

# Investigation of the Effects of Important Factors in Suburban Rail Route Determination with MCDM

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**Abstract** Thorough evaluation of suburban rail route alternatives is essential for determining the appropriate route. Suburban lines provide transportation services to suburban areas; that is, they provide transportation services to distant points of the city where demand is high. In this study, five alternative suburban rail routes in the commuter rail standard, starting from the Fatih Sultan Mehmet Bridge's European exit and ending at Istanbul Airport, were determined as a sample corridor in the province of Istanbul. High-standard suburban rail routes and their infrastructure construction costs were determined, and route options were delineated according to their construction costs. Multi-criteria decision-making (MCDM) methods were examined, including the application of the decision matrix method (DMM) and analytical hierarchy process (AHP) to rank the routes in terms of the factors examined in the study. These routes were ranked according to the construction costs and according to the DMM and AHP methods, and the results were compared. In the decision matrix application, geomorphological-geological, geotechnical, infrastructural, and environmental factors were considered in the evaluation and determination process. A solution was developed in which all aspects were weighted to indicate their relevance, and these factors contributed to the determination of the results. The AHP method was also applied, in which five criteria were included in the evaluation: geology (including geomorphology and soil properties), engineering structures, construction costs, population

values addressed by the routes, and railroad length. In addition, the distances to the active faults were examined according to the Turkey Earthquake Hazard Map specified in the Turkish Building Earthquake Code (TBDY) 2018. Depending on the factors studied, the ordering of the routes was the same for all three methods.

**Keywords** Infrastructure cost of railroad · Infrastructural factors · Decision matrix · Analytical hierarchy process · Route selection · Suburban rail

## 1 Introduction

Various studies have investigated the horizontal and vertical design of rail routes. Compared to the models used in vertical route design, the models used for horizontal route optimization are more complex. If the number of passengers is 20,000 or more, it would be appropriate to switch to the latter system. The most significant slope is 4%, and the slightest curve radius is 300 m. Accordingly, more data are needed.

In existing studies, different approaches, algorithms [1], formulations, and software are used to determine the general direction of the route. The main methods used in the studies are variations calculations, network optimization [2], dynamic programming, expanded benefit/cost analysis, the program that gives the most suitable vertical profile to horizontal profile [3], formulation of road route design as an optimization problem, feasibility analysis of geographic information system (GIS) use, route selection based on geological investigation, an iterative approach based on angle and length, and integration with genetic algorithm (GA) use [4].

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Other studies on transportation have explored multi-criteria decision-making (MCDM) methods discussed in the survey [5]. These include PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) I and PROMETHEE II for determining suitable railway corridors [6], the multilayer weighted overlay method for corridor planning in urban rail systems [7], MCDM in railway planning [8], PROMETHEE for container selection [9], MCDM methods for excavation machine selection [10], the decision matrix method (DMM) for examining slope stability [11], analytical network process (ANP) for network problems [12], and fuzzy TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) for data centers [13].

The analytical hierarchy process (AHP) [14] is a new approach for dealing with fuzziness in architecture. Studies have reported the use of AHP and fuzzy AHP in comparison with linguistic evaluations [15], evaluation of the sustainability of big data centers using the ANP and fuzzy TOPSIS [15], with rational network process decision-making [16], evaluation of power plants in Turkey using the ANP [17], an ANP model for financial crisis forecasting [18], and performance evaluation of Indian railway districts using a combination of DEMATEL (decision-making trial and evaluation laboratory) and VIKOR (VIekriterijumsko KOMpromisno Rangiranje) [19]. Many studies have been applied to various fields such as the evaluation of flexible production systems using multi-feature decision-making methods [20], the use of the fuzzy VIKOR method to plan water resources [21], and the selection of light commercial vehicles by applying the AHP-based PROMETHEE sequencing method [22]. Although there are quite different methods and programs for creating routes, the investigation of the applicability of the DMM and AHP in this field brings an essential innovation to the area, since the approaches to determine the most appropriate among the route options are generally cost-based. In addition, geotechnical, geological, infrastructural, and environmental factors are influential in selecting the route. Since infrastructure-related deterioration of rail is a widespread situation in Turkey, this study aimed to search for a solution that will reduce the problem using this method. For this, a sample section was taken, and possible alternative routes and their construction costs were determined within the framework of railway geometric standards. For this purpose, the area from the exit of the Fatih Sultan Mehmet (FSM) Bridge on the European side to the Istanbul Airport was considered. After creating five alternative routes in railway standard and determining the construction cost, the DMM developed in the study and then the AHP were used to determine the most appropriate route. In the DMM, various factors in groups, such as morphological-geological structure, geotechnical features, environmental situation, and infrastructure, were considered. Following the use of DMM as an approach in which the factors belonging to these four groups of matrices

are predominant, AHP was applied to the same routes. Thus, the routes were evaluated and ranked according to the infrastructure construction cost, DMM, and AHP. The consistency of the methods with each other was investigated, and the most appropriate route was determined according to each plan.

If geological structure, geotechnical conditions, and environmental and infrastructure characteristics are considered unimportant, then rail construction and maintenance costs increase, uneconomical railways may be designed during the operation period due to infrastructure problems, and railways incompatible with the environment may emerge. Correcting the issues that may arise later takes time and increases the costs of the entire operating life. Since MCDM was used for the first time in the selection of the alternative routes, the current study is different and original, and this method can be applied to railways and pipelines as well as roads. In developing countries such as Turkey, transportation investments continue rapidly, and since the maintenance and repair of roads are quite expensive, it is essential to focus on studies with different methodologies and different approaches to find appropriate and economical solutions to problems.

