Journal of Soft Computing in Civil Engineering 3-4 (2019) 51-66

Contents lists available at SCCE

Journal of Soft Computing in Civil Engineering

Journal homepage: www.jsoftcivil.com

Selecting the Suitable Tunnel Supporting System Using an Integrated Decision Support System, (Case Study: Dolaei Tunnel of Touyserkan, Iran)

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https://doi.org/10.22115/SCCE.2020.212995.1150

ARTICLE INFO

Article history:
Received: 23 December 2019
Revised: 10 January 2020
Accepted: 10 January 2020

Keywords:
Supporting systems;
FDAHP;
ELECTRE;
Integrated decision;
Dolaei tunnel.

ABSTRACT

The main goal of this study is the selection of an appropriate tunnel supporting system according to the combination of FDAHP method (Fuzzy Delphi Analytic Hierarchy Process) and ELECTRE (Elimination and Choice Expressing Reality) technique. This integrated decision support system provides useful support for selecting a tunnel supporting system. The weights of the criteria was determined by FDAHP method, and a suitable tunnel supporting system for Dolaei tunnel of Touyserkan in Iran was determined by the ELECTRE. The study was supported by the results obtained from a questionnaire carried out to understand the opinions of experts in this subject. According to surveys in this regard, six significant criteria and five alternatives such as reinforced shotcrete, metal frames, concrete prefabricated segments, in situ reinforced concrete implementation, rock bolt and reinforced shotcrete implementation have been examined. The obtained results showed that the rock bolt with reinforced shotcrete supporting system is the most suitable.

How to cite this article: Shaffiee Haghshenas S, Mikaeil R, Abdollahi Kamran M, Shaffiee Haghshenas S, Hosseinzadeh Gharehgheshlagh H. Selecting the suitable tunnel supporting system using an integrated decision support system, (case study: dolaei tunnel of Touyserkan, Iran). J Soft Comput Civ Eng 2019;3(4):51–66. https://doi.org/10.22115/scce.2020.212995.1150.

1. Introduction

Civil structures and especially underground constructions have a key role in road and railway networks worldwide. Underground structures are also utilized in the countries' infrastructure development, energy production [1–5]. The development of underground structures such as tunnels requires huge financial costs and amounts of time to be built on one hand, and on the other hand to keep them efficient and safe permanently [6,7]. This makes the designing of these structures a significant task. As tunnels cannot bear the weight of rocks surrounding and above them in unstable situations, they need to be supported systematically for keeping stable after excavation. In this matter, one of the most important parts of tunnel construction is tunnel supporting system which has a significant role for stabilizing tunnel. Hence, the study of tunnel stability against wrecking factors is very important [8]. In this research, Dolaei tunnel of Touyserkan, located in one of the most unsafe geological zones of Iran, was investigated as a case study. Dolaei tunnel of Touyserkan is one of the most important communication roads of western states of Iran in trade and industrial equipment transition. This tunnel has a length of 675 m and a cross-section of 75 m^2. Drilling-blasting and handheld drilling in some parts are used for excavation [9–11].

The main purpose of this paper is the evaluating and selecting the suitable tunnel supporting system using fuzzy Delphi analytic hierarchy process (FDAHP) and ELimination and Choice Expressing REality (ELimination Et Choix Traduisant la REalité or Elimination and Choice that Translates the Reality technique: ELECTRE) based on six criteria for analyzing five common tunnel supporting systems, it has been tried to consider most appropriate systems for stabilizing this tunnel. For this purpose, the pseudo-codes of these techniques are written in MATLAB software and the required analyses are accurately conducted for modeling.

2. Methodology of FDAHP

The analytic hierarchy process (AHP) is a powerful tool for choosing among several alternatives. This technique was firstly introduced by Saaty in 1980 [12]. The analytic hierarchy process can not show the human thinking style [13,14]. This technique is evaluated due to the practise of the unstable scale of judgments [15,16]. Recently, soft computing approaches are used in a variety of engineering problems, which FDAHP is a reliable alternative in comparison to classical approaches [17,18,27,28,19–26]. Delphi method is a technique for structuring an effective group communication process. Since its development in the 1960s at Rand Corporation, the Delphi technique was used in various studies [29–31].

