



Finding High-Speed Railways Routes between Nasiriyah and Najaf in GIS Platform

Ali Hussein Majeed^a, Nooraldeen Sameer Majeed^b
^{1,2} National University of Science and Technology, Nasiriyah, Iraq.
hussein.g.shukir@nust.edu.iq

Abstract

Over the past years, population growth has become a major challenge in developing countries. The starting point of this challenge is the resulting volume of urban traffic leading to increased time, demand and public transport costs. As a result, the purpose of this study is to use spatial analysis and the ability to represent three-dimensional analysis of geographical information system (GIS) to locate the construction of high-speed rails. Basically, the selection of high-speed railways is an exploratory process involving a diverse set of conditions and choices. Therefore, experts and professionals based on their knowledge use different criteria to solve decision problems. Criteria used in this study include proximity to the Nasiriyah and Najaf, slope, user maps, proximity to settlements, access to roads, water resources and the status of oil transmission lines. First, the data were analyzed in two separate steps using the multi-criteria decision model (MCDM). At the same time, the analytic hierarchy process (AHP) has been used to weight each criterion, and a new technique has been proposed to prioritize routes based on the technique for order of preference by similarity to ideal solution (TOPSIS) method for single-rail trains. Then, by overlapping the weighted layers of the optimal paths, the best paths were categorized into five categories including "very appropriate", "appropriate", "moderate", "inappropriate" and "very inappropriate". The results proved that the length of the selected optimal route from Nasiriyah to Najaf is exactly 224 km.

Keywords: High-Speed railway; Geographical Information System (GIS); Routing, Railway; Multi-criteria decision model (MCDM).

DOI Number:10.14704/nq.2022.20.8.NQ44572

NeuroQuantology 2022; 20(8): 5410-5437

5410



1 Introduction

Rail transport is one of the safest and most efficient methods of communication in different societies connecting the social, economic, military, agricultural and cultural aspects. Rail transport transfers the largest volume of goods and passengers with the desired reliability. A variety of reasons, such as low fares, an integrated service system, minimal pollution, high carrying capacity and low energy consumption, have made the industry popular among politicians and officials. Providing new transportation facilities is one of the main aspects of investing. Due to the large impact on investment profits and losses, the choice of inner-city and suburban railway lines is very important (Kosijer et al., 2012). Decisions regarding the situational distribution of facilities and services have a great impact not only on the economic conditions of the city, but also on the social lifestyle of the residential community. As a result, finding an optimal path meeting the technical and economic dimensions with minimal damage and deformation seems critical. Geographical information system as a new technology is able to solve this problem through a systematic and comprehensive approach.

Often, any public transportation infrastructure development project begins with a needs assessment and ends with a forecast of future demand. As a result, specific answers are identified through screening and spatio-temporal search of solution space. In this way, the paths meeting the screening criteria are accurately evaluated. In general, screening criteria include several indicators such as economic, social, cultural, religious, technical-engineering, organizational and environmental conditions (Alkubaisi, 2014). High-speed rail is one of the public transportation networks playing a vital role. With the increase in urban density, the complexity of the traffic situation and the growth of accident statistics, high-speed railways can provide a high level of comfort for passengers. At the same time, the construction

of high-speed and efficient railways will reduce depreciation on the roads, protect the environment, accelerate the process of industrialization and optimize fuel consumption. These dimensions represent cost-effective, efficient objectives as well as environmental aspects in the construction process. GIS technology, using multi-criteria analysis, can provide planners with several desirable solutions and select the best ones to assist decision makers. Of course, this process must be carried out in a complex framework and help stakeholders to achieve the desired result. Geographical information systems along with multi-criteria decision making model (MCDM) methods have been widely used in solving routing problems (Ngunyi et al., 2017). GIS is used for spatio-temporal analysis in the screening stages of candidate sites. MCDM is then used to weigh and identify the most suitable locations. As a result, a combination of multiple parameters, analytical techniques and decision-making methods can be used to solve the problem. In general, multi-criteria spatio-temporal decision methods involve a set of spatial options. One or more options are selected from the set according to the evaluated criteria. That is, the results of the analysis depend not only on the distribution of spatio-temporal characteristics, but also on the intelligent judgments of decision makers (Nedevska et al., 2017). Experimental results prove that scientific GIS is quite effective for optimizing the distribution of spatial and linear objects such as roads, railways and pipelines. With the development of GIS, the possibility of modeling variables as well as topography, environment, geology, residential areas and land use, the issue of high-speed rail routing has become a vital challenge. For this reason, we want to take an effective step in solving the problems of the Iraqi railways by considering the spatial variables in the geographical information systems and the implementation of multi-criteria decision-making processes.

5411



2 Literature review

It is very important to review the latest studies in order to achieve the research objectives. For example, to review the application of the GIS system in the field of railways, you can refer to the reference (El-Bakry & Awad, 2010). The title of this paper is "Using Different Multi-Criteria Analysis Methods for Railway Selection". The purpose of this paper is to select the best railway route according to the factors and a set of predetermined objectives. In the first step, the use of multi-criteria analysis of decision-making to select the best railway route is described. Subsequently, in the second step, the types of multi-criteria analysis methods in the study area are described using three different methods (weighted aggregation method, AHP method and VIKOR method).

In study (El-Bakry & Awad, 2010), railway lines between different stations are designed based on GIS. For this reason, a comprehensive geographical information system has been developed for rail routing. Finally, the successful operation of the system has been proven in some issues such as route determination, accident location recording and emergency services.

In the study (De Luca et al., 2012), the first Berlin-Palermo railway axis and its corridors were designed and managed using GIS. The objectives of this paper are the design of high-speed rail lines, the use of GIS and multi-criteria analysis. The multi-criteria decision-making approach used in this study has helped to design, evaluate and improve the final options for high-speed trains.

In the study (Ahmed & Asmael, 2015), the optimal routing of Baghdad metro was performed based on geographical information systems and multi-criteria decision making methods in catchments around stations. The results of this study showed that AHP and TOPSIS methods are very useful tools for selecting and evaluating desirable options.

In the reference (Darvishsefan et al., 2004), the issue of environment has been considered in

the selection of railway routes using geographical information systems in the Rasht-Anzali railway. In this research, a hierarchical analytical process has been used to determine the optimal paths for comparison with traditional methods. Subsequently, the results showed that the paths designed by GIS have better environmental dimensions compared to the results of traditional methods leading to significant profitability and efficiency for decision makers.

In study (Kiema et al., 2007), optimal railway routes in GIS have been evaluated based on the capability of multi-criteria decision-making models on the Kenya-Sudan route. This paper proved that the success of the AHP model largely depends on the integrity of the weights assigned to the criteria. For this reason, benchmarking weights should be specified in full consultation with all stakeholders, including engineers, consultants and environmentalists. As a result, after extracting the required data sets and classifying them, the layers were evaluated using the AHP process.

In the study (Djenaliev, 2007), multi-purpose decision making and GIS are used for railway planning in Kyrgyzstan. This paper first provides information on various factors that determine the location of stations and the planning of railway lines in Kyrgyzstan. To achieve these goals, multi-criteria stochastic decision model (MCDM) processes were designed and developed for the planning of railway stations and railways using GIS.

In research (Dufourd et al., 1996), the taboo search algorithm has been used to locate fast transport lines. In this algorithm, the objective function of maximizing the coverage of the route population is selected. Therefore, special restrictions such as the number of stations on the route, minimum and maximum distance between stations in an access network were calculated.