The paper is structured as follows. Section 2 provides a review of the material and methods. Section 3 presents the results and discussion of each method. Finally, Sect. 4 draws overarching conclusions.

## 2 Material and Methods

### 2.1 Field Study

Comprehensive research and observation studies have been carried out in the area of the railway routes, which will start from the European exit of the FSM Bridge and end at the Istanbul Airport within the province of Istanbul, supported by the existing project reports and studies. Factors including ground conditions [23], environmental conditions [24], geological structures [25], green areas [24], construction [23], and environment [26] were investigated. Railway specifications [27, 28], existing reports on urban rail systems [29], and studies [30, 31] were evaluated by combining them with the information obtained from the field study.

### 2.2 Route Research and Construction Costs

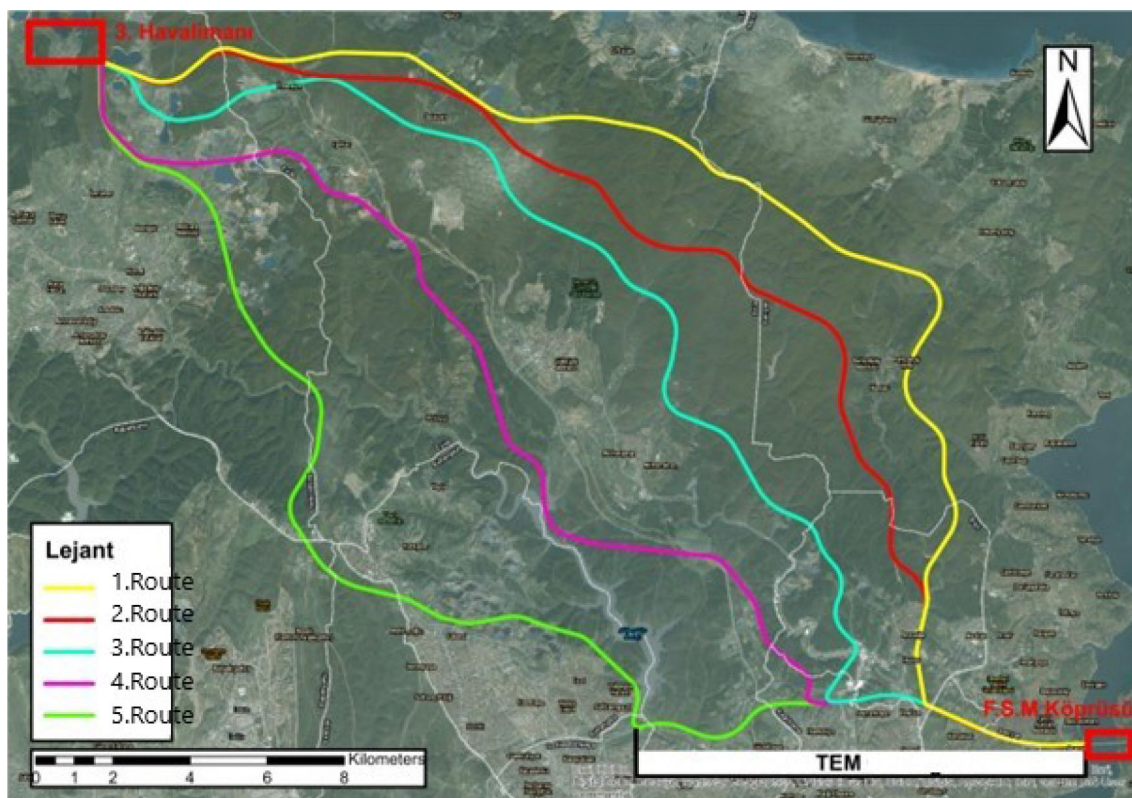
In the classical method, the plan and length sections of the alternative routes are determined within the framework of the relevant railroad's geometric standards using the classical method's contour map. For this, by providing the geological and geomorphological maps of the area to be surveyed, the curves are placed after the "zero line" is formed,

not exceeding the determined maximum slope. Then, the longitudinal section of the specified plan is created, and the red line is drawn. Computer programs have recently become available to conduct these types of processes. The Civil 3D program was used to determine the plan and length sections of the possible route options, the earthwork (cutting/filling) volumes, and the need for engineering structures.

The project carried out within the framework of the study includes five different railway crossing design studies, starting from the FSM Bridge and ending at Istanbul Airport. The project application has been studied with sensitivity at this stage regarding both the digital bases used and the standards complied with. The design values of similar road projects in the project area were also examined. For the high-standard railroad, using the geometric criteria determined by the Turkey General Directorate of Railways (TCDD) and using the Civil 3D program, the plan and sections of the crossing options were determined. Contour digital maps revealing the morphological structure, digital zoning plan maps containing new zoning plans, and geological maps showing the geological structures were used. Then, the amount of splitting, filling, necessary engineering (art) structures, and road construction costs were determined using the same program. Three-dimensional (3D) studies were carried out in ArcGIS as required. The necessary maps for the application

area were obtained from institutions including the Istanbul Metropolitan Municipality (IMM) [23, 24] and the General Directorate of Mineral Research and Exploration (MTA) [25]. Care was taken to ensure that the zoning plan, existing digital images, orthophotos, and geological substrates used within the scope of the project work were appropriate and up to date. A 1/5000 scale of Istanbul land use and zoning plans were preferred. Schematics of the route options created between the second Bridge (FSM) and Istanbul Airport are given in Fig. 1. Horizontal and vertical geometry standards were examined before the plans and sections were created. Standards published by the TCDD governing railway project designs in Turkey were used [27, 28]. Although the project area can be evaluated in the “wavy” group in terms of topography, it was found appropriate to take a project speed of 100 km/h to provide a connection between the two railways and to comply with the geometric standards of the other roads planned in Istanbul [27].