The procedure of FDAHP technique can be described as follows:

(1) Compute the triangular fuzzy numbers (TFNs) $\tilde{\alpha}_{ij}$ using the Eq. (1) to Eq. (4). In Fig. 1, the TFNs indicate the minimum, moderate and maximum estimates of experts' opinions.

$$\tilde{\alpha}_{ij} = \left(\alpha_{ij}, \delta_{ij}, \gamma_{ij}\right) \tag{1}$$

$$\alpha_{ij} = \min \beta_{ijk} \, (k = 1,2, \dots, n) \tag{2}$$

$$\delta_{ij} = \left[\prod_{k=1}^{n} \beta_{ijk}\right]^{\frac{1}{n}} \;\; (k = 1,2, \dots, n) \tag{3}$$

$$\gamma_{ij} = \max \beta_{ijk} \;\;\; (k = 1,2, \dots, n) \tag{4}$$

Where $\alpha_{ij} < \delta_{ij} < \gamma_{ij}$ and $\alpha, \delta, \gamma \in \left[\frac{1}{9}, 1\right] \cup [1,9]$and α_{ij} and γ_{ij} are the lower and upper bounds, respectively. β_{ijk} is the relative intensity of importance of expert k between activities i, j and n is the number of experts in a group.

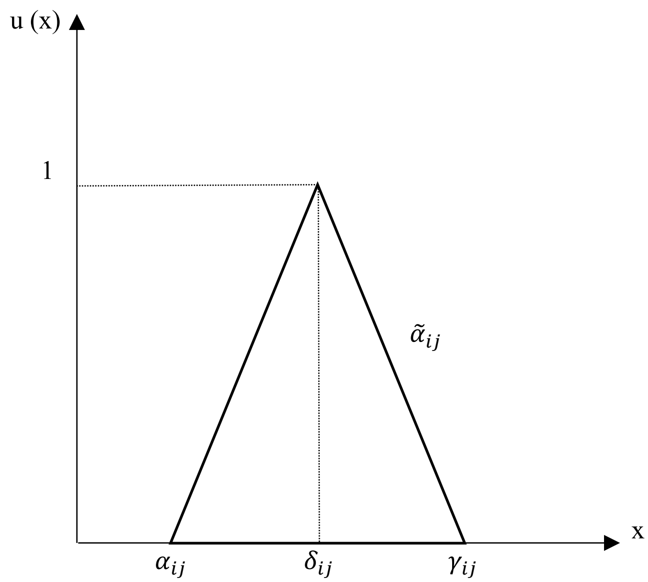

Fig. 1. The triangular fuzzy numbers (TFNs).

(2) Determine the fuzzy positive reciprocal matrix $\tilde{A}$ by using the Eq. (5):

$$\tilde{A} = [\tilde{a}_{ij}], \tilde{a}_{ij} \times \tilde{a}_{ji} \approx 1, i,j = 1,2, \dots, n \;\; or \;\; \tilde{A} = \begin{bmatrix} (1,1,1) & (a_{12}, \delta_{12}, \gamma_{12}) & (a_{13}, \delta_{13}, \gamma_{13}) \\ \left(\frac{1}{\gamma_{12}}, \frac{1}{\delta_{12}}, \frac{1}{a_{12}}\right) & (1,1,1) & (a_{23}, \delta_{23}, \gamma_{23}) \\ \left(\frac{1}{\gamma_{13}}, \frac{1}{\delta_{13}}, \frac{1}{a_{13}}\right) & \left(\frac{1}{\gamma_{23}}, \frac{1}{\delta_{23}}, \frac{1}{a_{23}}\right) & (1,1,1) \end{bmatrix} \tag{5}$$

(3) Compute the relative fuzzy weights of the evaluation factors based on Eq. (6):

$$\tilde{Z}_i = [\tilde{a}_{ij} \otimes \dots \otimes \tilde{a}_{in}]^{1/n}, \widetilde{W}_i = \tilde{Z}_i \otimes (\tilde{Z}_i \oplus \dots . \oplus \tilde{Z}_n)^{-1} \tag{6}$$

Where $\tilde{a}_1 \otimes \tilde{a}_2 \cong (a_1 \times a_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2)$; the symbol $\otimes$ shows the multiplication of fuzzy numbers, and the symbol $\oplus$ shows the addition of fuzzy numbers; $\widetilde{W}_i$ is a row vector consisting of the fuzzy weight of the ith factor, $\widetilde{W}_i = (\omega_1, \omega_2, \dots, \omega_n)$ $(i = 1,2,\dots,n)$; and W_i is the fuzzy weight of the i^{th} factor.

