THE OPTIMUM SUPPORT SELECTION BY USING FUZZY ANALYTICAL HIERARCHY PROCESS METHOD FOR BEHESHTABAD WATER TRANSPORTING TUNNEL IN NAIEN

R. RAFIEE, M. ATAEI AND S. M. E. JALALI

Abstract. The engineers can frequently encounter with the situation to select the optimum option among the alternatives related with tunneling operations. The optimum choice can be selected by the experienced engineers taking into consideration their judgment and intuition. However, decision-making methods can offer to the engineers to support their optimum selection for a particular application in a scientific way. The Fuzzy Analytical Hierarchy Process (FAHP) is one of the multi attribute decision-making (MADM) methods utilizing structured pair-wise comparisons. This paper presents an application of the FAHP method to the selection of the optimum support design for water transporting tunnel in Naien. The methodology considers six main criteria, considering: displacement values for determined history locations, factor of safety (FOS), cost (total cost), time, mechanization and applicability factor for the selection of support design. The displacements and stress values were obtained by using the finite difference program FLAC2D as the numerical studies have been widely used by engineers examining the response of tunnels, in advance. After carrying out several numerical models for different support designs, the FAHP method was incorporated to evaluate these support designs according to the pre-determined criteria. These studies show that such FAHP application can effectively assist engineers to evaluate the alternatives support system for tunnels.

1. Introduction

Beheshtabad water transporting tunnel approximately with 65 kilometers length and 6 meters width is one of the biggest water supplying project for transporting water to central plateau of Iran. This tunnel is located near Ardal city with east north-west south direction. From the entrance to 17 km of the tunnel is located in Zagros zone and the output of it is in Sanandaj-Sirjan zone. This tunnel will transfer Beheshtabads water for resolving water deficiencies problem and industrial and agriculture use in the central plateau of Iran, 1070 cubic million meters annually. The most important criteria in the support design of Beheshtabad tunnel was estimating value of stress distribution, displacements and failure zone. Therefore; the finite difference code FLAC2D has been employed and to obtain the results realistically, great attention has been paid to determine the geomechanical parameters of rock mass in the site. Among modeling studies, six different models were

Received: February 2011; Revised: June 2012 and November 2012; Accepted: April 2013
Key words and phrases: FAHP, Optimum support system, Tunnel.

constituted and the solutions of these models were carried out by using FLAC2D. After realizing several numerical analyses, different support designs were evaluated by using the FAHP method, considering the results obtained from the numerical analysis, in decision-making process.

2. **Fuzzy Sets and Fuzzy Numbers**

To deal with vagueness of human thought, L. A. Zadeh introduced the fuzzy set theory at first, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. This theory also allows mathematical operators and programmer to apply to the fuzzy domain. A fuzzy set is a class of objects with a continum grade of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranges between zero and one. With different daily decision making problems of diverse intensity, the result can be misleading if fuzziness of human decision making has not considered (see [16]) Fuzzy sets theory providing more widely frame than classic sets theory has been contributed to the capability of reflecting real world (see [5]). Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling: uncertain system in industry, nature and humanity and facilitators for commonsense reasoning in decision making in the absence of complete and precise information. Their role will be significant when applied to complex phenomenons which are not easily described by traditional mathematical method, especially when the goal is finding a good approximate solution (see [1]). Fuzzy set theory is a better means of modeling imprecision arising from mental phenomena which are neither random nor stochastic. Human beings are complicatedly involved in the process of analysis decision. A rational approach toward decision making should be taken into human subjective account, instead of employing only objective probability measures. This attitude, towards imprecision of human behavior depended on the study of a new decision analysis filed fuzzy decision making. A tilde $\sim$ will be placed above a symbol if the symbol shows a fuzzy set. A triangular fuzzy number (TFN) $\tilde{\mathrm{M}}$ is shown in Figure1. A TFN is denoted simply as $\langle l, m, u\rangle$. The parameters l, m and u, respectively, denoted the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event (see [3]).