According to the mentioned researches, the most important challenge is to consider different perspectives in the final routing.



Therefore, in this paper, we present an effective solution by implementing hybrid scenarios involving the opinions of different experts and combining two methods of hierarchical analysis and proximity to the ideal solution.

3 Theoretical foundations

Geographical information system is an efficient system for decision making and consulting in the field of route design. In optimal path design, the GIS system offers important capabilities for information analysis, monitoring, processing, management and planning. Also, based on GIS, we can model effective factors such as technical-engineering, economic and environmental dimensions and determine the optimal path by evaluating and implementing the required algorithms. Given the amount of spatial data required and the need to update them, geographical information systems play a vital role. This information is collected in the form of tables, lists of names and addresses. As a result, processing them with conventional and non-computer methods is very difficult and sometimes impossible. These data are easily processed and analyzed when they enter the geographical information system. This process leads to cost savings in time and money. The geographical information systems provide vital capabilities for analyzing, monitoring, processing, and managing information (John, 1993). GIS workflows in the field of routing include information gathering, initial processing, existing information management, final analysis, and product production. Initially, the information needed to prepare large-scale maps is collected and the necessary aerial photographs are processed. In the next step, the conditions for entering and storing data in the geographical information system database are provided. Next, information is analyzed at different layers in GIS using processing functions. The prepared layers are weighed and the overlaps of the layers are formed by applying weights. Finally, the optimal paths are determined based on the combination and overlapping layers (Dubey, 2010).

The first step in the path selection process is to set efficient criteria. The list of criteria determines the conditions for performing the routing process. In fact, the criteria are rules followed by experts in the routing process. Such criteria vary in different organizations and project. So defining them is crucial at the beginning of any project. These criteria include duration of activity, cost of activity, criticality of activity, buoyancy of activity, necessity of activity, required resources, and technical-engineering complexities in construction, design, supply, management, cost-effectiveness, management, concept environmental issues and security-safety issues and so on.

The general rule for choosing evaluation criteria is to pay attention to the problem framework and its objectives. Usually, two general methods are used to determine the evaluation criteria. First, identify the number of evaluation criteria so that the decision model best describes the status of the problem. Second, the situation of the problem is described based on a few criteria and makes the problem too simple. In the second method, access to data and their quality are usually considered (Malczewski, 1999). In this research, a comprehensive and measurable set of attributes is used for decision making. These criteria are:

- Geographical proximity to the Nasiriyah and Najaf.
- Slope degree.
- User map.
- Proximity to urban settlements.
- Proximity to the road.
- Proximity to water sources.
- Proximity to oil transmission lines.
- Proximity to the old railway.

3.1. High-speed rails routing process using multi-criteria decision-making techniques

In general, transportation systems include four categories: air, road, rail and sea. To access any of these systems, passengers must reach airports, terminals, railway stations, ports, and docks. Therefore, one of the most important



aspects in choosing a transportation system is the issue of access to the system location. That is, the location process is critical to any transportation system. The advent of high-speed technology as the most efficient way of transporting passengers on inter-city routes has revolutionized rail transportation. The high-speed rail transportation system has many advantages such as less energy consumption, high safety, bulk cargo and passenger transportation, environmental-friendliness and less space occupation. For this reason, it has a special position in the transportation industry. Deciding and choosing the right option is crucial in the process of high-speed rail routing. In the routing process, the most important parameter is finding the best way to communicate and evaluating the source-destination connection with a low-cost route. Shortening of railway lines leads to a huge reduction in equipment costs. As a result, we must use appropriate decision-making techniques to select and rank the effective parameters. In this section, the concepts of decision-making techniques used in this research are described.

3.1.1. History of Analytic Hierarchy Process (AHP)

The AHP technique was first proposed in 1980 by Professor Thomas L. to make decisions and evaluate different options and activities (Process, 1980). This technique falls into the category of multi-criteria evaluation and decision-making methods (Process, 1980). The method of hierarchical analysis has sufficient ease and flexibility in solving problems related to different sciences. The main application of this technique is in engineering sciences and design of technical projects. In addition, this method has many applications in environmental studies and urban planning. Most research in this field has been conducted in the late 1990s and early twentieth century, and has provided flexible results for programmers and application designers. However, in some studies, a fuzzy hierarchical analysis process with uncertainty modeling has been used.

3.1.2. Modeling of factors affecting railways routing with AHP

Hierarchical analysis method has been used to determine the relative importance of different criteria in railways planning. To carry out this process, the researchers formulated the decision problem with seven criteria including land use, slope, settlements, old rail network, roads, water resources and oil pipelines.

3.2. TOPSIS method

In this method, in addition to considering the distance of the A_i option from the ideal point, its distance from the negative ideal point is also calculated. That is, the selected option must have the shortest distance from the ideal solution, at the same time it must have the maximum distance from the negative ideal solution. The assumptions of this method are:

A) The desirability of each criterion should be uniformly ascending or descending (the higher the R_{ij} , the more desirable and vice versa). The highest value of a criterion indicates its ideal and the lowest value indicates a negative ideal for it.

B) The distance of an option from the ideal (or from the negative ideal) is calculated in the form of Euclidean distance or the sum of absolute values from linear distances (block distances). This process depends on the exchange rate and replacement between criteria (Triantaphyllou, 2000).

4 Implementation

The optimal route of a high-speed railway is determined by a multi-criteria decision-making method. The innovation presented in this paper is the evaluation of proposed routes based on AHP using TOPSIS method. First, basic knowledge and basic data are combined in stages. Features and specifications of raw data and analyzed data include classified layers, and tabular information. In the study area, potential routes between the cities of Nasiriyah and Najaf are being investigated. Also, different scenarios are designed using the opinions of different decision makers (14 people). Finally, using the TOPSIS ranking technique, the steps of selecting



the best route for the construction of the railway are completed.

4.1. Area under study

The study area is the area between the cities of Nasiriyah and Najaf. Nasiriyah is the capital of Dhi Qar province (Iraq's fourth largest city). The city is located 370 km southeast of Baghdad on the Euphrates River. The ruins of the ancient city of Ur are located near this city. Also, the population of the city is about 560,200 people. Najaf is located 160 km south of Baghdad at 31.99 ° and 44.33 ° northwest. Its population is estimated at 675,000. The Najaf is geographically close to the city of Kufa. The Najaf and Kufa are so close to each other that the two cities cannot be separated from each other. This city is the capital of Najaf province (one of the holiest cities and the center of Shiite political power in Iraq). Najaf has always been the residence of pilgrims and devotees of religious sciences. These factors have led to trade popularity in the city. For a long time, this city has been on the route of Hajj caravans that have gone to Mecca and Medina by land. This feature has a great impact on creating an effective connection between Najaf and other cities and centers.

The most important railways in Iraq include the following:

- Baghdad - Baiji - Mosul - Rabieh (524 km): This standard railway starts from Baghdad and ends to the Mosul (412 km). The railway line continues from the northwest to Rabieh, 112 km from the Syrian border, and eventually connects to Turkey and Europe. This route is called the "Eastern high-speed railways".
- Baghdad - Hila - Devaniyah - Samawah - Nasiriyah - Basra - Umm Al-Qasr (609 km):
- This railway starts from the west of Baghdad, passes through Hila, Devaniyah and Nasiriyah and reaches Basra. Then it continues towards Umm Al-Qasr.
- Baghdad al-Qaim line (approximately 375 km long): This route connects Iraq to the Arab ports of Syria and Lebanon in the Mediterranean Sea and has several tributaries:
 - Qabishia - Basra - Umm Al-Qasr (158 km);
 - Al-Shuaibi - Umm Al-Qasr (56 km);
 - Sabonia - Rabieh (100 km);
 - Baiji - Al-Ali Bath (156 km);
 - Haditha-Baiji-Kirkuk (252 km);
 - Musayyib-Karbala-Samawah.