3. Methodology of ELECTRE

Elimination and Choice that Translates the Reality technique (ELECTRE) is one of the useful multi-criteria decision making (MCDM) techniques to manage real-world problems when compensation among criteria is not allowed. This technique was firstly introduced by Benayoun and developed by Roy and his colleagues in the mid-1960s [32]. ELECTRE uses the concept of outranking comparisons for modeling the preference information between each pair of alternatives and to achieve such a goal it uses concordance and discordance sets [33–36]. In this research, to rank the different tunnel supporting systems, ELECTRE technique was employed as follow:

Step 1. Make the decision matrix. According to alternatives and criteria, the decision matrix is made as follows by Eq. (7):

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \qquad (i = 1,2,\ldots,m; j = 1,2,\ldots,n) \tag{7}$$

Step 2. Compute the normalized decision matrix. The decision matrix is normalized via the following Eq. (8):

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} {x_{ij}}^2}} \tag{8}$$

Step 3. Compute the weighted normalized decision matrix. It is formed via the following Eq. (9):

$$v_{ij} = \omega_j \times r_{ij} \tag{9}$$

Step 4. Determine the concordance and discordance sets. For each pair of alternative k and l ($k, l = 1,2,..,m$ and $k \neq l$), the set of criteria is divided into two distinct subsets. If the alternative k is preferred over alternative l for all the criteria, then the concordance set is composed. This can be written as Eq. (10):

$$S_{kl} = \{\forall_j | v_{kj} < v_{lj}\} = J - S_{kl} \tag{10}$$

The complement of S_{kl}, the discordance set, contains all the criteria for which k is worse than l. This can be written as Eq. (11):

$$D_{kl} = \{\forall_j | v_{kj} > v_{lj}\} = J - S_{kl} \tag{11}$$

Step 5. Calculate the concordance matrix.

The relative value of the concordance sets is measured using the concordance index. The concordance index is equal to the sum of the weights associated with those criteria and relation which are contained in the concordance sets. Therefore, the $\bar{I}$ and the concordance index I_{kl} between k and l are defined as Eq. (12):

$$I_{kl} = \sum_{j \in S_{kl}} w_j \quad , \quad 0 \leq I_{kl} \leq 1 \qquad \bar{I} = \sum_{k=1}^{m} \sum_{l=1}^{m} {I_{kl}}/{m(m-1)} \tag{12}$$

Based on the threshold value, a Boolean matrix F can be constructed, the elements of which are defined as Eq. (13):

$$\begin{cases} if\ I_{kl} \geq \bar{I} \ \rightarrow f_{kl} = 1 \\ if\ I_{kl} < \bar{I} \ \rightarrow f_{kl} = 0 \end{cases} \tag{13}$$

Then each element of 1 on the matrix F represents the dominance of one alternative with respect to another one.

Step 6. Determine the discordance dominance matrix.

This matrix is constructed in a way analogous to the F matrix based on a threshold value $\overline{NI}$ to the discordance indices. The elements of g_{kl} of the discordance dominance matrix G are calculated as Eq. (14):

$$\begin{cases} \overline{NI} = \sum_{k=1}^{m} \sum_{l=1}^{m} {NI_{kl}}/{m(m-1)} \\ \qquad if\ NI_{kl} \leq \overline{NI} \ \rightarrow g_{kl} = 1 \\ \qquad if\ NI_{kl} > \overline{NI} \ \rightarrow g_{kl} = 0 \end{cases} \tag{14}$$

Also, the unit elements in the G matrix represent the dominance relationships between any two alternatives.

Step 7. Determine the aggregate dominance matrix (H matrix). This step is to calculate the intersection of the concordance dominance matrix F and discordance dominance matrix G as Eq. (15):

$$h_{kl} = f_{kl} \times g_{kl} \tag{15}$$

Step 8. Eliminate the less favorable alternatives.

The aggregate dominance matrix E gives the partial-preference ordering of the alternatives. If $h_{kl} = 1$, then k is preferred to l for both the concordance and discordance criteria, but k still has the chance of being dominated by the other alternatives. Hence the condition that k is not dominated by ELECTRE procedure is:

$$\begin{cases} if\ k \neq l; for\ at\ least\ one\ l\ (l = 1,2,..,m) \quad \rightarrow h_{kl} = 1 \\ if\ i \neq l\ and\ i \neq k; for\ at\ all\ i\ (i = 1,2,..,m) \rightarrow h_{kl} = 0 \end{cases}$$

This condition appears difficult to apply, but the dominated alternatives can be easily identified in the H matrix. If any column of the H matrix has at least one element of 1, then this column is 'ELECTRE cally' dominated by the corresponding row(s). Hence, any column(s) which have an element of 1 is simply eliminated.