Each TFN has liner representation on its left and right that its membership function can be defined as

$$\mu(x/\tilde{M}) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases} \tag{1}$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

$$\tilde{M} = (M^{l(y)}, M^{r(y)}) = (l + (m-l)y, u + (m-u)y) \qquad y \in [0,1] \tag{2}$$

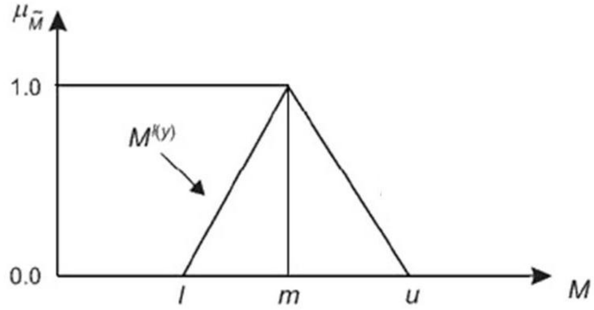

FIGURE 1. A Triangular Fuzzy Number, $\tilde{\mathrm{M}}$

Where $l(y)$ and $r(y)$ denote the left representation and the right side representation of fuzzy number, respectively. Many ranking method for fuzzy number have been developed in the literature. These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. The algebraic operations with fuzzy number have been explained by kahraman and kahraman et al (see [9, 12]).

3. Fuzzy Analytic Hierarchy Process

AHP is a multi-criteria decision making (MCDM) method helping decision-maker facing a complex problem with multiple conflicting and subjective criteria (e.g. location or investment selection, projects ranking, etc). Several MCDM methods have been developed (e.g. ELECTRE, MacBeth, SMART, PROMETHEE, UTA) and all are based on four steps: problem modeling, weights valuation, weights aggregation and sensitivity analysis. In the next sections we will review these four steps used by AHP and its evolutions (see [7])

The AHP is a tool that can be used for analyzing different kinds of social, political, economic and technological problems, and it use both qualitative and quantitative variables. The fundamental principle of analysis is the possibility of connecting information, based on knowledge, to make decisions or previsions; the knowledge can be taken from experience or derived from the application of other tools. Among different context in which the AHP can be applied, mention can be made from creation of the priorities list, the choice of the best policy, the optimal allocation of resources, the prevision of results and temporal dependencies, and the assessment of risks and planning (see [13])

Although the AHP is to capture the experts knowledge, the traditional AHP still cannot really reflect the human thinking style (see [10]). The traditional AHP method is problematic for its use of an exact value to express the decision makers opinion in a comparison of alternative (see [17]). Also AHP method is often criticized due to its use of unbalanced scale of judging its inability to handle the inherent uncertainty and imprecision in the pair-wise comparison process adequately (see [4]). To overcome these entire shortcomings, FAHP was developed to solving the hierarchical problems. Decision makers usually realize that it is more confident to give interval judgment instead of fixed value judgment. This is because usually he/she is unable to explicit his/her preference to explicit about the fuzzy nature of comparison processsee(see [11]).

3.1. **Methodology of FAHP.** In this study extent FAHP is utilized, which was originally introduced by Chang (1996). Let $X = (x_1, x_2, x_3, ...x_n)$ an object set, and $G = (g_1, g_2, g_3, ...g_n)$ be a goal set. According to the method of Changs extent analysis, each object is taken and extent analysis for each goal is performed respectively. Therefore, "m" extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1, M_{gi}^2, ...M_{gi}^n \qquad i = 1, 2, 3, .., n, \tag{3}$$

where $M_{gi}^j = (j = 1, 2, ..., m)$ all are TFNs. The steps of Changs extent analysis can be given as in the following:

Step 1 : The value of fuzzy synthetic extent with respect to the i^{th} object is defined as:

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j\right]^{-1} \tag{4}$$

To obtain $\sum_{j=1}^m M_{gj}^j$, the fuzzy addition operation of "m" extent analysis values for a particular matrix is performed such as:

$$\sum_{j=1}^m M_{gi}^j = \left(\sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j\right) \tag{5}$$

And to obtain $\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j\right]^{-1}$, the fuzzy addition operation of $M_{gi}^j = (j = 1, 2, ..., m)$ values is performed such as:

$$\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j = \left(\sum_{i=1}^n l_i, \sum_{i=1}^n m_i, \sum_{i=1}^n u_i\right) \tag{6}$$