This project is one of the major projects under construction connecting key parts of the Middle Euphrates region. At the same time, some of these lines are two-sided.





Figure1. Area under study

Figure (1) provides an overview of the area under study.

4.2. Method

The main purpose of this study is to determine the appropriate routes for the construction of high-speed rail lines in Iraq using geographical information systems and multi-criteria decision-making techniques. This process has been implemented in the study area between the Nasiriyah and Najaf using slope data, distance from roads, waterways, pipelines, condition of residential areas and types of land use. We have used four selected decision scenarios. All opinions are combined and formulated as a scenario. The implementation of decision-making models has been achieved in the following steps.

- Data preparation
- Applying AHP method and determining decision scenarios
- Implementing the TOPSIS method to select the best route

4.2.1. Data and preparation steps

In this section, the quality of the collected data (Table1) is checked and corrected using geographical information system tools. Errors such as phenomenon geometry, characteristics, logical relationships, and storage time were investigated and corrected. Subsequently, each layer of information in the study area is cut and making reference is applied to them along with the conversion of the coordinate system. The data is also stored in the GCS-WGS84 nonlinear geographic system. To merge layers, each of the available data must be displayed in a raster structure. Therefore, the ability to convert vector to raster has been used in GIS, and based on 30-meter pixels, the data has been converted to raster data. The following table shows the specifications and features of these criteria:

5416

Table1
Criteria and their characteristics

data	type	objective	Spatial resolution	source	year
------	------	-----------	--------------------	--------	------

ASTER Digital Models pipelines	Global Elevation	raster	slope map	30 m	LandSAT	2014
Land use		vector	Location analysis	30 m	shape file from GIS	2014
railways		vector	Location analysis	30 m	shape file from Mapcruzin	2014
roads		vector	Location analysis	30 m	shape file from Mapcruzin	2014
waterways		vector	Location analysis	30 m	shape file from Mapcruzin	2014
Settlements		vector	Location analysis	30 m	shape file from Mapcruzin	2014
Railway stations		vector	Location analysis	30 m	shape file from Mapcruzin	2014

The characteristics of each layer are used in subsequent analyzes. Layers are also scaled or standardized for utility. Numerical units in raster layers are divided into five different classes based on cost or benefit parameters. These five classes increase researchers' understanding of the state of existing locations. The effect status of each location (pixel) is expressed in the form of "very low, low, medium, high and very high". There are several ways to achieve this goal, such as re-classifying in the GIS environment. By re-classifying, the scale of the data restoration files becomes the same in terms of utility in the target. Also, all the mentioned spatial analyzes have been performed using Arcgis10.6 system environment.

4.2.2. *Digital Elevation Model*

Elevation data and the topographic status of the area are usually the starting point for railway

design. This data is very important in displaying the elevation of the earth and the presentation of various products such as slope maps. Digital model of earth is displayed in2D and3D with structures such as vector and raster. Each point in the digital model has a certain height. Digital elevation model is generally prepared using remote sensing techniques, Lidar, photogrammetry, satellite positioning and so on. The digital models used in this research include a network of raster cells and an irregular triangular network of elevation data. Also, a model based on ester satellite images with a resolution of30 meters has been used (Figure2). The following figure shows the digital elevation model study area. As shown in the figure, the northern parts of Iraq are higher.



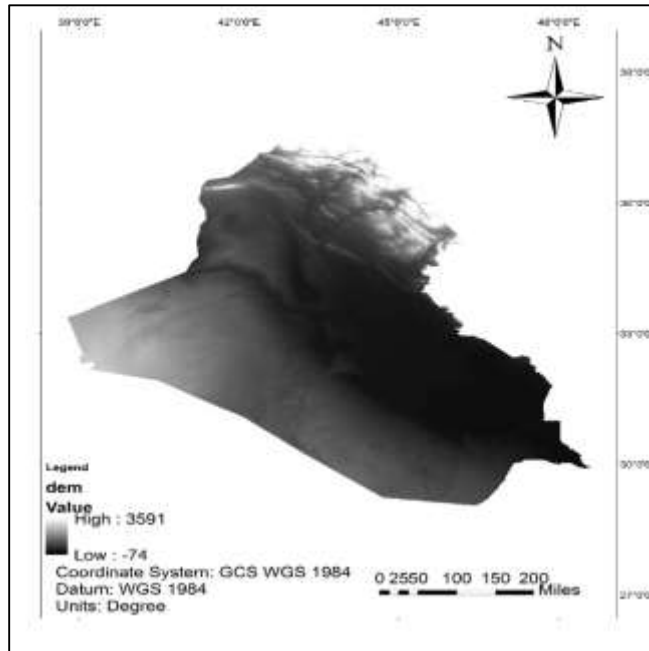


Figure2. Digital elevation model of Iraq

Land slope is a factor directly affecting the implementation and maintenance costs of the project. There are several limitations to the slope criterion for the construction of railways. For example, the slope should not exceed a

certain value. Therefore, the slope map of the study area has been created using the digital elevation model. In the slope map, the percentage of slope degree for the construction of railway lines is classified.

5418

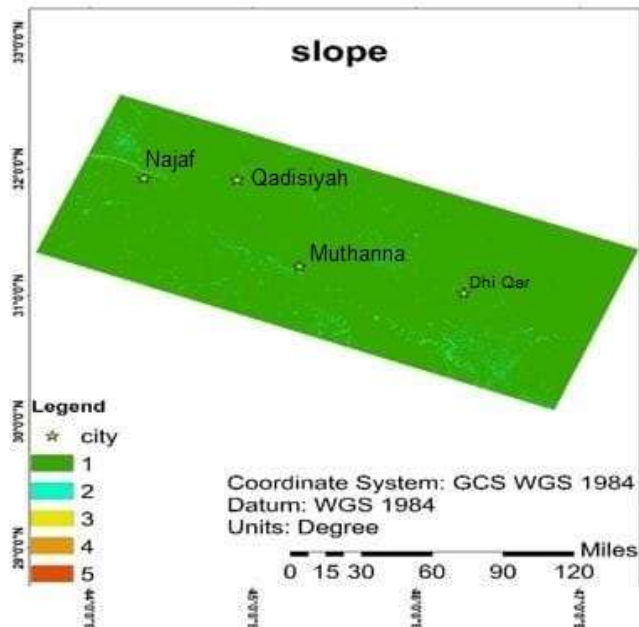


Figure3. Slope map of the study area

Table2

Slope parameter classification and initialization

Slope	Value
0-2.5	1
2.5-5	2
5-10	3
10-15	4
15-20	5

As shown in Figure (3), most parts of the range are flat and have a rank of 1 (i.e. very good) for achieving the goal. Before combining the slope with other classes, the slope map is a cost layer. That is, a lower slope is better for the construction of high-speed rail lines. Table (2) shows the rank of each class. According to the existing regulations, areas with zero slopes are the best areas for the construction of the route.

In order to calculate the least expensive route, the above parameter must be converted to a cost layer.

4.2.3. Land use layer (environmental)

Land use layer includes general land features such as agricultural lands, grasslands, military and residential areas. When designing railway, user appropriateness must be considered.