Despite the very useful outlook and several findings that can be deduced from the results of ELECTRE, still, a detailed full ranking of alternatives doesn't exist. To achieve such a significant issue, Van delft and Nijkamp in 1976 introduced a complementary technique to ELECTRE [37]. According to their method, net concordance and discordance values should be calculated (based on Eqs 16 and 17). Higher net concordance value and lower net discordance value hints to better-ranking alternatives. If the full ranking based on net concordance value and net discordance value were not alike, an average ranking from the two rankings is applicable [38].

$$C_k = \sum_{l=1}^{m} I_{kl} - \sum_{l=1}^{m} I_{lk} \tag{16}$$

$$D_k = \sum_{l=1}^{m} NI_{kl} - \sum_{l=1}^{m} NI_{lk} \tag{17}$$

4. Application of FDAHP-ELECTRE technique for evaluation of tunnel supporting system system

4.1. Project description and geology of the study area

Dolaei tunnel of Touyserkan is located in Sanandaj- Sirjan geological zone. This zone is one of the most active and unsafe zones of Iran. The main rocks of this region include the blocks of granite and Hornfels Schists, which have been produced by transformation of Alvand's huge blocks of granite, and also there are Hornfels with Schist properties. The current hornfelses of the region, as a result of the tunnel excavation on the way of the old fault, have broken into tiny pieces and have become semi stone-semisoil [39]. Major sedimentary- structural units of Iran and the geological map of the tunnel's zone are shown in Fig. 2.

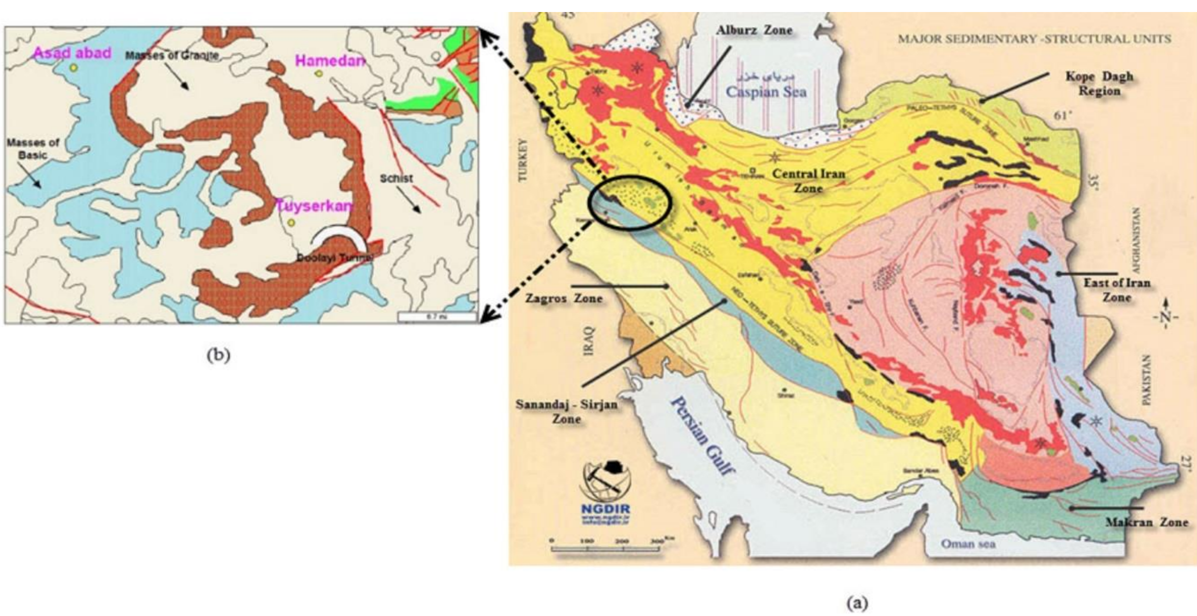

Fig. 2. (a) Geological Map of Iran (1:1000.000 Scales) and (b) Geological Map of Tunnel's Zone [40].

Also, there is displacement in horizontal direction and settlements at the tunnel roof. Both of them are given completely in Figs. 3 and 4. Thus, it is very important to study the tunnel stability against existing conditions [41].

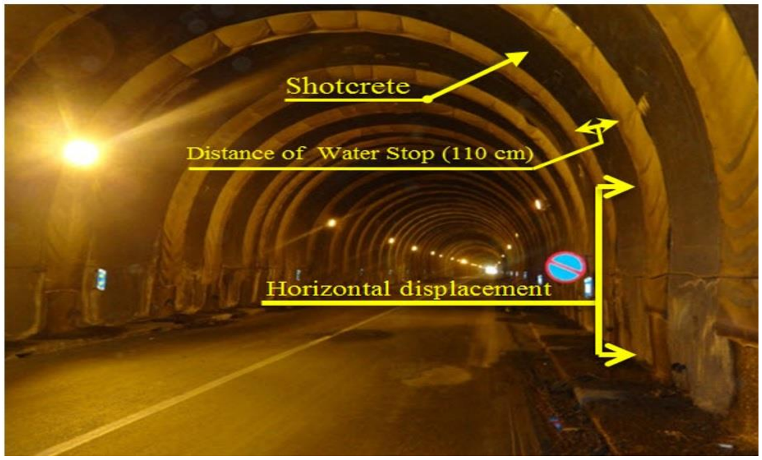

Fig. 3. Horizontal Displacement.