And then the inverse of the vector above is computed, such as :

$$\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j\right]^{-1} = \left(\frac{1}{\sum_{i=1}^n u_i}, \frac{1}{\sum_{i=1}^n m_i}, \frac{1}{\sum_{i=1}^n l_i}\right) \tag{7}$$

Step 2: As $M_1 = (l_1, m_1, u_1)$ and$M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(M_2 \geq M_1) = SUP_{y \geq x}\left[min \mu_{M1}(x), \mu_{M2}(y)\right] \tag{8}$$

And can be expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d) \tag{9}$$

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{if} \quad m_2 \geq m_1 \\ 0 & \text{if} \quad l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{if} \quad otherwise \end{cases} \tag{10}$$

Figure2 illustrates equation (9) where "d" is the ordinate of the highest intersection point "D" between μ_{M1} and μ_{M1} to compare M_1 and M_1, we need both values of $V(M_1 \geq M_2) and V(M_2 \geq M_1)$.

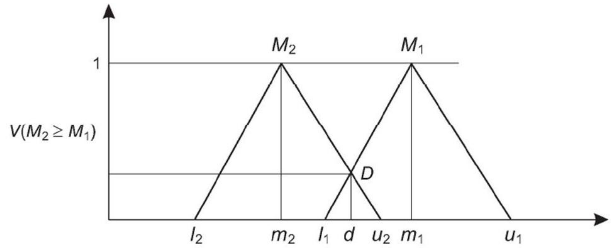

FIGURE 2. The Intersection Between M_1 and M_1 (see [2])

Step 3: The degree possibility for a convex fuzzy number to be greater k convex fuzzy $M_i = (i = 1, 2, ..., k)$ number can be defined by:

$$\begin{aligned} V(M \geq M_1, M_2, ..., M_k) = V\left[(M \geq M_1) and (M \geq M_2) and ... and (M \geq M_k)\right] = \\ minV(M \geq M_i) \qquad i = 1, 2, ..., k \end{aligned} \tag{11}$$

Assume that $d(A_i) = minV(S_i \geq S_k)$, for $k = 1, 2, ..., n; k \neq i$, then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T, \tag{12}$$

where $A_i = (i = 1, 2, ..., n)$ are n elements.

Step 4: Via normalization, the normalize weight vector are:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T, \tag{13}$$

where W is a non-fuzzy number

4. Numerical Modeling Studies

4.1. **The Geomechanical Properties of Rock Mass in the District.** The geomechanical structure of the site has been investigated and the geomechanical properties of the rock formation, that will be driven in Beheshtabads tunnel, have been determined by experimental studies and also utilizing the geomechanical report prepared by rock mechanic reports of Zayandeab Consulting which made drilling works in the site. The rock formations mostly are Lime marl, with shale and sometimes silt between layers of limestone and sandy limestone in Beheshtabad tunnel. Geotechnical property of region is given in the Table 1 (see[6])

4.2. **Numerical Models.** In order to preserve stability of excavation space and to help create a new balance in the earth they must determine the appropriate initial support system; including the important cases of design comes. The support system used convergence-confinement method for determining and FLAC2D was used for drawing the ground reaction curve.

The base model has been designed with the model boundary (8-10) times higher than the gallery dimension and suitable mesh has been created for the model after

Density	(kg/m^3)	2270
Intact Parameters	UCS (MPa)	30
	E (GPa)	8
	ν	0.26
Method Excavation	-	DBM
Rock Mass Parameters	Cohesion(Mpa)	1.5
	$\phi(0)$	30
	UCS	50
	E(GPa)	1
	ν	0.3

Table 1. Geotechnical Property of Beheshtabad Tunnel (see[6])

describing the coordinates in order to simulate the gallery dimension and dip (see [14]). The FLAC2D grid is shown in Figure 3.

In Figure 4(a) contours of vertical stress (in-situ stresses) before excavation has been shown.