Considering the sections through which the designed routes were planned, the number of the population it could appeal to on average was investigated. This analysis was also evaluated as an indicator for providing access to regions with high residential density. For this, five routes were imported into the GIS environment using ArcGIS and overlapped with the neighborhood data for Istanbul,



**Fig. 1** Suburban route options

which include the population information provided by the IMM. One-kilometer strips were created along the route axes, and the population status was checked along the corridor. In cases where the routes contacted the same district borders more than once in different regions, the population value for the relevant district was evaluated only once. Population values for the regions containing the routes obtained from the analysis are given in Table 1 [24, 26].

Accordingly, route 5 addresses the largest population, and route 2 addresses the smallest population. The approximate construction costs of the routes were calculated by considering the cost of earthworks, superstructure costs, and engineering structures (culverts, tunnels and viaducts, and bridge costs) according to the terrain type [27] and then updated to 2022. In undulating and mountainous terrain, 60% of the cut excavation was used for filling, and the remaining 40% was sent to storage. The remaining filling need was met from the quarry loan (borrowing). When calculating the construction cost of a 1-km road segment and the volume of earthworks, it is predicted that 30% remains in flat land type, 50% in undulating land, and 70% in mountainous land [27]. The results of the cost calculations including the components of the approximate costs for the routes are given in Table 2. Since the relevant land is of the wavy type, the total cost value (USD) for each route was determined using the corresponding unit cost values.

Regarding road construction costs, the most economical route is route 4, at US\$ 53,968,711.09, while the most costly change is route 1, at US\$ 92,867,015.89. The order of the routes from highest to lowest are routes 1, 5, 3, 2, and 4.

**Table 1** Routes and relevant populations

Population values related to routes (persons)				
Route 1	Route 2	Route 3	Route 4	Route 5
244,037	233,080	262,837	338,506	654,954

**Table 2** Construction costs of routes

Values	Route 1	Route 2	Route 3	Route 4	Route 5
Route length (km)	39.750	36.580	37.429	35.715	38.277
Splitting amount (m <sup>3</sup> )	10,180,122.470	7,281,517.180	6,846,258.280	4,883,114.070	8,096,536.890
Fill amount (m <sup>3</sup> )	7,881,571.130	6,741,415.580	6,151,039.160	4,651,564.060	7,248,826.340
Bridge-viaduct (m)	2634.30	1083.70	1402.00	929.10	1979.33
Railroad length (km)	37.116	35.496	36.028	34.786	36.299
Number of culverts	39	49	25	33	22
Number of underpasses	4	3	8	7	4
Total infrastructure cost (USD)	92,867,015.89	57,983,370.57	65,338,241.67	53,968,711.09	78,001,606.26

### 2.3 MCDM and the Application of the Decision Matrix

Multi-criteria decision-making (MCDM) methods and the DMM, which were deemed appropriate for the study, were used to investigate the principles of their application as related to the research subject.

#### 2.3.1 Decision Matrix Method

MCDM is a set of methods that forms a sub-branch of decision science and incorporates different approaches. MCDM is based on modeling the decision process according to criteria and analyzing the decision-making in a way that maximizes the benefit obtained at the end of the process. MCDM approaches proposed for use in decision problems try to reach a “best/suitable” solution that meets multiple conflicting criteria [5]. MCDM methods are used to evaluate more than one criterion (or factor) for each alternative at the same time. With these methods, since the effect of the factors varies according to the conditions, the choice that gives the greatest overall benefit is sought. MCDM methods include ATM (air traffic management), ELECTRE (Elimination and Choice Translating Reality), TOPSIS, PROMETHEE, DMM, AHP, MOORA (multi-objective optimization on the basis of ratio analysis), VIKOR, and ANP MACBETH (measuring attractiveness through a categorical-based evaluation technique). The decision matrix is the least used method among them and has not been applied for route research to date. Since the AHP method was applied differently from the previous ones, it added originality to the study.

The Joyner–Boore distance, which is the distance at a right angle to the surface of active faults, was examined in the Turkish Earthquake Hazard Map for each route specified in the Turkish Building Earthquake Code (TBDY 2018) [32]. Since there is no significant difference based on the location of the routes considered, the decision was made that there was no need to add when creating the matrices.

The DMM considers elements such as a subject, an event, an occurrence, or a phenomenon. Decision matrices

are used to determine the order of importance and priority of the factors involved in the preparation and creation. DMM was chosen for the research topic of interest because it allows for detailed analysis, the application process, and the solution method. In decision matrices, the factors that create and direct the subject are placed on the diagonal, the row sums of the matrix show the degree of the factor (cause), and the column totals show the degree of the effect (result). The number assignments (coding) used in rows and columns are made by comparing the effects of the factors on the diagonal to each other [11].

