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Selection of Tunnel Support System by Using Multi Criteria Decision-Making Tools

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ABSTRACT

Selection of the optimum support system for underground openings such as tunnels is a complex process. In this paper, a new approach, based on a combination of the Analytical Hierarchy Process (AHP), the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and the Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE) is introduced. For this purpose, the selection process is assumed to be a multi criteria decision-making problem. First, different support systems by using $FLAC^{3D}$ numerical code, based on technical, safety and stability parameters of the tunnel are specified. Then, taking economic and performance parameters as the decision criteria, by using the combination of AHP, TOPSIS, and PROMETHEE, the optimum support system is selected. As a real mine case study, this approach is used in the main access entry to C_1 coal seam of Tabas collieries. Results clearly demonstrate that the proposed support system selection method is advantageous to other alternatives.

INTRODUCTION

Generally, the support system for a tunnel is selected primarily with the aid of the experience of design engineers. In other word, personal judgment instead of intellectual and scientific criteria is mostly the main basis (Oraee, 2005). However, since various support systems can be applied in any particular situation, accurate selection of the optimum support method depends on integration of many technical, economical, and performance parameters, and also on the analysis of the intensity of influence by each of the criteria.

In this paper, an applicable approach based on Multi Attribute Decision Making (MADM) techniques including: AHP (Oraee et al., 2009a; Saaty, 1980), TOPSIS (Hwang, and Yoon, 1981; Yoon, and Hwang, 1995), and PROMETHEE (Brans, and Vincke, 1985; Brans, and Mareschal, 1992) for selection of tunnel support systems is introduced. As a field study, this approach was applied to tunnel C_1, as one of the main entries in the Tabas coal mine which is the major collieries in central part of Iran (Hosseini, 2008).

Due to the coal seam conditions, coal is mined by mechanized longwall mining (Hosseini, 2008). This method requires the excavation of several entries, some of which will be used for many years and even for the entire life of the mine (Peng, 2006). Therefore, the selection of the support system in these entries is very important in mining design.

MODELING THE BEHAVIOR OF THE SUPPORT SYSTEM

The validity of numerical modeling and the final results of simulation analysis mainly depend on the accurate determination of geomechanical parameters of surrounding rock masses (Oraee et al., 2008). The results obtained by field studies and also the published technical reports (Hosseini, 2007; Hosseini, 2008; Oraee et al., 2009b) were used in order to provide the geo-mechanical properties of surrounding rock mass. Based on laboratory and field data, the determined uni-axial compressive strength of this rock mass was 10.7 MPa. The Compressive strength based on Brazilian test is calculated to be 1.3 MPa and the Young's modulus and Poisson's ratio are determined as 4,385 MPa and 0.25 respectively. Based on tri-axial compressive test, the resultant friction angle is 35 degrees and cohesion of the rock mass is 5 MPa. Also, based on engineering field study due to beds and joints properties, the rock mass assumed as a pseudo-continuum domain and therefore the FLAC^{3D} code for this study is selected. The geomechanical parameters of rock mass are shown in *Table 1*.

Table 1 Geomechanical parameters of the rock mass

σ_c	σ_t	E	v	φ	C
10.7 MPa	1.3 MPa	4385 MPa	0.25	35 Deg.	5 MPa

The states of various support systems such as the steel arch, concrete liner, shotcrete, rock bolt, etc., were analyzed by using numerical modeling. The defaulted mechanical properties of each support system such as Young's modulus, Poisson's ratio, Bulk modulus and Rigidity modulus were defined based on relevant standards (Hosseini, 2008; Oraee, 2005).

IN-SITU STRESS

One of the important parameters affecting tunnel stability is the state of in-situ stresses. For the evaluation of support systems with numerical modeling, the magnitude and direction of in-situ stress must be defined. In this study, the in-situ stresses are calculated *Equation 1* to *3* (Sheory, 1994).

$$\sigma_v = \gamma . z \qquad (1)$$

$$k = 0.25 + 7E_h(0.001 + \frac{1}{z}) \qquad (2)$$

$$\sigma_h = k.\sigma_v \qquad (3)$$

where σ_v is the vertical in-situ stress, γ is the average density of overburden, h is the depth below surface, k is the ratio of horizontal to vertical in-situ stress, E_h is the average horizontal deformability modulus and σ_h is the horizontal in-situ stress. The vertical and horizontal in-situ stresses are calculated to be 12.50, and 4.71MPa respectively.