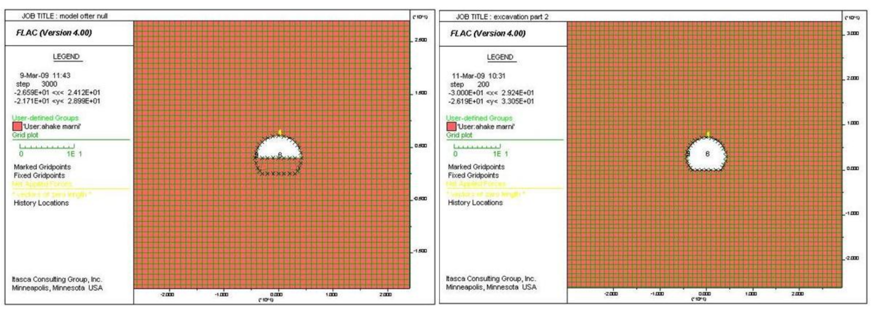

Figure 3. Mesh Generation for the Model

The geomechanical properties of marl such as Youngs modulus, Poissons ratio, bulk modulus, shear modulus; tensile strength and density (Table 1) were introduced as input to the FLAC2D program (see[8])

The first model in the relation with opening after excavation (without support) has been studied by using the finite difference program FLAC2D in order to investigate the rock behavior around the opening. The present work demonstrated huge displacements and failure zones around the opening Figure 4(b) and Figure 5 ; therefore it revealed that supporting the opening with a suitable support system was necessary.

For this model, six support systems have been considered that is shown in Table 2.

The displacement of support system is total displacements that occur in a model. The results of these model studies are summarized in Table 3. Maximum displacements and factor of safety (FOS) values obtained in the model studies has been included in Table 3. The factor of safety (FOS) values for support systems has been calculated by PCACOL software.

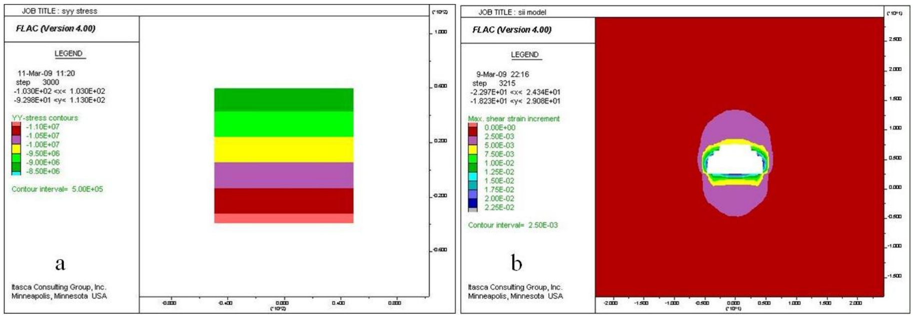

FIGURE 4. (a) Contours of Vertical Stress Before Excavation
(b) Shear Strain Plot After Full Excavation

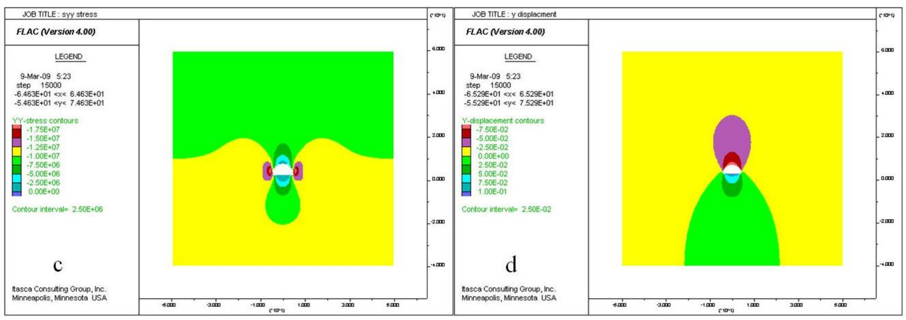

FIGURE 5. (c) S_{yy} Stress Plot After Full Excavation
(d) Y Displacement Plot After Full Excavation

model	Explanation	FOS
A	Supporting by shotcrete lining by 25 cm in thickness together with IPE_{18}	1.575
B	Supporting by shotcrete lining by 30 cm in thickness together with IPE_{16}	1.64
C	supporting by shotcrete lining by 20 cm in thickness together with wire mesh	1.51
D	This system is combination of shotcrete with steel fiber by 20 cm in thickness	1.71
E	application of rock bolt 3 m in length with 1×1 distance together with shotcrete lining by 10 cm in thickness	2.037
F	application of rock bolt 3 m in length with 2×2 distance together with shotcrete lining by 20 cm in thickness	1.3