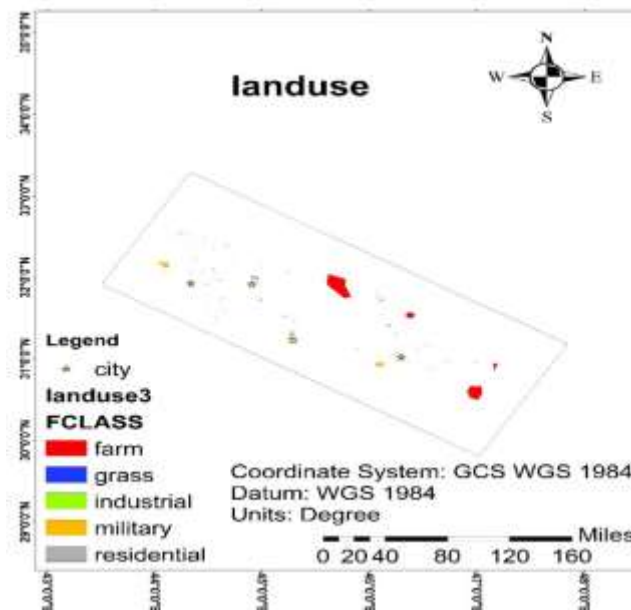


Figure4. Land use map

Table3

Land use classification

Land-use	Value
Farm	1
Grass	2
Military	5
Residential	5
Industrial	5

As shown in Table (3), within the study area, there are uses such as agriculture, meadow, military, residential and industrial. Because

agricultural land is less expensive, it is more desirable. Meadow areas have environmental considerations and are considered as a



constraint. In Figure (4), the cost of barren lands is assumed to be zero. The cost of these lands is calculated according to the proximity to other uses.

4.2.4. Settlement layer (socio-economic)

The settlement layer includes areas of collective living and residence of the people. This layer is a point layer including cities, villages and in the study area. Figure (5) shows a map of existing settlements as a point vector layer. After the

necessary processing with the help of analytical tools, the raster map related to the effective areas in the settlements was determined (Figure6). Also, a multiple buffer was defined by introducing ranges including 5,10,30,60 and 150 km. The steps related to the ranking of each region were performed based on the zoning in Table (4), and the desired output was standardized.

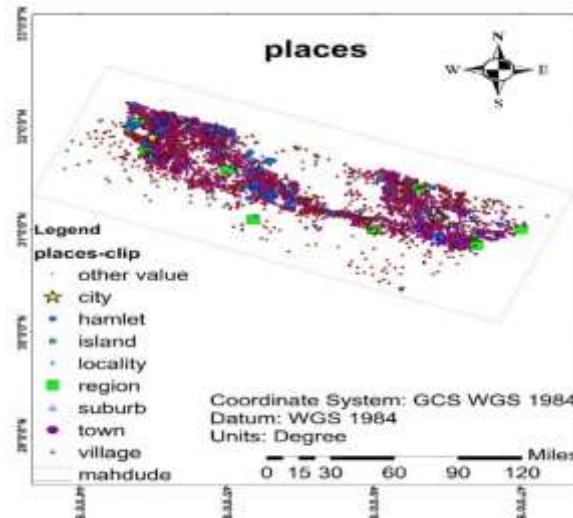


Figure5. Map of settlements

Table4

Classification of distances from settlements

Distance to cities	Value
0-5 km	1
5-10km	2
10-30km	3
30-60	4
<60km	5



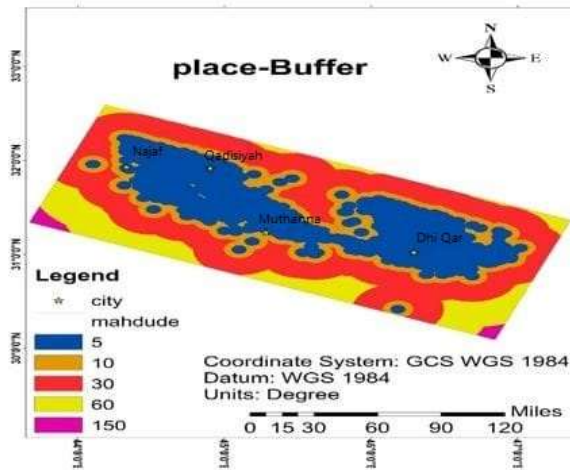


Figure6. Settlements exclusion map

4.2.5. Road layer (access)

Access to high-speed rail lines is critical to tasks such as design, repair, maintenance, accident management, and service. For this purpose, medium scale road layer has been used. The road layer of the study area includes first grade,

second grade and third grade roads (Figure7). These roads are vital in choosing the optimal route and reduce transportation costs and increase access to lanes for maintenance, upkeep and repair.

5421

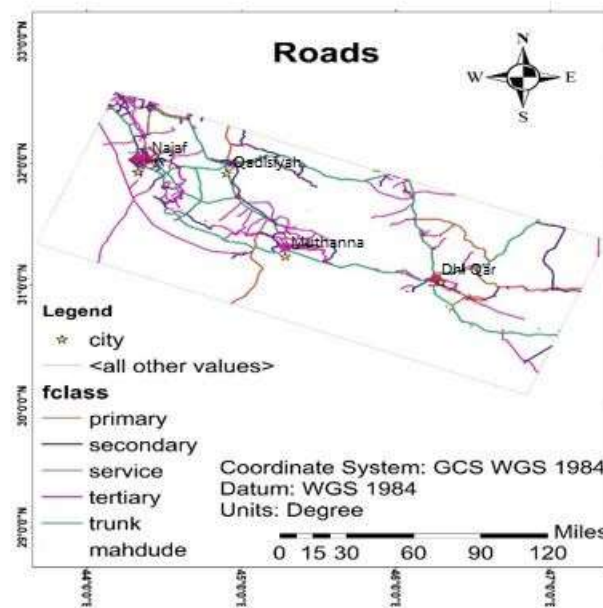


Figure7. Map of existing routes

Table5

Classification of distances from routes

Distance to Roads	Value
0-5 km	1
5-10km	2



10-30km	3
30-60	4
<60km	5

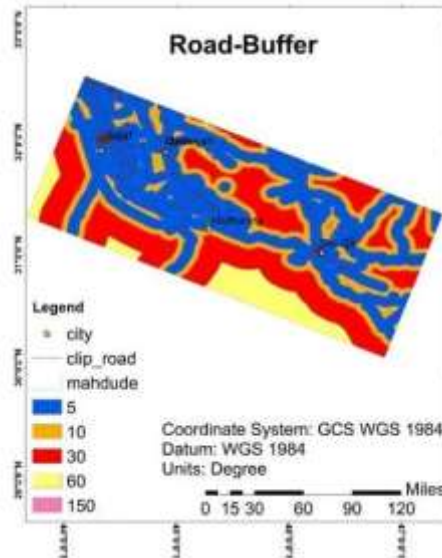


Figure8. Existing routes exclusion map

According to Figure (8), based on the access distance, Euclidean access to roads was also divided into 5 classes. These five classes were selected based on expert opinion. Thus, the utility factor map was obtained in terms of access costs.

4.2.6. Rivers layer and waterways (hydrological)

In designing railway lines, the greater the distance from waterways and rivers, the better

the designed route. The closer the route is to waterways, canals, rivers and waterways, the more bridges should be placed along the route. In some seasons, there is a possibility of flooding and destruction of lines. Water flow and diversion lead to difficult route design and increased costs. For this reason, the greater the distance from the waterways, the better the route.