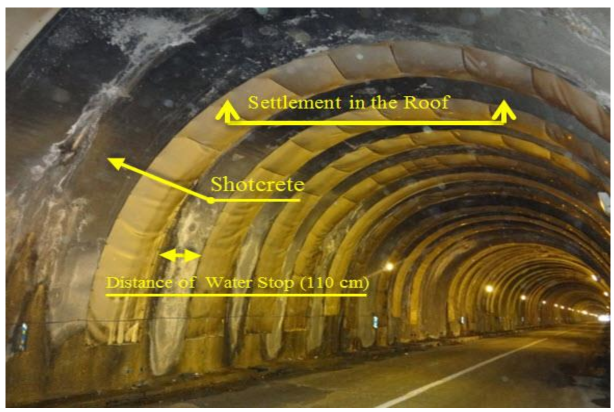

Fig. 4. Settlement in Tunnel Roof.

In this case, some numerical studies have been done [42][43]. All surveys are conducted to analyse the local geological condition and tunnel stability.

4.2. Defining the criteria and alternatives

Tunnelling construction is a complex process that is affected by many factors that interact with each other. Therefore, it is very difficult to explain the reasons for delaying and unpredicted cost in the tunnelling process. To understand and improve the tunnelling process, and consequently minimize the sources of delay and increasing costs, various types of controlling and uncontrolling factors such as geotechnical investigations should be investigated. In this section, the major factors are explained as criteria for selecting a suitable support system. Six criteria have been adopted to evaluate and examine the tunnel supporting system. These criteria include underground water condition, geotechnical and geological properties of the area, economical capability, access to implementation technology, hardship of doing the job, and service life of the tunnel. In the tunnelling process, all of the criteria mentioned above must be investigated and documented well. In general, the investigation of geology (such as geological and tectonic layout, the most important parameters of soils and rocks), hydrological (influence of groundwater on support system, groundwater flow and its relation to surface water) and geotechnical (all geotechnical characteristics related to excavation and supporting system such as characteristics of discontinuities) conditions are important in the first step of tunnel construction.

One of the most important steps of tunnel design and construction is the tunnel's supporting system. Five important and common support systems consist of prefabricated segments, reinforced shotcrete, and field implementation of reinforced concrete, steel retaining, and implementation of rock bolt with reinforced shotcrete. These support systems were identified as alternatives to select the optimum tunnel supporting system. Actually, in this research, there have been used expert ideas, local pieces of evidence and collected data on the six criteria and five alternatives.

4.3. Determination of criteria's weights

Because different decision-makers have different objectives and expectations, they may judge a tunnel support system from different perspectives. So, the same criterion may have a dissimilar level of importance for different users. For this reason, some decision-makers are selected from different areas to assess the importance of criteria. FDAHP is used to take into consideration subjective judgments of decision-makers and to decrease the doubt and vagueness in the decision-making process. Decision-makers with different backgrounds may define different weight vectors. They usually cause not only the imprecise evaluation but also serious persecution during the decision-making process. Therefore, a group of decisions based on FDAHP is proposed to determine and improve pair-wise comparison. Firstly, a pair-wise comparison is made for each decision-maker (D_i) with the use of Saaty's 1–9 scales [12]. The results of the experts' opinion questionnaire are given in Table 1.

Table 1
The results of the experts' opinion questionnaire.