TABLE 2. Explanation of Model Notations

5. Optimum Model Selection by Using the FAHP Method

Different model studies have been carried out in order to obtain the FOS and the displacement (deformation) values for the tunnel which will be foreseen to serve for

model	History for displacement (m)	FOS
A	1.98×10^{-2}	1.575
B	1.87×10^{-2}	1.64
C	2.083×10^{-2}	1.51
D	2.0173×10^{-2}	1.71
E	2.243×10^{-2}	2.037
F	2.2×10^{-2}	1.3

Table 3. Results of Studied Models

Criterion	Explanationl
C_1	Support Cost
C_2	FOS
C_3	Applicability
C_4	Time
C_5	Displacement
C_6	Mechanization

Table 4. Considered Criteria for Selection of the Support System

a long period of time. It was aimed at minimize the displacements and maximum stress and to maximize the FOS. In the process of deciding on the selection of the optimum support type, the FAHP method was utilized by considering the results obtained from numerical studies and also evaluating some criteria by interviewing the experts working in the tunnel management for years. It was planned to evaluate these selected alternatives in terms of displacements, FOS, cost (total cost), time, mechanization and applicability criteria. Among these criteria, three criteria having a numerical value obtained from the numerical analyses have been included in the decision-making process as it is, while the others having a non-numerical value (i.e. subjective criterion) have been included by assigning the weighted value by the expert team. Therefore, the six different types of support systems were evaluated according to the six criteria given in Table 4.

All decisions have a common hierarchical structure whereby options are evaluated against the various criteria promoting the ultimate decision objective. The problem of the selection of the support design was structured in a hierarchy of different levels constituting goal, criteria and alternatives as shown in Figure 6

Decision makers from different background may define different weight vectors. They usually cause not only the imprecise evaluation but also serious persecution during decision process. For this reason, we proposed a group decision based on FAHP to improve pair-wise comparison.

Each criterion affecting the support design selection was compared with the others and the pair-wise comparison matrix was constructed. FAHP is proposed to take the decision makers subjective judgments in to consideration and to reduce the uncertainty and vagueness in the decision process. The pair-wise comparison scale that using by Saaty (see [15]) as shown in Table 5.

After forming fuzzy pair-wise comparison matrix, weights of all criteria are determined by the help FAHP. According to the FAHP method, firstly value must be calculated. From Table 6, synthesis values respect to main goal are calculated.

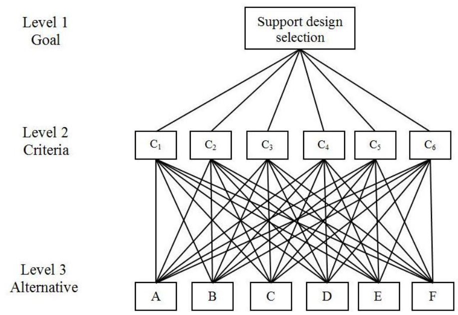

FIGURE 6. Hierarchy Design for the Tunnel Support Selection

$S_{c1} = (9.6, 13.84, 23.5) \otimes (1/75.63, 1/43.04, 1/28.71) = (0.127, 0.321, 0, 819)$
$S_{c2} = (7.3, 10.76, 18.67) \otimes (1/75.63, 1/43.04, 1/28.71) = (0.097, 0.25, 0, 65)$
$S_{c3} = (5.03, 7.69, 13.75) \otimes (1/75.63, 1/43.04, 1/28.71) = (0.067, 0.179, 0, 479)$
$S_{c4} = (3.39, 6.15, 11.21) \otimes (1/75.63, 1/43.04, 1/28.71) = (0.052, 0.143, 0, 390)$
$S_{c5} = (2.85, 4.61, 8.5) \otimes (1/75.63, 1/43.04, 1/28.71) = (0.038, 0.107, 0, 269)$
$S_{c6} = (1.84, 3.07, 5.13) \otimes (1/75.63, 1/43.04, 1/28.71) = (0.024, 0.071, 0, 179)$

Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	5
Equal	3
Intermediate value between the two adjacent judgment	2,4,6,8

TABLE 5. Comparison Index

The pair-wise comparison matrix was constructed as shown in Table 6

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	(1,1,1)	(1,1.28,1.67)	(1.3,1.8,2.5)	(1.6,2.3,3.4)	(2,3,5)	(2.7,4.5,10)
C_2	(0.6,0.77,1)	(1, 1, 1)	(1,1.4,2)	(1.2,1.75,2.67)	(1.5,2.3,5)	(2,3.5,8)
C_3	(0.4,0.56,0.75)	(0.5,0.72,1)	(1, 1, 1)	(0.8,1.25,2)	(1,1.67,3)	(1.33,2.5,6)
C_4	(0.3,0.44,0.63)	(0.38,0.57,0.83)	(0.5,0.8,1.25)	(1, 1, 1)	(0.75,1.3,2.5)	(1,2,5)
C_5	(0.2,0.33,0.5)	(0.25,0.43,0.67)	(033,0.6,1)	(0.4,0.75,1.33)	(1, 1, 1)	(0.67,1.5,4)
C_6	(0.1,0.22,0.37)	(0.13,0.28,0.5)	(0.17,0.4,0.75)	(0.2,0.5,1)	(0.25,0.67,1.5)	(1, 1, 1)

TABLE 6. Comparison of Criteria with Respect to Overall Goal

The fuzzy values are compared by using equation (10) and these values are obtained.

$$
\begin{array}{lll}
V(S_{c1} \geq S_{c2}) = 1 & V(S_{c2} \geq S_{c1}) = 0.88 & V(S_{c3} \geq S_{c1}) = 0.71 \\
V(S_{c1} \geq S_{c3}) = 1 & V(S_{c2} \geq S_{c3}) = 1 & V(S_{c3} \geq S_{c2}) = 0.84 \\
V(S_{c1} \geq S_{c4}) = 1 & V(S_{c2} \geq S_{c4}) = 1 & V(S_{c3} \geq S_{c4}) = 1 \\
V(S_{c1} \geq S_{c5}) = 1 & V(S_{c2} \geq S_{c5}) = 1 & V(S_{c3} \geq S_{c5}) = 1 \\
V(S_{c1} \geq S_{c6}) = 1 & V(S_{c2} \geq S_{c6}) = 1 & V(S_{c3} \geq S_{c6}) = 1 \\
V(S_{c4} \geq S_{c1}) = 0.6 & V(S_{c5} \geq S_{c1}) = 0.44 & V(S_{c6} \geq S_{c1}) = 0.17 \\
V(S_{c4} \geq S_{c2}) = 0.73 & V(S_{c5} \geq S_{c2}) = 0.58 & V(S_{c6} \geq S_{c2}) = 0.31 \\
V(S_{c4} \geq S_{c3}) = 0.9 & V(S_{c5} \geq S_{c3}) = 0.76 & V(S_{c6} \geq S_{c3}) = 0.51 \\
V(S_{c4} \geq S_{c5}) = 1 & V(S_{c5} \geq S_{c4}) = 0.87 & V(S_{c6} \geq S_{c4}) = 0.64 \\
V(S_{c4} \geq S_{c6}) = 1 & V(S_{c5} \geq S_{c6}) = 1 & V(S_{c6} \geq S_{c5}) = 0.8
\end{array}
$$

Then priority weight are calculated by using equation (12)

$d'(C_1) = min(1, 1, 1, 1, 1) = 1$
$d'(C_2) = min(0.88, 1, 1, 1, 1) = 0.88$
$d'(C_3) = min(0.71, 0.84, 1, 1, 1) = 0.71$
$d'(C_4) = min(0.6, 0.73, 0.9, 1, 1) = 0.6$
$d'(C_5) = min(0.44, 0.58, 0.76, 0.87, 1) = 0.44$
$d'(C_6) = min(0.17, 0.31, 0.51, 0.64, 0.8) = 0.17$