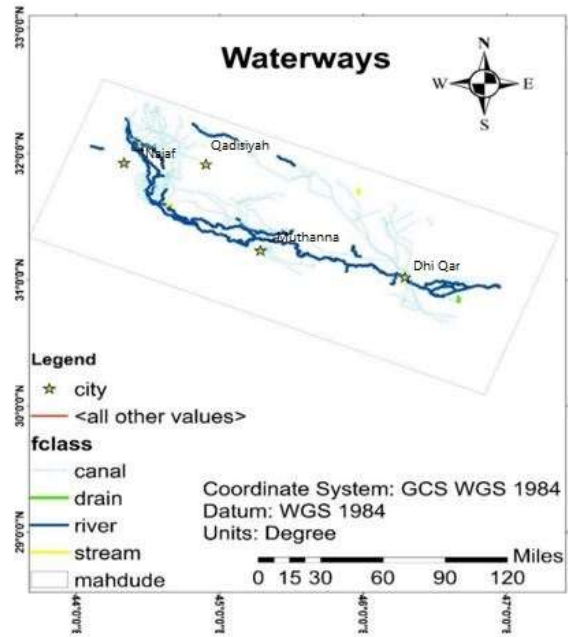


Figure9. Map of existing waterways

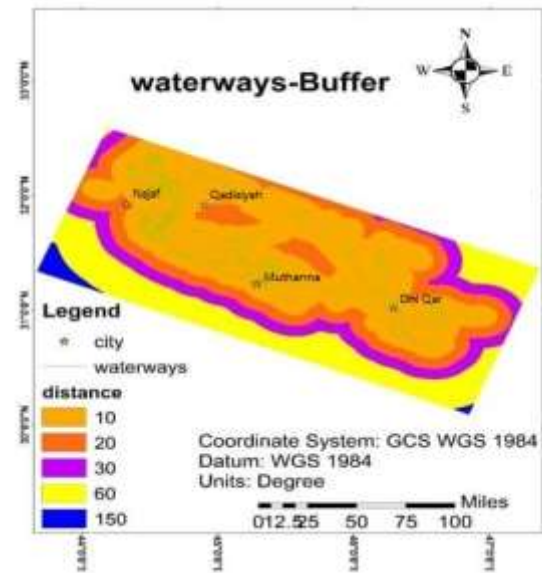


Figure10. Waterway exclusion map

Table6

Classification of the importance of distance from waterways

Distance to waterways	Value
0-10 km	5
10-20 km	4
20-30 km	3
30-60	2
<60km	1

As shown in Figures (9) and (10), after collecting information about important waterways and rivers, zoning steps were performed based on spatial distance calculation tools. Also, the cost impact of each level is determined based on the opinions of experts according to Table (6).

4.2.7. Pipeline layer (energy infrastructure)

Iraq is one of the countries with rich oil reserves, so when locating and designing the

route, infrastructure and energy transmission lines must be taken into account. The railway provides the conditions for the rapid movement of hazardous materials with less risk, so the shorter the distance between the railway lines and the power transmission lines, the better the designed route. Of course, the exclusion standard of power transmission lines must be observed in accordance with the regulations.

5424

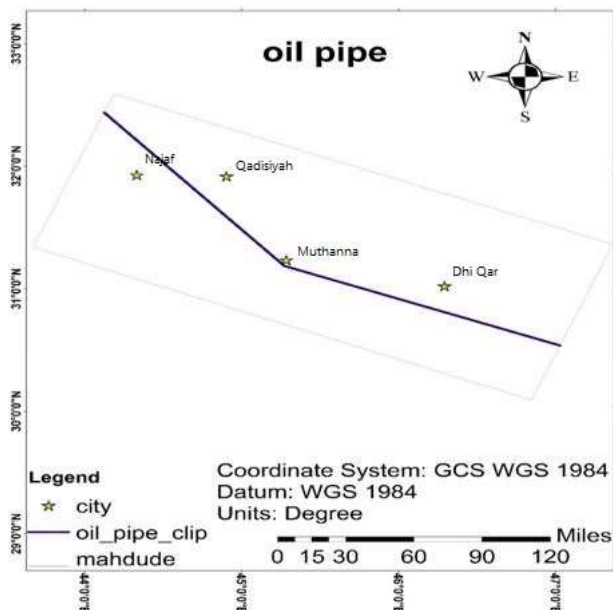


Figure11. Pipeline map



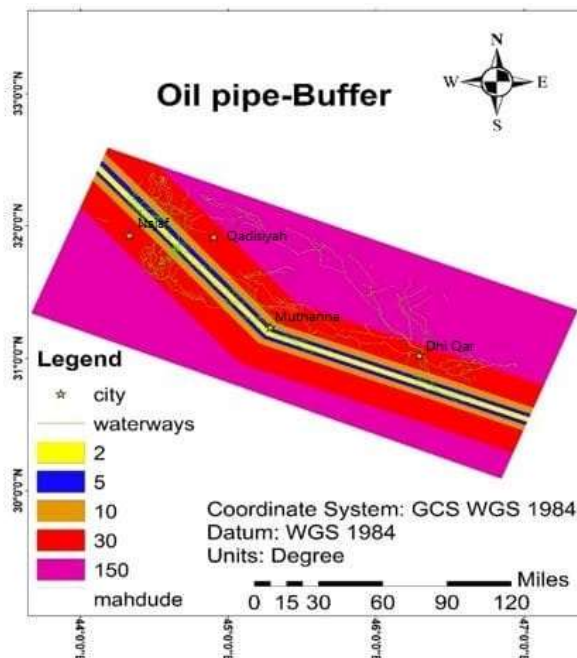


Figure12. Pipeline exclusion map

5425

Table7
 Classification of the importance of distance from pipelines

Distance to waterways	Value
500m-2km	5
2-5 km	4
5-10 km	3
10-30 km	2
<30km	1

In Figures (11) and (12), the zoning is based on the scores listed in Table (7).

4.3. Calculation of criteria weight by AHP method

The AHP method is one of the pairwise comparison algorithms for suitable specification analysis. This method is used to extract the weights used in the overlap analysis. The reason for using this method is the accuracy and speed of implementation in real engineering issues. In this method, all layers are organized in a hierarchy formed by decision makers.



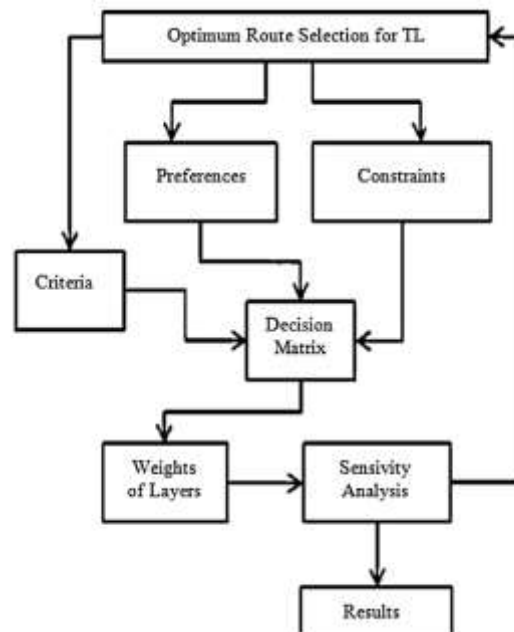


Figure13. Decision making method (Malczewski, 1999).