The factors evaluated in the four decision matrices examined in the study are as follows:

- Compatibility matrix and elements with geology and geomorphology
- Slope, water condition, weathering, media type, media strength, layer orientation, vegetation, discontinuity feature
- Environmental compatibility matrix and factors: agricultural area, forest area, protection area, construction area, expropriation, population density, traffic, accident risk, aesthetics
- Compatibility matrix and factors with engineering geology and geotechnical
- Hydrology, geology, bearing capacity, mass movement, excavatability, cut/fill suitability, material availability,

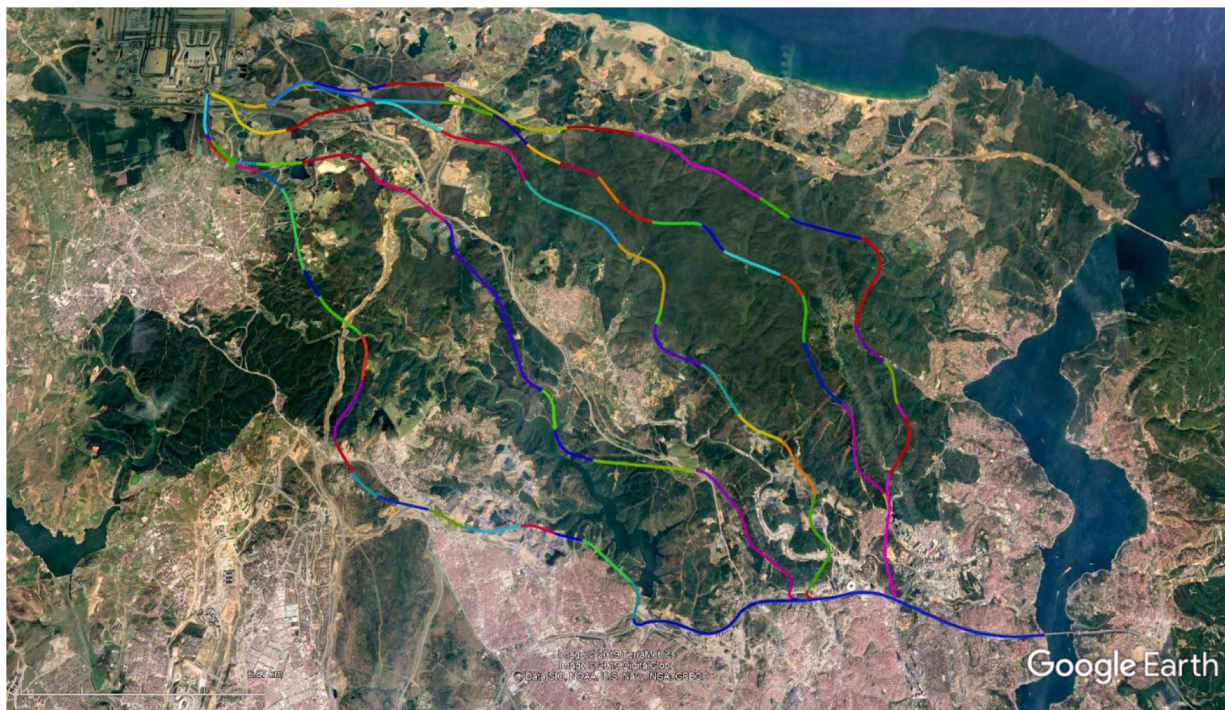
slope angle, abutment structures, slope support, bridge/tunnel

- Infrastructure compatibility matrix and its factors
- Soil type, soil improvement, drainage, landslide and slope stability, splitting, filling, bridge/culvert/viaduct, tunnel.

To use it in decision matrices, each route created by preparing the plan and length section must be divided into regions (zones). The zoning process was applied by separating the parts where the geometric properties of the routes (horizontal curve radius, vertical curve coefficient, slope, intersections of horizontal and vertical curves) are different. Depending on the determined route intervals (such as longitudinal slope and curve radius, km), scoring was made according to the geometric standard sizes of the railroad and transferred to the routes using the ArcGIS program. Thus, as a result of the zoning study, 88 zones obtained in the routes were moved onto the related route. Zones created depending on the scores obtained for each cross-section are marked with different colors in the routes (Fig. 2).

### 2.3.2 Data Provision and Processing

To determine the matrix factor values, the analysis features of the ArcMap program were used along with the current bases. For each region obtained, the characteristics under investigation were taken into account. To compare, analyze,



**Fig. 2** Suburban routes and zones

and score the parameters determined for the matrices, the necessary studies, documents, and maps were provided by the Public Transportation Services Directorate, Transportation Planning Directorate, Infrastructure Directorate, GIS Directorate, City Planning Directorate, and General Directorate of Railways within the body of IMM. For matrix scoring, numerous resources were used for each factor.

### 2.3.3 Solution Steps of the Decision Matrix

When estimating the scores for the previously explained matrices and zones for the suburban routes, the determination of the effect and effect relationship of the variables in the decision matrices was made according to Table 3 in general terms.

The following steps were applied to determine the appropriate route with the DMM:

1. Each of the proposed passages is divided into subsections of varying lengths. The number and size of this segmentation were determined using aerial photography and/or the Google Earth application.
2. Compatibility matrices were then prepared to represent each route. For this purpose, compatibility matrices were first created for the subsections of each path. While these matrices were being prepared, the influence and influence relationship of variables were defined with the values given in the tables.
3. The determination of the numerical values suggested in this definition was made according to the proposed relations with the zoning detail evaluation tables for each compatibility matrix.
4. The compatibility matrices for the relevant subsections of each route produced ( $f_e$ ) values for each of the decision matrices produced for the subsections of each route were calculated in the relationship of influence degree ( $N_i+E_i$ ) and impact level ( $N_i-E_i$ ).
5. The balancing factor ( $f_d$ ) values of each compatibility matrix zoning evaluation detail tables produced for the subsections of each route were calculated.
6. Weighting coefficient ( $f_e \times f_d$ ) values were calculated for each compatibility matrix produced for the subsections of each route.