C_i	C_1				C_2				C_3			
	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4
C_1	1	1	1	1	3	3	3	3	5	5	5	5
C_2	0.33	0.333	0.333	0.333	1	1	1	1	5	3	5	3
C_3	0.2	0.2	0.2	0.2	0.2	0.33	0.2	0.33	1	1	1	1
C_4	0.2	0.2	0.2	0.2	0.2	0.33	0.2	0.33	0.333	0.333	0.333	0.333
C_5	0.14	0.143	0.143	0.143	0.2	0.33	0.2	0.33	0.143	0.2	0.143	0.2
C_6	0.2	0.2	0.2	0.2	0.33	0.2	0.33	0.2	0.333	0.2	0.333	0.2
C_i	C_4				C_5				C_6			
	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4	D_1	D_2	D_3	D_4
C_1	5	5	5	5	7	7	7	7	5	5	5	5
C_2	5	3	5	3	5	3	5	3	3	5	3	5
C_3	3	3	3	3	7	5	7	5	3	5	3	5
C_4	1	1	1	1	5	7	5	7	1	3	1	3
C_5	0.2	0.143	0.2	0.143	1	1	1	1	0.333	0.333	0.333	0.333
C_6	1	0.333	1	0.333	3	3	3	3	1	1	1	1

Where C_1 to C_6 are the criteria describing groundwater condition, geotechnical and geological data of the area, economical capability, access to implementation technology, hardship of doing the job, and service life of the tunnel, respectively. The weighting factors for each criterion are determined in the following steps:

(1) Calculate the triangular fuzzy numbers (TFNs):

$$\tilde{a}_{ij} = \left(a_{ij}, \delta_{ij}, \gamma_{ij}\right)$$

According Eqs. (2) and (4), it results that:

$$a_{ij} = \min \beta_{ijk} \, (k = 1,2, \dots, n)$$

In this study the value of n is 3. There have been used three different groups of decision-makers.

(2) Make a fuzzy pair-wise comparison matrix ($\tilde{A}$).

In this way, the values of decision-makers' pair-wise comparison are transformed into TFNs, as listed in Table 2.

Table 2
Fuzzy pair-wise comparison matrix.

C_i	C_1	C_2	C_3	C_4	C_5	C_6
C_1	(1, 1, 1)	(3, 3, 3)	(5, 5, 5)	(5, 5, 5)	(7, 7, 7)	(5, 5, 5)
C_2	(0.33, 0.33, 0.33)	(1, 1, 1)	(3, 3.87, 5)	(3, 3.87, 5)	(3, 3.87, 5)	(3, 3.9, 5)
C_3	(0.2, 0.2, 0.2)	(0.2, 0.26, 0.33)	(1, 1, 1)	(3, 3, 3)	(5, 5.92, 7)	(3, 3.9, 5)
C_4	(0.2, 0.2, 0.2)	(0.2, 0.26, 0.33)	(0.33, 0.33, 0.33)	(1, 1, 1)	(5, 5.92, 7)	(1, 1.7, 3)
C_5	(0.14, 0.14, 0.14)	(0.2, 0.26, 0.33)	(0.14, 0.17, 0.2)	(0.14, 0.17, 0.2)	(1, 1, 1)	(0.33, 0.33, 0.33)
C_6	(0.2, 0.2, 0.2)	(0.2, 0.26, 0.33)	(0.2, 0.26, 0.33)	(0.33, 0.58, 1)	(3, 3, 3)	(1, 1, 1)

(3) Determine the relative fuzzy weights of the evaluation factors:

$$\begin{cases} \tilde{Z}_1 = [\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \dots \otimes \tilde{a}_{16}]^{1/6} = [3.714, 3.714, 3.714] \\ \tilde{Z}_2 = [\tilde{a}_{21} \otimes \tilde{a}_{22} \otimes \dots \otimes \tilde{a}_{26}]^{1/6} = [1.732, 2.053, 2.434] \\ \tilde{Z}_3 = [\tilde{a}_{31} \otimes \tilde{a}_{32} \otimes \dots \otimes \tilde{a}_{36}]^{\frac{1}{6}} = [1.103, 1.235, 1.383] \\ \tilde{Z}_4 = [\tilde{a}_{41} \otimes \tilde{a}_{42} \otimes \dots \otimes \tilde{a}_{46}]^{\frac{1}{6}} = [0.637, 0.749, 0.880] \\ \tilde{Z}_5 = [\tilde{a}_{51} \otimes \tilde{a}_{52} \otimes \dots \otimes \tilde{a}_{56}]^{\frac{1}{6}} = [0.241, 0.266, 0.293] \\ \tilde{Z}_6 = [\tilde{a}_{61} \otimes \tilde{a}_{62} \otimes \dots \otimes \tilde{a}_{66}]^{1/6} = [0.447, 0.534, 0.637] \end{cases} \Rightarrow \sum \tilde{Z}_i = [7.873, 8.55, 9.341]$$

$$\begin{cases} \widetilde{W}_1 = \tilde{Z}_1 \otimes \left(\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3\right)^{-1} = [0.398,0.434,0.472] \\ \widetilde{W}_2 = \tilde{Z}_2 \otimes \left(\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3\right)^{-1} = [0.185,0.240,0.309] \\ \widetilde{W}_3 = \tilde{Z}_3 \otimes \left(\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3\right)^{-1} = [0.118,0.144,0.176] \\ \widetilde{W}_4 = \tilde{Z}_4 \otimes \left(\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3\right)^{-1} = [0.068,0.088,0.112] \\ \widetilde{W}_5 = \tilde{Z}_5 \otimes \left(\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3\right)^{-1} = [0.026,0.031,0.037] \\ \widetilde{W}_6 = \tilde{Z}_6 \otimes \left(\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3\right)^{-1} = [0.048,0.062,0.081] \end{cases}$$