In Figure14, the steps of the AHP method begin with a correct definition of the problem and the purpose. In this research, the main purpose is to route high-speed rail lines. After comparing the layers and considering their importance by different experts, the weighting process is performed. Figure (13) presents the steps for identifying expert preferences, problem constraints, and required criteria. Finally, the sensitivity analysis operation is performed and the resistance of the problem to the change in the answers is determined based on the change in weights. The end result is determining the best route based on different defined scenarios.

4.4. Pairwise comparison method

For the first time, the pairwise comparison method has been introduced by Saaty to implement a hierarchical analysis process (Triantaphyllou, 2000). This method involves pairwise comparing criteria and creating a square matrix of significance ratios. This method receives pairwise comparisons as input and presents relative weights as the output of matrix analysis (Triantaphyllou, 2000). In determining the relative importance of the criteria by the pairwise comparison method, the following steps are critical:

- Producing of pairwise comparison matrix
- Calculating of criteria weights
- Estimating the ratio of compatibility

4.4.1. Creating a pairwise comparison matrix

In this study, four comparison matrices extracted from the results of expert opinions were used to determine the weights of the criteria and prepare a cost map. Given that we are looking for the lowest cost route in routing, all criteria and factors should be specified on a cost basis. First, a form is prepared for each expert and several matrices are obtained in the results evaluation process. Depending on the weight of each expert, the degree of matrix incompatibility and its proximity to the studies performed, four final comparison matrices are obtained. For example, the following comparison matrix, called the "first decision maker", is the result of combining the opinions of different experts. In Table (8), the first decision-making matrix has given more importance to the slope criterion than other criteria. After the slope factor, access is more important than other criteria and other criteria are of equal relative importance. This means that heights and elevations and access to



transportation routes are more important for this scenario.

Table8
 Pairwise comparison matrix called the first decision maker to generate the first scenario

	Slope (topography)	Land use (environmental)	Roads (access)	Waterways (Hydrologic)	Settlements (Economic- social)	Pipelines (energy infrastructure status)
Slope	1	5	3	3	4	5
Land use	1/5	1	1/3	1/4	1	2
Roads	1/3	3	1	3	3	4
Waterways	1/3	4	1/3	1	3	3
Settlements	1/4	1	1/3	1/3	1	2
Pipelines	1/5	1/2	1/4	1/3	1/2	1

In Table (9), the comparison matrix is named as the second decision maker. Accordingly, in the second decision maker matrix or scenario2, the slope criterion is the most important compared to the other criteria. In this scenario, the two criteria of hydrological status and access are more important than the first decision matrix.

Based on the sum of the table numbers, it is clear that the topographic factor is less important than these two criteria. In this scenario, land use and environmental issues have the least impact compared to other criteria.

5427

Table9
 Pairwise comparison matrix called the second decision maker

	Slope (topography)	Land use (environmental)	Roads (access)	Waterways (Hydrologic)	Settlements (Economic- social)	Pipelines (energy infrastructure status)
Slope	1	6	2	2	7	7
Land use	0/167	1	1/5	1/2	1/3	1/2
Roads	0/5	5	1	5	5	6
Waterways	0/5	2	0/2	1	1	6
Settlements	/143	3	0/2	1	1	3
Pipelines	/143	2	0/167	0/167	0/33	1

Table10
 Pairwise comparison matrix called the third decision maker

	Slope (topography)	Land use (environmental)	Roads (access)	Waterways (Hydrologic)	Settlements (Economic- social)	Pipelines (energy infrastructure status)
--	-----------------------	-----------------------------	-------------------	---------------------------	--------------------------------------	---



Slope	1	7	2	2	3	6
Land use	0/143	1	1/5	1/5	1	1/3
Roads	0/5	5	1	4	5	4
Waterways	0/5	5	0/25	1	6	1
Settlements	0/333	1	0/2	1/6	1	3
Pipelines	0/167	3	0/25	1	0/333	1

The third decision matrix is reflected in Table (10). This scenario is almost similar to the first decision-making matrix, but in this matrix, the settlement criterion (or socio-economic issues) is more important. The fourth decision matrix is also presented in Table (11). In this matrix, the slope criterion is relatively more important than other criteria, and environmental and energy infrastructure criteria are less important.

Table11
 Pairwise comparison matrix of the fourth decision maker

	Slope (topography)	Land use (environmental)	Roads (access)	Waterways (Hydrologic)	Settlements (Economic-social)	Pipelines (energy infrastructure status)
Slope	1	5	3	3	4	5
Land use	1/5	1	1/3	1/4	1	2
Roads	1/3	3	1	3	3	4
Waterways	1/3	4	1/3	1	3	3
Settlements	1/4	1	1/3	1/3	1	2
Pipelines	1/5	1/2	1/4	1/3	1/2	1

4.4.2. Calculating the weight of criteria

Now, based on comparative scenarios and hierarchical analysis method, the relative weight of each criterion is calculated. In this regard, AHP extension is used in ArcGIS environment and the hierarchical structure of decision making is introduced. After applying the theoretical calculations, the resulting weights

for each criterion are according to Table12. Because the incompatibility rate for each of the matrices is less than 0.1, the results are acceptable. As a result, the resulting weights will be measurable. The weights obtained from the first scenario are given in Tables (12), (13), (14) and (15).

Table12
 Weights of the first decision maker

Parameter	Weight (percentage)
slope	39.88
Land use	7.09
Road	23.87
Waterways	16.47
Settlements	7.62
Pipelines	5.07



Table13
Weights of the second decision maker

Parameter	Weight (percentage)
slope	35.76
Land use	4.215
Road	31.909
Waterways	15.84
Settlements	7.394
Pipelines	4.87

Table14
Weights of the third decision maker

Parameter	Weight (percentage)
slope	32.9
Land use	4.25
Road	30.69
Waterways	18.78
Settlements	7.5
Pipelines	5.8

Table15
Weights of the fourth decision maker

Parameter	Weight (percentage)
slope	39.88
Land use	7.09
Road	23.87
Waterways	16.47
Settlements	7.6
Pipelines	5.0

Using the weights obtained for each criterion and the tools for combining the weights of the layers in geographical information systems, a zoning map of the desired locations for the construction of the railway route has been

obtained. Also, all mandatory points for crossing routes can be selected. Figure (17) shows a map of potential areas based on the first scenario. In the map, black spots are better for high-speed rail routes because they cost less.