**Table 3** Impact classification and values

Classification	Value
Very efficient	5
Effective	4
Moderately effective	3
Low impact	2
Very low impact	1
Ineffective	0

7. Based on the weight coefficient (WC) values of each compatibility matrix produced for the subsections of each route, the result weight coefficient (RWC) values of the route were calculated by taking the geometric average.
8. The appropriate route was determined based on these numbers by ordering the result decision number (RDN) obtained jointly for all matrices.

### 2.3.4 Solution of Compatibility Matrices (CM)

Tables were prepared for the solution of each of the 88 zones of the five routes for the four groups' compatibility matrices, and the desired solution was achieved by determining the resultant decision number from the obtained effect weight-balancing factor-weighting coefficient values. However, since it is impossible to present all generated tables and the complete solution herein, a solution example is given for each matrix type and zone [26], using ground and geological surveys for the metro line, a ground survey report of the Gayrettepe-Arnautköy metro [29], a survey prepared for Istanbul [30], and a general geological survey [31]. For this purpose, information [33] and geological studies [34, 35] were obtained from TCDD and other companies involved in road construction in the region. For each factor of each matrix examined, a grouping from positive to negative was made, and tables were prepared for the balancing factor criteria. Influence ( $N_i$ ) and influence ( $E_i$ ) scores of the compatibility matrix of each factor were evaluated for each zone of each route in the solution, according to the DMM. The balancing factor criteria and values of the compatibility matrices were ranked from positive to negative and evaluated according to the grouping style and criterion scores for the compensation factor of the compatibility matrix of geology–geomorphology. The highest number of seven criteria belong to the slope, and the number of criteria is lower for the others; for example, there are four criteria in the case of water. For balancing purposes, the most significant number of criteria is divided by the number of other relevant criteria, and the balancing factor ( $f_d$ ) is obtained. This factor is used in the solution tables (for example,  $7/4 = 1.75 = f_d$ ). The relevant regulation [36], existing reports [26], current study [37], and analysis [26] were used to prepare the sample solution tables for the environmental compatibility matrix. Engineering geology was obtained from current road study [19], current work [29], and IMM for the geotechnical compatibility matrix solution. The municipality's existing project reports [20] that overlap with the region, the relevant publication [30], and the relevant book [31] were used. For balancing factor criteria of the infrastructure compatibility matrix, geology and soil books [38–40], existing studies [41–43], IMM report [44], specification survey [45], geological investigation for Istanbul [30, 31], expert opinion,

and field studies were used. After applying the solution described for the four compatibility matrices, the resultant decision numbers (RDN) were obtained from the average values found for all of them.

### 2.4 Implementing the Analytical Hierarchy Process

The AHP was developed by Thomas L. Saaty, and enables scoring decision parameters according to multiple criteria and making the most appropriate decision based on them. This method can be used in all areas that require scoring from the best to the worst, such as finance, database selection, transportation, resource allocation, facility location selection, and product design [46–52].

Following the determination of the criteria that are important in the decision process in AHP, a scoring system is created, and importance values are defined according to the standard preference table in Table 4 [5].

The stages of the AHP method consist of three steps, as follows:

1. Configuring the problem
  - Identification of the problem and goal
  - Determining and structuring decision criteria and alternatives
2. Evaluation
  - Establishing the relative value of the alternatives in each decision criterion
  - Demonstrating the relative importance of decision criteria
  - Group of decisions
  - Analysis of inconsistency of judgments
3. Choice
  - Calculating the weights of the criteria and priorities of the alternatives
  - Conducting behavioral sensitivity analysis.

Numerical operations to be performed: Numerical operations for AHP at these stages are summarized in seven steps

**Table 4** Standard preference table

Importance values	Value definitions
1	Equally important
3	Moderately important (slightly superior)
5	Strongly important (moderately superior)
7	Very strongly important (much superiority)
9	Definitely important (absolute superiority)
2, 4, 6, 8	Intermediate values (compromise values)

[53]. The values in each column are summed, and column totals are obtained. The values in each column are summed, and column totals are obtained:

1. The values in each column are summed, and column totals are obtained.
2. In the new matrix obtained by dividing the obtained values by the sum of the same column, the sum of all columns equals 1.
3. By converting the captive numbers to decimal numbers, the sum of each row is divided by 2, thus averaging the rows.
4. All row averages are written as a single matrix.
5. The first matrix is created by using the standard value table given in the first step, after ordering the importance of the criteria by making an order of importance according to the criteria discussed.
6. All the operations are performed for the other criteria, and the averages of the rows and the order of importance of the criteria are obtained according to the averages of these rows.
7. The first matrix gives the order of importance according to the criteria, and the second matrix gives the order of importance of the criteria. By multiplying these two matrices, decimal weights are found and the largest value between them provides the most relevant result [14].

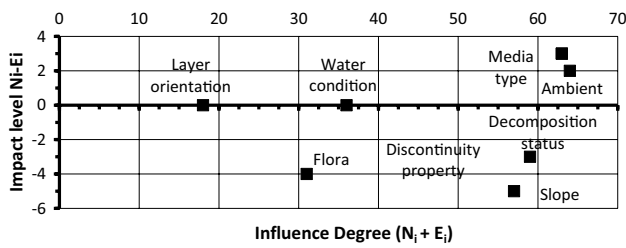
## 3 Results and Discussion

### 3.1 Solutions of Decision Matrices

In the study, firstly, the scores of the compatibility matrix elements were determined by using the analysis features of the ArcMap program (such as Buffer, Overlay, Proximity, and Statistics) on the numerical maps. Here, zone cards showing the maximum and minimum values.