Priority weight form $w' = (1, 0.88, 0.71, 0.6, 0.44, 0.17)$ vector. After the normalization of these value priorities weight respects to main goal are calculated as $(0.263, 0.232, 0.187, 0.157, 0.116, 0.045)$. Mentioned priority weights have indicated for each criterion in Table 7.

criteria	Local Weight	Global Weight
Cost	1	0.263
FOS	0.88	0.232
Applicability	0.71	0.187
Time	0.6	0.157
Displacement	0.44	0.116
Mechanization	0.17	0.045

Table 7. Priority Weights for Criteria

Similarly, the alternatives pair-wise comparison matrix into criteria Constituted and according to the above process the final weights of alternative into the criteria obtained which is given in follow Tables:

alternatives	Local Weight	Global Weight
A	0.160	0.040
B	0.437	0.109
C	0.710	0.177
D	0.710	0.177
E	1	0.249
F	1	0.249

Table 8. Weights Between Cost Criteria and Alternatives

alternatives	Local Weight	Global Weight
A	0.249	0.092
B	0.678	0.235
C	0.264	0.092
D	0.678	0.235
E	1	0.347
F	0	0

Table 9. Weights Between FOS Criteria and Alternatives

The overall rating of each alternative is calculated by summing the product of the relative priority of each criterion with the relative priority of the alternatives considering the corresponding criteria in Tables (7 - 13). For example, the overall rating of alternative "E" can be calculated as:

$W_E = (0.249 \times 0.263) + (0.347 \times 0.232) + (0.249 \times 0.187) + (0.182 \times 0.157) + (0.106 \times 0.116) + (0.045 \times 0.235) = 0.244$

alternatives	Local Weight	Global Weight
A	0.437	0.109
B	0160	0.4
C	0.710	0.177
D	0.710	0.177
E	1	0.249
F	1	0.249

Table 10. Weights Between Applicability Criteria and Alternatives

alternatives	Local Weight	Global Weight
A	0.432	0.111
B	0.153	0.039
C	0.878	0.226
D	1	0.258
E	0.707	0.182
F	0.707	0.182

Table 11. Weights Between Time Criteria and Alternatives

alternatives	Local Weight	Global Weight
A	0.877	0.218
B	1	0.249
C	0.704	0.175
D	0.877	0.218
E	0.452	0.106
F	0.140	0.035

Table 12. Weights Between Displacement Criteria and Alternatives

alternatives	Local Weight	Global Weight
A	0.318	0.083
B	0.318	0.083
C	0.533	0.139
D	1	0.261
E	0.901	0.235
F	0.761	0.199

Table 13. Weights Between Mechanization Criteria and Alternatives

Alternatives weight	Overall result
W_A	0.099
W_B	0.129
W_C	0.163
W_D	0.212
W_E	0.244
W_F	0.154

Table 14. Overall Result

Considering the overall results in Table 14, the alternative "E" must be selected as the optimum support system to satisfy the goals and objectives of Behashtabad tunnel because the priority of this alternative (0.244) is the highest value than that of the others.

6. Conclusion

The selection of proper support system for tunnel involves in the consideration of several criteria. Many methods such as numerical analyses have been used for determining the support system. However, the importance of each criterion affected the selection of support system can not be included in the numerical analyses although it is very useful tool for the engineers to inspect the tunnel behavior by trying different support alternatives in advance. However, such a decision process can be evaluated in a more scientific way by utilizing the FAHP method. Therefore, in this paper, the application of FAHP method (the results of numerical models were used, as well) to the selection of support system for Beheshtabad tunnel in Naien were introduced. In the proposed FAHP model; six criteria, namely: displacement, FOS, cost, time, mechanization and applicability were evaluated according to the importance of the selection of support system. Among the considered 6 support system alternatives,"E" was the most convenient support system when the alternatives were evaluated according to the considered criteria. Unlike the traditional approaches to support selection, the FAHP method can offer more scientific way to the engineers to cope with that kind of decision-making process in tunneling industry. Also, the FAHP method requires less data and reduces the time consumed in the decision-making process. Besides, this method considers both subjective and objective criteria.