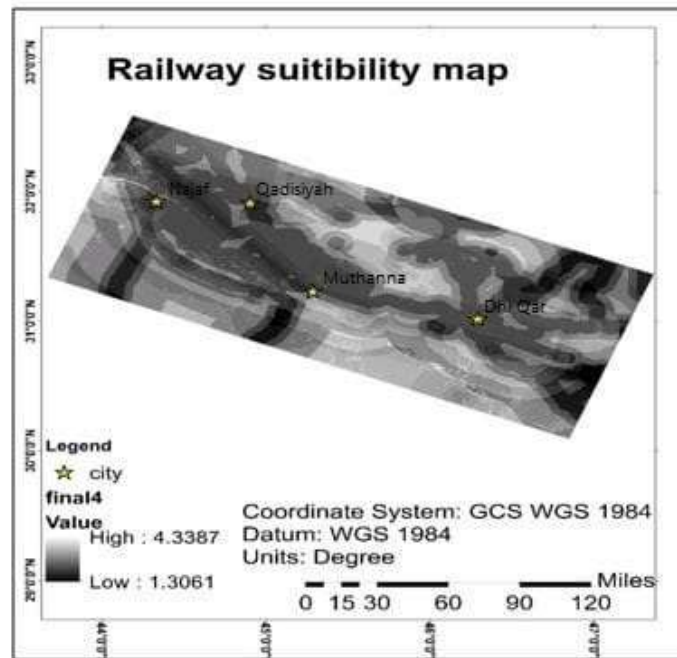


Figure17. Zoning cost map of suitable locations for railway construction for the first scenario

Now, using 4 scenarios, the best railway construction route is suggested. In order to access the routes, geographical information systems analysis tools and distance-cost mapping capabilities have been used in Arcgis software. First, the Nasiriyah was selected as the point of source and the Najaf as the destination. Then, using four maps, the costs are determined based on the distance from the point of source. To achieve this goal, distance cost map and cost distance tools have been

used. This tool specifies the lowest source cost for each image cell. Other tools used in this research are backlink raster software to identify the shortest paths to access points of source and destination. Figure (18) shows the cost distance map and backlink raster. Each pixel in the cost-distance map shows the cost of the shortest path to the source. The colors in the backlink layer indicate the direction of the path closest to the source pixel.

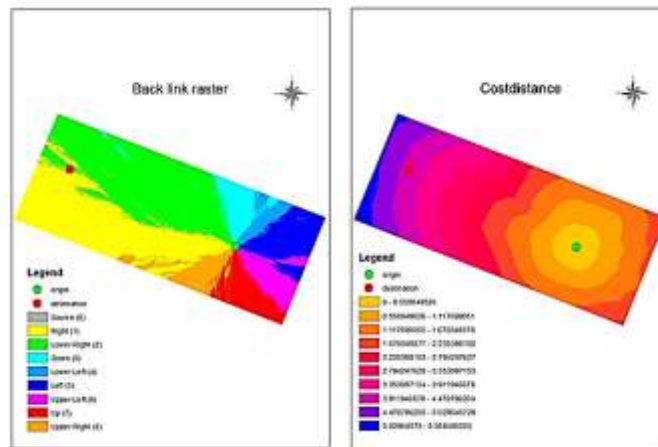


Figure18. Cost and distance direction maps

Now, the steps of analyzing the least expensive route are determined using distance-cost maps

and direction maps (Figure18). The distance-cost raster layer is determined using the source

(starting point) and the weighted sum of the computational costs. Also, the distance-cost tool acts like the Euclidean distance, meaning that the length of the path is equal to the cost of the least weighted distance between the pixels. For

each of the assigned scenarios, cost and direction distance maps are formed similar to Figures (19,20, and21). Finally, after calculating the cost path, the final optimal paths are determined for each of the scenarios (Figure22).

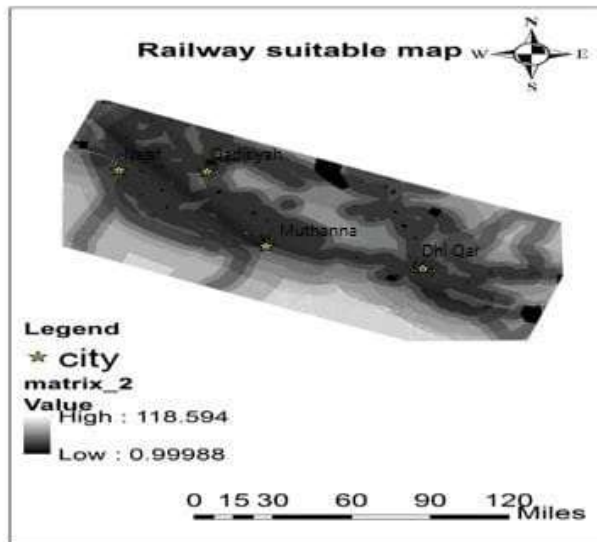


Figure19. Zoning cost map of suitable locations for railway construction for the second scenario

5431

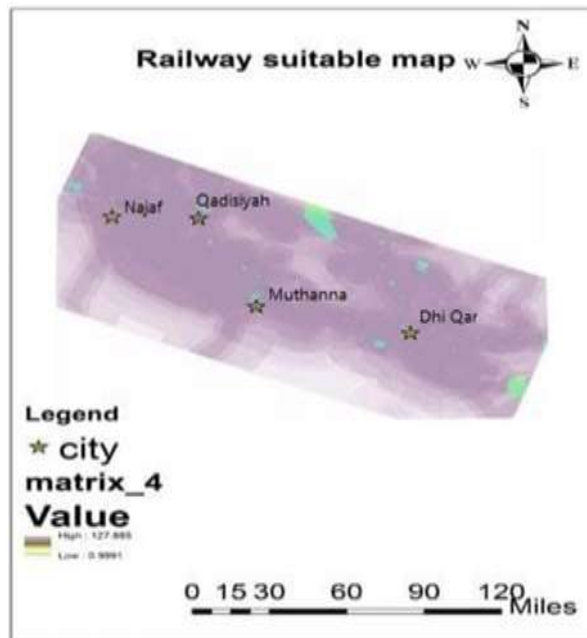


Figure20. Zoning cost map of suitable locations for railway construction for the third scenario





Figure21. Zoning cost map of suitable locations for railway construction for the fourth scenario



Figure22. Paths determined based on the weight of decision makers

4.4.3. Ranking routes using TOPSIS method

Now, each of the generated routes is evaluated according to the length of the route, the number of intersections with roads and the number of intersections with waterways. To determine the best route for the construction of the high-speed railways, the TOPSIS method determines the weight of each parameter through comparisons and is approved by the

community of second decision makers (including 10 people). For this purpose, the method of hierarchical analysis has been used again to determine the weights. In Table (16), the matrix of pairwise comparisons completed by decision makers is reflected.

Table16
Importance of criteria in ranking routes

	Route length	Intersection with waterway	Intersection with roads
Route length	1	0.25	0.16
Intersection with waterway	4	1	0.5
Intersection with roads	6	2	1

According to Table (16), the criterion of intersection with the road has the highest weight. This is due to the large impact of the number of intersections on rail accidents. The length of the path affects the cost of construction is the least important. This shows

that the issue of road safety is very important for the design of this project. Intersections with waterways affect flood damage and the cost of building bridges. Finally, the weight of each of the extracted criteria is shown in Table (17).

Table17
Final weight of criteria in route ranking

Cr.iterion	weight
Route length	8.9
Intersection with waterway	32.3
Intersection with roads	58.8

5433

The best route has the shortest length and the least intersection with roads and waterways. Examination of the parameters and criteria for assessing utility is shown in Table (23).

Table18
Specifications of criteria for each route

Factors	Routes			
	Route1	Route2	Route3	Route4
Route length (km)	222	224	219	227
Intersection with waterway (number)	23	17	26	24
intersection with roads (number)	24	26	22	20

Now, in order to calculate the closest option to the ideal solution, we develop the decision matrix in the form of Table (19).

Table19
Decision matrix in TOPSIS method

intersection with	intersection with roads	length	Decision matrix
-------------------	-------------------------	--------	------------------------

waterways			
24	23	222	Route1
26	17	224	Route2
22	26	219	Route3
20	24	227	Route4

The matrix normalization process must also be performed. According to the relations expressed in the theory section, we divide each column by the square sum root of their. This results in a scale-less matrix (Table20).