Samples were prepared, and the value of the relevant element was determined. In the tables prepared,  $f_d$  represents the balancing factor,  $f_e$  is the impact weight,  $f_e \times f_d$  is the weight coefficient (WC), the maximum number of criteria/number of criteria of the relevant factor is the  $f_d$  value, and the influence degree/maximum effect degree is  $f_e (N_i + E_i) / \max (N_i + E_i) = f_e$ , gives the value.

*Weighting coefficient (WC:  $f_e \times f_d$ )* values were found for each compatibility matrix produced for the subsections of each route, and RWC (result weighting coefficient) was determined from the average of the WC values for the relevant matrix. The general standard obtained for all matrices gives the result decision number (RDN) values, that is, the result. The solution form is used for each compatibility matrix produced for the subsections



**Fig. 3** Effect status of the variables in the first matrix (route 1, zone 7)

of each route, for example, Fig. 3 and Tables 5, 6, and 7 using the first route and seventh zone.

Factor scores were determined by evaluating other matrices with similar solution steps.

### 3.2 Ranking by Result Values

For the four groups of matrices, the RDN values were determined first so that the most appropriate route according to BMD was determined, taking into account all the compatibility matrices. Here, the option with the lowest RDN score is the most congruent; that is, it indicates the most appropriate passage being investigated. The highest score indicates the route that is the furthest from the targeted goal. To determine the compatibility of each route and each matrix, when the resultant decision numbers (RDN) calculated from the result weight coefficient (RWC) values are ordered from the largest to the smallest, the routes from the most incompatible to the most compatible are listed. According to this explanation, when the numbers obtained from the solution of all matrices are considered, the order of the routes is as in Fig. 4.

When all the compatibility matrices examined in the scope of DMM are solved together, the most suitable one is

**Table 5** Compatibility matrix factor scores of first matrix, first route, and seventh zone

Compatibility matrix with geology and geomorphology slope									
ROCK	5	5	5	5	3	5	5	Ni	GROUND
	5	Water condition	5	5	3	5	5	33	
	5	5	Decomposition status	4	4	2	4	4	28
	4	4	4	Media type	4	2	4	4	26
	5	5	5	5	Ambient resistance	3	5	5	33
	2	2	2	2	2	Layer orientation	2	2	14
	5	5	5	5	5	3	Discontinuity property	5	33
	5	5	5	5	5	3	5	Flora	33
Ei	31	31	31	31	30	19	30	30	

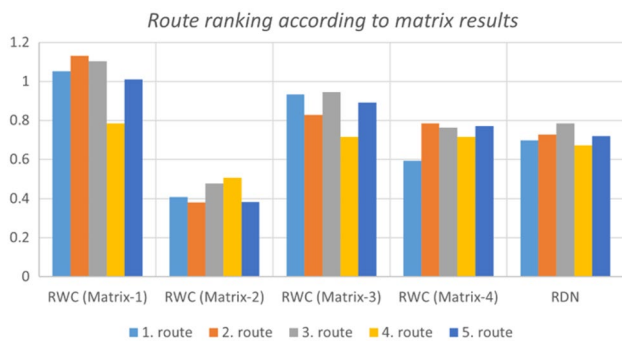
**Table 6** Impact weights in the first matrix, first route, seventh zone

	Influence degree–influence level relationship factors					
	Ei	Ni	Impact dec. (Ni+Ei)	Affected level (Ni-Ei)	Impact weight (f <sub>c</sub> )	Maximum (Ni+Ei)
Slope	31	33	64	2	1.000	64
Water condition	31	33	64	2	1.000	
Decomposition Status	31	28	59	-3	0.922	
Media type	31	26	57	-5	0.891	
Ambient resistance	30	33	63	3	0.984	
Layer orientation	19	14	33	-5	0.516	
Discontinuity property	30	33	63	3	0.984	
Flora	30	33	63	3	0.984	



**Table 7** Weight coefficient (AK) values of the seventh zone

	Impact weight-equalization multiplier weight factors		
	Impact weight ( $f_e$ )	Balancing factor ( $f_d$ )	Weight coefficient WC:( $f_e \times f_d$ ) coefficient
Slope	1.000	1.000	1.000
Water condition	1.000	1.750	1.750
Decomposition status	0.922	1.167	1.076
Media type	0.891	1.167	1.039
Ambient resistance	0.984	1.000	0.984
Layer orientation	0.516	2.333	1.203
Discontinuity is special	0.984	2.333	2.297
Flora	0.984	1.167	1.148
Arithmetic mean			1.312



**Fig. 4** Route ranking according to matrix results

compatibility matrix 4, while the most inappropriate one is compatibility matrix 3.

**3.3 Solution with AHP Method**

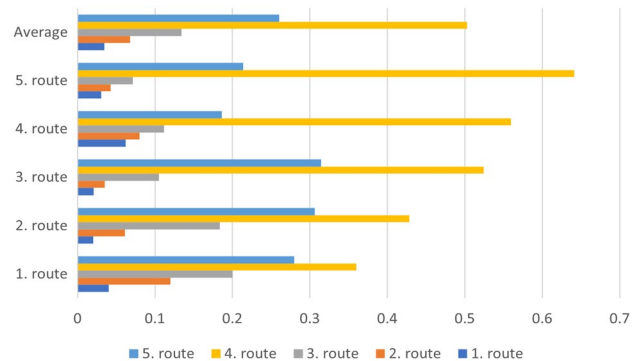
By making use of the proposed routes, available information, and the studies for the decision matrix, the relevant criteria in AHP were examined according to this relationship.