The final weights of each parameter are determined and given as follows:

$$W_1 = \left[\prod_{i=1}^{3} \omega_j\right]^{1/3} = 0.434, W_2 = 0.240, W_3 = 0.144, W_4 = 0.088, W_5 = 0.032, W_6 = 0.062.$$

The priority weights mentioned above are indicated for each criterion in Table 3.

Table 3
Priority weights for criteria.

Criteria	Global weights
Underground water conditions	0.434
Geotechnical and geological condition	0.240
Economical capability	0.144
Access to technology implementation	0.088
Hardship of doing the job	0.032
Service life of the tunnel	0.062

4.4. ELECTRE Method

Ranking of the proposed tunnel supporting system is performed using the ELECTRE method. The weights of the criteria should be determined by the FDAHP method. Firstly, the value of each alternative is inserted in a decision matrix concerning excavation conditions (Table 4). The decision matrix is normalized according to Eq. (7) (Table 5). Then, a weighted normalized matrix is formed by multiplying each value with their weights (Table 6).

Table 4
Decision matrix.

		UWc	*GGc*	*Ec*	*TI*	*HD*	*SL*
		C_1:	C_2:	C_3:	C_4:	C_5:	C_6:
PS	A_1:	9	3	9	7	3	7
RS	A_2:	1	5	3	5	1	3
SCI	A_3:	3	5	7	5	5	5
SR	A_4:	7	7	7	5	3	3
RB&S	A_5:	9	9	9	7	1	7

Table 5
Normalized decision matrix.

		UWc	*GGc*	*Ec*	*TI*	*HD*	*SL*
		C_1:	C_2:	C_3:	C_4:	C_5:	C_6:
PS	A_1:	0.6054	0.2182	0.5487	0.5322	0.4472	0.5895
RS	A_2:	0.0673	0.3637	0.1829	0.3801	0.1491	0.2526
SCI	A_3:	0.2018	0.3637	0.4268	0.3801	0.7454	0.4211
SR	A_4:	0.4709	0.5092	0.4268	0.3801	0.4472	0.2526
RB&S	A_5:	0.6054	0.6547	0.5487	0.5322	0.1491	0.5895

Table 6
Weighted normalized matrix.

		UWc	*GGc*	*Ec*	*TI*	*HD*	*SL*
		C_1:	C_2:	C_3:	C_4:	C_5:	C_6:
PS	A_1:	0.2627	0.0524	0.0790	0.0468	0.0143	0.0365
RS	A_2:	0.0292	0.0873	0.0263	0.0335	0.0048	0.0157
SCI	A_3:	0.0876	0.0873	0.0615	0.0335	0.0239	0.0261
SR	A_4:	0.2044	0.1222	0.0615	0.0335	0.0143	0.0157
RB&S	A_5:	0.2627	0.1571	0.0790	0.0468	0.0048	0.0365

The concordance and discordance matrices are calculated using Eq. 11 and 12. These matrices are shown in Tables 7 and 8. After determining the thresholds for matrices and determining the concordance and discordance dominance matrix (steps 7 & 8 – Tables 9&10), the aggregate dominance matrix is calculated via Eq. (8).

Table 7
Concordance matrix.

Alternatives	*A1*	*A2*	*A3*	*A4*	*A5*
A1	-	0.76	0.73	0.76	0.76
A2	0.24	-	0.33	0.15	0.03
A3	0.27	1	-	0.33	0.03
A4	0.27	1	0.91	-	0.03
A5	0.97	1	0.97	0.97	-

Table 8
Discordance matrix.

Alternatives	*A1*	*A2*	*A3*	*A4*	*A5*
A1	-	0.15	0.2	1	1
A2	1	-	1	1	1
A3	1	0	-	1	1
A4	0.84	0	0.09	-	1
A5	0.09	0	0.11	0.16	-

Table 9
Concordance dominance matrix (*F* matrix).