Table20
 Normalized decision matrix in TOPSIS method

intersection with waterways	intersection with roads	length	Matrixnormalized
0.56	0.61	0.58	Route1
0.63	0.43	0.58	Route2
0.54	0.66	0.57	Route3
0.51	0.61	0.59	Route4

5434

Next, multiplying the weight of each criterion in the corresponding column leads to the creation of a weighted normalized matrix according to Table (21).

Table21
 Weighted normalized decision matrix in TOPSIS method

intersection with waterways	intersection with roads	length	Weighted normalized
0.56	0.61	0.58	Route1
0.63	0.43	0.58	Route2
0.54	0.66	0.57	Route3
0.51	0.61	0.59	Route4
0.33	0.59	0.08	Weight

Then, by examining the maximum and minimum scores in each of the criteria, ideal and non-ideal vectors are obtained (Table22).

Table22

Ideal and non-ideal options

intersection with waterways	intersection with roads	length	
0/18	0.36	0/05	Route 1
0.21	0.26	0/05	Route 2
0.18	0.39	0/05	Route 3
0.16	0.36	0/05	Route 4
0.16	0.26	0/05	Ideal
0.21	0.39	0.05	Anti-ideal



Finally, the criteria of proximity to the ideal option and distance from the non-ideal option and the rank of each route are calculated.

Table23
 Selecting the best route by TOPSIS method

Route 1	Si+	0.108	0.001	0.011	0.000	$(vij-vi+)^2$
	Si-	0.039	0.001	0.001	0.000	$(vij-vi-)^2$
Route 2	Si+	0.048	0.002	0.000	0.000	$(vij-vi+)^2$
	Si-	0.135	0.000	0.018	0.000	$(vij-vi-)^2$
Route 3	Si+	0.136	0.000	0.018	0.000	$(vij-vi+)^2$
	Si-	0.032	0.001	0.000	0.000	$(vij-vi-)^2$
Route 4	Si+	0.105	0.000	0.011	0.000	$(vij-vi+)^2$
	Si-	0.057	0.002	0.001	0.000	$(vij-vi-)^2$
Route 4	Route 3		Route 2		Route 1	
0.351	0.191		0.737		0.263	

According to Table (23), Route2 is the best option for the construction of high-speed rail. This route has good safety and is more cost-effective than other routes.

In Figure23, the final path is marked with the arrow. As it is clear, the Path2 from Najaf to Al-Samawa is partly close to path1. Also, from Al-Samawa to Dhi Qar, Path1 and Path2 are quite distinct from each other.

5435

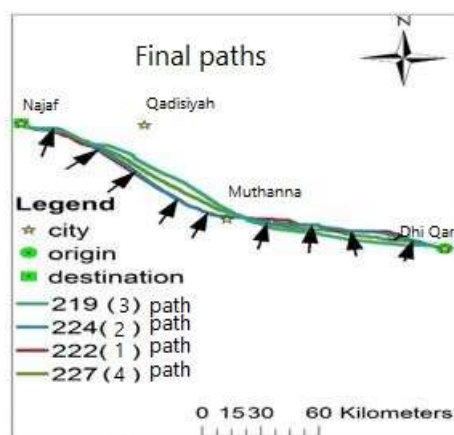


Figure23. The final form of the best path compared to other paths

5 Results

In this study, depending on the opinions of previous experts and research, fourteen opinions were evaluated in the form of fourteen matrices of separate judgment and the information needed was collected with two methods of baseline data and baseline knowledge. In the first method, the factors state

(for example, the road, rivers and pipelines) were identified through forms designed on Internet sites and prioritized using multi-criteria decision-making methods. In the second method, expert's opinions were reviewed based on direct interviews and judgment forms. The overall process consists of four basic steps, including identification and evaluation,



weighing, select the final option (superior option) and sensitivity analysis. In the identification phase, all effective parameters in routing were identified based on the needs of the transportation organization and traffic. The designed parameters include region topography, susceptible lands, natural complications, demographic density, environmental protected areas and historical works. These factors are very effective in choosing the best rail route. Then weigh in the evaluation process, participants and decision-makers, and the steps of choosing options, indicators and final grades are implemented by decision makers. By examining different methods of weighting criteria and selecting the best answers, it was found that the hierarchical analysis method is the best way to weigh. By analyzing the design constraints of the four paths, the proposed pathways were selected from among possible paths and attention to the characteristics of each. At the same time, the TOPSIS model was used and three utility criteria (path length, distance from road and water basin) were investigated. Finally, Path2 was recognized as the best plan for the implementation of the Railway. The Path2 of 224-kilometer length is economically cost-effective and will play a vital role in providing services to Nasiriyah and Najaf cities.

References

Ahmed, N. G., & Asmael, N. M. (2015). A GIS-assisted optimal BAGHDAD metro route selection based on multi criteria decision making. *Journal of Engineering and Sustainable Development*, 19(6), 44–58.

Alkubaisi, M. I. T. (2014). Predefined evaluating criteria to select the best tramway route. *Journal of Traffic and Logistics Engineering*, 2(3).

Darvishsefan, A. A., Setoodeh, A., & Makhdom, M. (2004). Environmental consideration in railway route selection with GIS (Case study: Rasht-Anzali railway in Iran). *Map Asia*.

De Luca, M., Dell'Acqua, G., & Lamberti, R. (2012). High-speed rail track design using GIS

and multi-criteria analysis. *Procedia-Social and Behavioral Sciences*, 54, 608–617.

Djenaliev, A. (2007). *Multicriteria decision making and GIS for railroad planning in Kyrgyzstan*.

Dubey, R. P. (2010). A Remote Sensing and GIS based least cost routing of pipelines. Accessed on 12th March.

Dufourd, H., Gendreau, M., & Laporte, G. (1996). Locating a transit line using tabu search. *Location Science*, 4(1–2), 1–19.

El-Bakry, H. M., & Awad, W. A. (2010). Geographic information system for railway management. *Proceedings of the 3rd WSEAS International Conference on Visualization, Imaging and Simulation*, 149–163.

John, K. (1993). *Oil and gas pipeline fundamentals*. PennWell Publishing Company, Tulsa.

Kiema, I. J. B. K., Dang'ana, M. A., & Karanja, I. F. N. (2007). GIS-based railway route selection for the proposed Kenya-Sudan railway: case study of Kitale-Kapenguria section. *Journal of Civil Engineering Research and Practice*, 4(1).

Kosijer, M., Ivić, M., Marković, M., & Belošević, I. (2012). Multicriteria decision-making in railway route planning and design. *Građevinar*, 64(03.), 195–205.

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. John Wiley & Sons.

Nedevska, I. Z., Krakutovski, Z. M., & Zafirovski, Z. S. (2017). Application of different methods of multicriteria analysis for railway route selection. *Tehnika*, 72(6), 797–805.

Ngunyi, J., Mundia, C. N., & Gachari, M. K. (2017). *Analysis of standard gauge railway using GIS and remote sensing*.

Process, A. H. (1980). *Planning, Priority Setting, Resource Allocation*. New York, NY: McGraw-Hill International Book Co.

Triantaphyllou, E. (2000). Multi-criteria decision making methods. In *Multi-criteria decision making methods: A comparative study* (pp. 5–21). Springer.



Biography of Authors

	Ali Hussein Majeed() National University of Science and Technology, Nasiriyah, Iraq. <i>Email:</i> ali.majeed@nust.edu.iq
	Nooraldeen Sameer Majeed(PhD) DNational University of Science and Technology, Nasiriyah, Iraq. <i>Email:</i>