In terms of the examined criteria considering the project, expert opinion, and fieldwork, the following is the order of the routes for AHP from the most negative to the most positive [38, 41]:

- In terms of geology and geomorphology: 1st route, 2nd route, 3rd route, 5th route, 4th route
- In terms of engineering structures (art structures): 1st route, 5th route, 3rd route, 2nd route, 4th route
- In terms of construction costs: 1st route, 5th route, 3rd route, 2nd route, 4th route
- In terms of population values addressed by the routes: 2nd route, 1st route, 3rd route, 4th route, 5th route

**Table 8** Scoring for geology and geomorphology

	Scores for geology and geomorphology				
	1st route	2nd route	3rd route	4th route	5th route
1st route	1	1/3	1/5	1/9	1/7
2nd route	3	1	1/3	1/7	1/5
3rd route	5	3	1	1/5	1/3
4th route	9	7	5	1	3
5th route	7	5	3	1/3	1



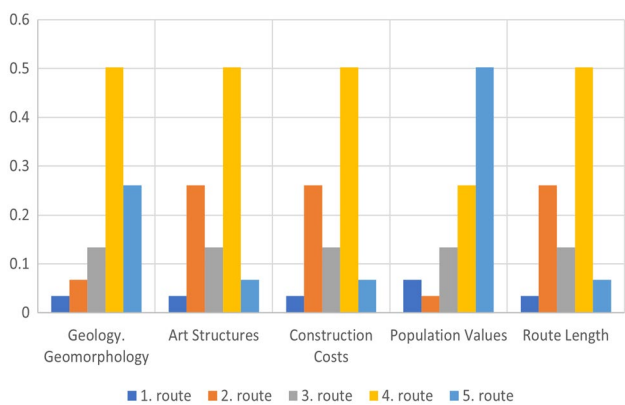
**Fig. 5** Percentages for geology, geomorphology, and average

- In terms of route lengths: 1st route, 5th route, 3rd route, 2nd route, 4th route.

**3.4 Pairwise Comparisons of Criteria**

This stage includes making a pairwise comparison of the criteria and forming a matrix according to the relative importance scale of the decision-makers, or in other words, the standard value table. In order to create the comparison matrix, the importance levels of the criteria are determined. Considering the examined projects and previous field, observation and other studies, and expert opinion, nine points were given to the geology and geomorphology characteristics criterion, seven points to the art structures, five points to the construction costs, three points to the population values addressed by the routes, and one point to the road length criterion, and a pairwise comparison matrix was created. Using the standard data table, the routes were first scored and compared, as shown in Table 8 [54]. This process was also done for the other criteria examined, but not all of them were included in the study (Fig. 5).

Subsequently, the values in each column were added one under the other, and column totals were obtained and divided by the total of the same column. In the newly obtained matrix, each column’s sum equals 1. Figure 6 is obtained by converting fractional numbers to decimal numbers, dividing



**Fig. 6** Proportional weights of criteria

the sum of each row by 5, that is, the number of columns, and finding their average.

This process is also applied to the other examined criteria; the average values are obtained from all of them and converted into a matrix, and the proportional weights of the criteria for the alternatives are determined as shown in Fig. 7.

In AHP, the realism of the results depends on the consistency ratio (CR) of the pairwise comparisons made by

**Fig. 7** Percentage weights of criteria as a result of pairwise comparison



**Table 9** Pairwise comparison of criteria

	Geology and geomorphology	Art structures	Construction costs	Population values	Route length
Geology and geomorphology	1	3	5	7	9
Art structures	1/3	1	3	5	7
Construction costs	1/5	1/3	1	3	5
Population values	1/7	1/5	1/3	1	3
Route length	1/9	1/7	1/5	1/3	1

the decision-makers between the criteria. If the ratio is below 0.10, it is concluded that the matrix is consistent. Since the random value index (RI) is taken as 1.12 for five elements and  $TO=0.05414 < 0.10$ , the analyzed matrix is consistent. As seen in the matrix in Table 9, the order of importance among the criteria should also be determined. For this purpose, as in the first step, Table 9 was created by using the values in the standard preference table.

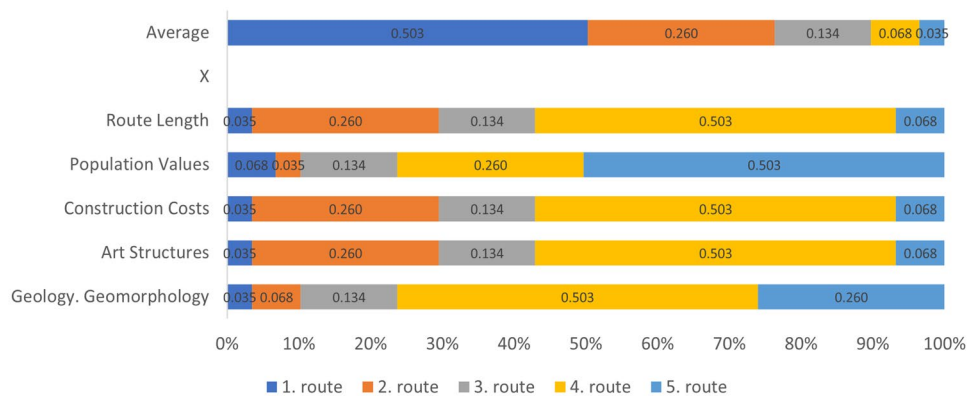
The averages shown in Fig. 8 were obtained by applying the operations in the first four stages and finding the values with decimal numbers.