Alternatives	*A1*	*A2*	*A3*	*A4*	*A5*
A1	-	1	1	1	1
A2	0	-	0	0	0
A3	0	1	-	0	0
A4	0	1	1	-	0
A5	1	1	1	1	-

Table 10
Discordance dominance matrix (*G* matrix).

Alternatives	*A1*	*A2*	*A3*	*A4*	*A5*
A1	-	1	1	0	0
A2	0	-	0	0	0
A3	0	1	-	0	0
A4	0	1	1	-	0
A5	1	1	1	1	-

Accordingly, the aggregate dominance matrix is obtained in Tables 11. Afterward, the elimination of alternatives with a less satisfactory level is begun. This preference is shown graphically in Fig 5. The preferences of the alternatives are illustrated in Fig 5 and Table 11.

Table 11
Aggregate dominance matrix (*H* matrix).

Alternatives	*A1*	*A2*	*A3*	*A4*	*A5*
A1	-	1	1	0	0
A2	0	-	0	0	0
A3	0	1	-	0	0
A4	0	1	1	-	0
A5	1	1	1	1	-

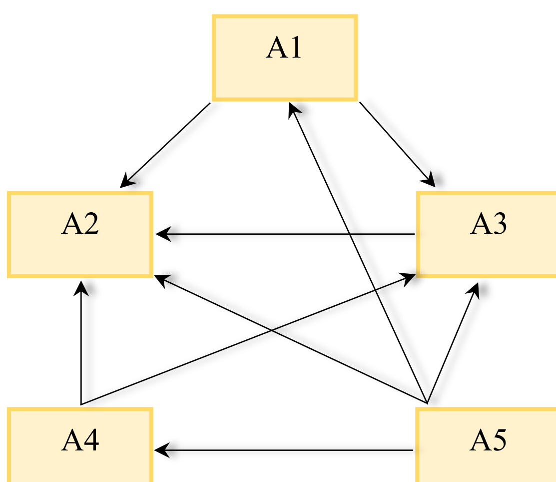

Fig. 5. Aggregate dominance matrix preferences (*H* matrix) of the tunnel supporting system.

As it can be deduced, alternative 5 dominated over the other alternatives and alternative 2 is defeated by the other four ones. Therefore, the rock bolt and reinforced shotcrete system is the most efficient supporting system in the attempted tunnel. In general, the rock bolt works by connecting different layers and segments of rocks. Using the rock bolt and reinforced shotcrete simultaneously to keep the tunnel stability against microseismicity and weight increases the resistance and efficiency of the tunnel's final covering that is considered a compound and more efficient system. But as mentioned above in order to achieve a detailed full ranking of alternatives, net concordance, and discordance values should be calculated based on Eq. 15 and 16 (Table 12). Higher net concordance value and lower net discordance value leads to higher quality alternatives. As the full ranking based on net concordance and net discordance value were not similar, an average ranking from the two rankings could be applicable.

Table 12
Net Concordance and Discordance values; Ranks based on net concordance and discordance values and the total average ranking.

	A1	*A2*	*A3*	*A4*	*A5*
Net Concordance Value	1.26	-3.01	-1.31	0	3.06
Rank based on net concordance value	2	5	4	3	1
Net Discordance Value	-0.58	3.85	1.6	-1.23	-3.64
Rank based on net discordance value	3	5	4	2	1
Total Rank	2.5 ≅ 3	5	4	2.5 ≅ 2	1

According to Table 12, the highest score has been dedicated to rock bolt and reinforced shotcrete system. Steel retaining was positioned in second place; and similarly, prefabricated segments, field implementation of reinforced concrete and reinforced shotcrete are ranked respectively from third to fifth.

5. Conclusions

In the present study, a hierarchical model was established to evaluate and rank the tunnel supporting systems with the use of effective factors considering decision-makers' judgments. The proposed approach was constructed based on the combination of the FDAHP method and the ELECTRE technique. FDAHP was utilized to determine the weights of the factors according to the decision matrix, and then the ranking of alternatives was obtained by ELECTRE. The proposed method was applied to Dolaei tunnel located in Touyserkan to evaluate the supporting system. Some factors such as groundwater condition, geotechnical and geological data of the area, economical capability, access to implementation technology, hardship of doing the job, and service life of the tunnel were investigated for the optimal support system ranking. The results showed that the rock bolt and reinforced shotcrete system were the most suitable supporting system. Finally, it is suggested to use another fuzzy number except triangular one for the first step of the AHP process.

Acknowledgments

We would like to express our deepest thanks to Professor Mahdi Ghaem for his excellent advice. The authors would like to express their appreciation to the University of Birjand and Urmia University of Technology for providing the Facilities for us to execute the present research as a common work.

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