to 9, where the 1 is used to represent the less suitable areas, while the 9 is used to represent the high suitable areas. The reclassified map aids to distinguish between bad and well areas to choose the highway route.

After weighing the criteria and the formation of the surface of suitability concerning the relative importance of each criterion as well as the suitability index, after which the criterion maps are overlapped using the weight output from AHP, a final Spatial suitability map was developed using a weighted overlay for obtaining the equal surface cost for all standards, the weighted overlay approach is considered an efficient technique for making multi-attribute spatial decisions. This process can be designed using a GIS system with overlay capabilities, allowing for the combination of the evaluation criteria map layers to be merged to determine the composite map layer.

The result of the study is a map of various colored regions ranging from very good to very poor in terms of suitability for choosing a road direction as shown in fig (4). The green areas were designated as very good Areas, light green areas were designated as good areas, yellow areas were designated as Medium areas, brown areas were designated bad areas, and red areas were designated very bad areas in the resulting weighted overlay map.

Figure 3. Thematic maps for weighted overlay criteria: a) Slope; b) Land use; c) Hydrology; d) Soil type
The most important part remains to find the optimal route, to achieve this all restrictions and limitations are taken into consideration to find a variety of highway alternatives, one of them will be the best highway route. From the weighted overlay map that resulted, it could be determined to select the best highway route by carefully designing the route to travel through the colored areas marked by a high suitable while avoiding the less suitable.

For verification aim, it was determined to select two routes as shown in fig (5). These two routes were compared with the current road to choose the best one.

2.2 Proposed alternatives routes and best route selection

After determining the alternative routes, the best highway route can be chosen by taking into account the multiple criteria imposed by the user, as the multicriteria decision helps in the selection of an alternative from a set of options identified by criteria values. To generate alternatives, this study chose two routes. These two routes will be compared to the current

![Suitability Map](image1)

**Figure 4.** Suitability map

![Proposed Alternatives](image2)

**Figure 5.** Proposed alternatives.
route and evaluated according to the criteria that have been mentioned above to choose the best one. It's important noting that, the analysis should help optimize performance by linking strategic places and optimizing network capacity. The two alternate routes are evaluated using the above-mentioned criteria. Taking into account route characteristics and user preferences, decision rules offer the foundation for separation and evaluating decision alternatives. The last step of the multi-criteria process can be implemented in the cross-tabulation of standards and alternative methods below. Decision-maker chooses the appropriate score of alternatives according to the criteria, and as shown in Table (6). The sum of all criteria for each option is calculated using the normalized sum method.

Among them, when selecting a preferred alternative, a higher value is more preferable to a smaller value. It is worth noting that the weights mentioned in the table of weights mentioned in the table were chosen according to the opinion of transport experts. Accordingly, the first alternative was chosen as the best route selection based on the multi-criteria evaluation.

Table 5. Summary Characteristics for Alternative Routes

| Criteria                        | existed route | The first alternative | The second alternative |
|---------------------------------|---------------|-----------------------|------------------------|
| Slope                           | 7             | 9                     | 9                      |
| Soil type                       | 6             | 9                     | 9                      |
| Length                          | 6             | 9                     | 7                      |
| Cut and fill/Earthwork          | 8             | 7                     | 9                      |
| Horizontal Alignment            | 8             | 7                     | 6                      |
| Vertical Alignment              | 6             | 9                     | 7                      |
| Noise                           | 9             | 8                     | 8                      |
| Air pollution                   | 8             | 7                     | 7                      |
| Agriculture land                | 8             | 6                     | 5                      |
| Hydrology                       | 8             | 8                     | 8                      |
| Landscape                       | 5             | 9                     | 8                      |
| Land use/cover                  | 8             | 6                     | 6                      |
| Degree of urbanization          | 7             | 9                     | 9                      |
| Population Density              | 5             | 9                     | 8                      |
| Cost of construction            | 5             | 9                     | 7                      |
| Cost of maintenance             | 6             | 9                     | 7                      |
| Number of bridges               | 8             | 8                     | 8                      |
| number of culverts              | 5             | 9                     | 7                      |
| Land tenure                     | 8             | 6                     | 6                      |
| Sum                             | 131           | 154                   | 141                    |
| **Normalized Score**            | **31%**       | **36%**               | **33%**                |
**Figure 6**. model for best highway route

**Conclusion**

Based on the application of GIS in transportation planning, the AHP is used to weigh the different viable variables in the proposed measures. The Spatial Analyst module of ArcGIS 10.8 is used to determine the best route. The current research looks at how non-spatial and spatial data can be combined in a multi-criteria decision system to formulate and choose the best route. In the current study, the first alternative was chosen with a length of 55 km, which starts with an approximate coordinate of (E339136.052, N3701212.88) and ends at an approximate coordinate (E298365.797, N3724687.642).

The GIS-based analysis used in this study revealed that the multi-criteria approach is well recognized as a tool for determining the best route by taking into account a variety of considerations that influence decision-maker's choices. It also saves effort, time, and cost.

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