Then, using the matrices obtained in Table 9 and Fig. 8, the value for each alternative in the matrix obtained in the fourth step, based on each criterion as shown in Fig. 9, was multiplied by the weight score of that criterion. Then, by summing the row it was in, Fig. 9 was obtained.

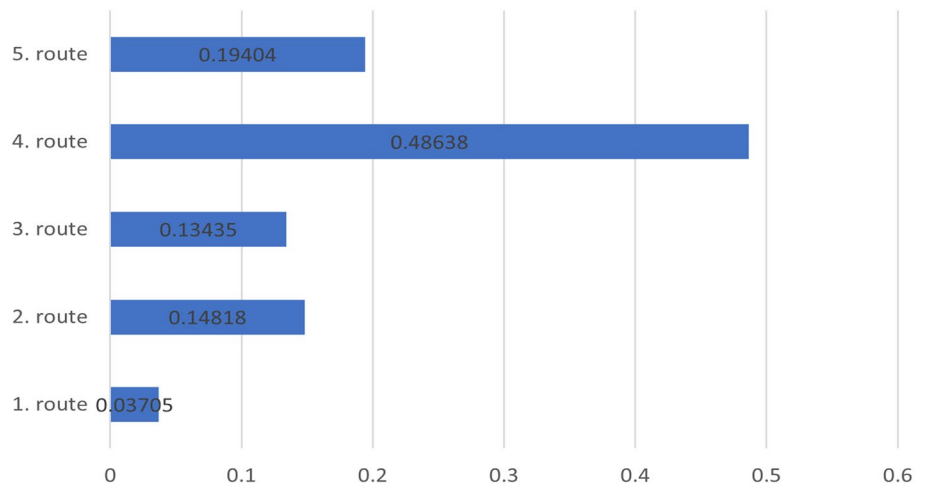
Ranking the routes according to the AHP

The ratios obtained in accordance with the solution steps and allowing the ordering of the five routes are given in Fig. 9. In this method, the highest ratio indicates the most relevant route. This result is consistent with the results obtained with previous approaches, and according to the evaluation in three different ways, the most appropriate route is route 4 in terms of the factors examined.

**Fig. 8** Multiplying the weights of the criteria by the percentage weights



**Fig. 9** Ratios that give the result of AHP



In addition, the subject was examined with the same factors using the ANP and ELECTRE methods. Although the ANP method is similar to the AHP method in that it uses the same scoring method, it is suitable for more comprehensive problems, as it also includes the interactions of criteria and alternatives without using a hierarchical order [55, 56]. In this study, numerically close results were obtained for both methods. The ELECTRE method is slightly different from the ANP and AHP methods. For the criteria determined in the ELECTRE method, a binary superiority comparison was made between the decision points. When compared with the ELECTRE method, a dominance comparison was made depending on the determined criteria and the weights of these criteria. Increasing the number of criteria provided a more favorable environment for the ELECTRE method. It was seen that the results obtained using the ELECTRE method were close to those of the previous two methods.

### 4 Conclusions

In this study, three different approaches were applied to determine the most suitable one among the existing

alternative suburban routes according to the factors examined. For this, in accordance with the design principles of TCDD, five routes in the suburban standard were created, their infrastructure construction costs were determined, and the rail routes were listed in terms of cost. While there are four viaducts in the first route and the amount of splitting and filling is high, the total infrastructure construction cost increases significantly. In contrast, the fourth route has the lowest cost in terms of construction cost, that is, the most convenient in terms of infrastructure construction costs.

Then, the DMM, which is one of the MCDM methods, and the AHP method were used to determine the most appropriate route among the alternatives in terms of factors. The matrices used in the solution for DMM were as follows: compatibility matrix with geology and geomorphology, environmental compatibility matrix, compatibility matrix with engineering geology and geotechnical, and compatibility matrix with infrastructure. Influence and influence scores, related effect weight, balancing factor, weight coefficient, result weight coefficient, and result decision number values were determined in four matrix groups, and the resulting values were listed by making use of them. According to the numbers that give the result, when the routes are listed,

the fourth route was determined to be the most appropriate route in terms of factors. In the solution with the AHP, the criteria related to the problem were first put forward. Geology and geomorphology, engineering structures, construction costs, population values addressed by the routes, and railroad length criteria were scored, and the routes were listed. Then, a hierarchical structure was created and a relative importance scale was determined. After determining the preference scores that were effective in decision-making, their percentage weights were calculated by pairwise comparison of the criteria. According to the result, based on the highest score among the five alternative routes, the most suitable one was again the fourth route, and the most unsuitable was the first route. According to the DMM and AHP methods, a similar ranking was obtained for all routes except route 1. In addition, the same results were obtained using the ANP and ELECTRE methods, but the details were not included in the article.

As a result, according to four groups of factors, examined according to three approaches, the fourth route was determined as the most appropriate route. This study found that MCDM could be used to determine the proper route for different factors. These approaches are worth considering in the evaluation of the routes in projects in Turkey, and it is expected that the “result route” decided in this way will be an appropriate route throughout its service life. In addition, even when the infrastructure construction costs and the results obtained according to MCDM are different, if there is not a huge cost difference, the results obtained according to MCDM will be worth considering, because the decrease in infrastructure maintenance and repair costs arising during the service life will significantly reduce the total cost. Different factors can also be considered in the solution if they can be provided.

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**Declarations**

**Conflict of interest** The authors declare that they have no conflicts of interest.

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