References

[1] G. Bojadzive and M. Bojadzive, *Fuzzy set fuzzy logic applications*, World scientific Publishing, **26(3)** (2000).

[2] D. Y. Chang, *Applications of the extent analysis method on fuzzy AHP*, European Journal Of Operational Research, **95(4)** (1996), 649–655.

[3] D. Chatterjee and B. Mukherjee, *Study of fuzzy-Ahp model to search the criterion in the valuation of the best technical institutions :a case study*, International Journal of Engineering Science and Technology, **2(7)** (2010), 2499–2510.

[4] H. Deng, *Multicriteria analysis whit fuzzy pair-wise comparison*, International Journal of Approximate Reasoning, **6(21)** (1999), 215–231.

[5] I. Ertugral and A. Tus, *Interactive fuzzy liner programming and an application sample at a textile firm*, Fuzzy Optimization and Decision Making, (2007), 29–49.

[6] M. Hashemi, *Rock mechanics reports*, Water Supply Project of the Central Plateau, Zayandehab Consulting, 2007.

[7] A. Ishizakal and A. Labib, *Review of the main developments in the analytic hierarchy process*, Expert Systems with Applications, **38(11)** (2011), 14336–14345.

[8] Itasca Consulting Group, *Flac version 4.10 Users manual*, Minneapolis, 1999.

[9] C. Kahraman, *Capital budgeting techniques using discounted fuzzy cash flow*, In: D. Runa, J. Kacprzyk, M. Fedrizzi, eds., Soft Computing for Risk Evaluation and Management: Application in Technology, Environment and Finance. Physica-Verlag, Heidelberg, (2001), 375–396.

[10] C. Kahraman, U. Cebeci and D. Runa, *Multi-attribute comparison of catering service companies using fuzzy AHP: the case of Turkey*, International Journal of Production Economics, **87** (2004), 171–184.

[11] C. Kahraman, U. Cebeci and Z. Ulukan, *Multi-criteria supplier selection using fuzzy AHP*, Logoistics Information Management, **6(16)** (2003), 382–394.
[12] C. Kahraman, D. Ruan and E. Tolga, *Capital budgeting techniques using discounted fuzzy versus probabilistic cash flows*, Information Sciences, **1-4(42)** (2002), 57–76.
[13] R. Mikaeil, M. Zare Naghdehi and M. Ataei, *A decision support system using fuzzy analytical hierarchy process (FAHP) and topsis approaches for selection of the optimum underground mining method*, Arch. Mine. Sci, **2(54)** (2002), 341–368.
[14] G. Once, M. Iphar and M. Yavuz, *Study of ground control of the main transport road of the deep coal seam panels of GLI Tuncbilek mine in Turkey*, In: Proceedings of the second FLAC Symposium, (2001), 281–286.
[15] T. L. Saaty, *The analytic hierarchy process*, New York: McGraw-Hil, 1980.
[16] S.H. Tsaur, T. Y. Chang and C. H. Yen, *The evaluation of airline service quality by fuzzy MCDM*, Tourism Management, **23** (2002), 107–115.
[17] S. H. Wang and Y. H. Chen, *Applying consistent fuzzy preference relations to partnership selection*, Omega, the International Journal of Management Science, **35** (2007), 384–388

Ramin Rafiee*, Mining Engineering, Petroliom and Geophysics Faculty, Shahrood University of Technology, Shahrood, Iran
E-mail address: raminlamezi@gmail.com

Mohammad Ataei, Mining Engineering, Petroliom and Geophysics Faculty, Shahrood University of Technology, Shahrood, Iran
E-mail address: ataei@shahroodut.ac.ir

Seyyed Mohammad Esmaeil Jalali, Mining Engineering, Petroliom and Geophysics Faculty, Shahrood University of Technology, Shahrood, Iran
E-mail address: jalalisme@gmail.com

*Corresponding author