NUMERICAL MODELING AND THE SUPPORT SYSTEMS OPTIONS SELECTION

The FLAC^{3D} (Fast Lagrangian Analysis of Continua in 3 Dimensions) software is used for the modeling. FLAC^{3D} is a numerical code based on a three-dimensional explicit finite-difference method, provided by Itasca Consulting Group, Inc., which is nowadays used extensively in rock mechanics problems (ITASCA, 2010).

For modeling, the geometry of tunnel C_1 (Hosseini, 2008) in FLAC^{3D} is defined as the first step. Then, the geomechanical parameters of the surrounding rock mass were input to the model (Hosseini, 2008). Consequently, the potential values for failure and displacement parameters based on the analysis of the behavior of the tunnel in the surrounding rock mass are calculated. Various support systems are then applied in the model, and the mechanical behavior and the stability of the tunnel after application of each support system is determined. Thus, the potential support systems based on technical view points are selected. The 3D grid model and stresses contours in X, Y, and Z direction of FLAC^{3D} model are shown in *Figure 1*.

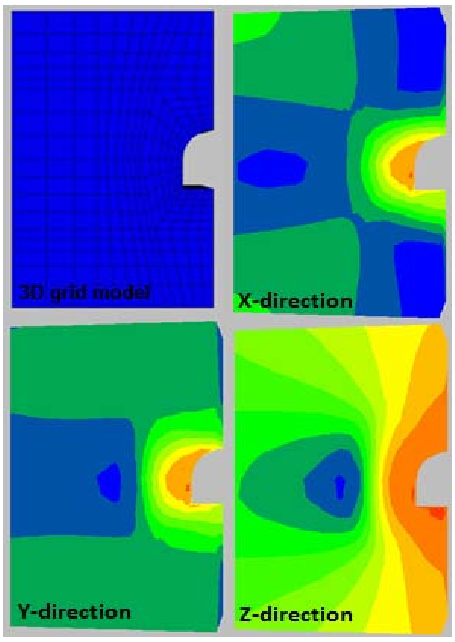

Figure 1 The 3D grid model and stresses contours in X, Y, and Z direction

In total, 10 various support systems are applied in the model and the tunnel stability for each system is evaluated. These applied support systems are shown in *Table 2*.

Table 2 The studied Support systems and their indices

No.	Support system explanation	Index
1	Supporting by B40 shotcrete 5 cm in thickness	A
2	Supporting by B40 shotcrete 8 cm in thickness	B
3	Supporting by B40 shotcrete 8 cm in thickness together with rock bolts	C
4	Application of roof piping together with cement injection	D
5	Application of rock bolts to the gallery, roof and sides	E
6	Application of steel arches with 1m spacing	F
7	Application of steel arches with 0.5 m spacing	G
8	Supporting by B50 shotcrete, 5 cm in thickness	H
9	Supporting by B50 shotcrete, 8 cm in thickness	I
10	Application of steel arches with 1 m spacing together with rock bolts	J

After application of each support system, the state of displacement in the surrounding rock mass of the tunnel is calculated at four points, as shown in *Figure 2*. As seen in this figure, point 1 is on the tunnel roof; point 2 is on the floor and points 3 and 4 are located on the intersection of the wall and floor, horizontal and vertical directions, respectively.

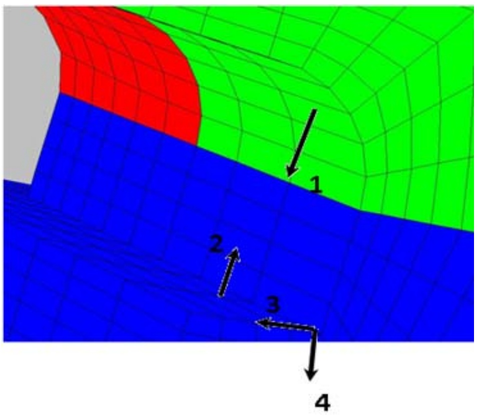

Figure 2 The selected critical points in the tunnel

Also, the maximum stress within the strata surrounding the tunnel is calculated. Based on these results and the maximum load on the support system, the applicable factor of safety is calculated. The displacements, maximum stress, and safety factor of each model are shown in *Table 3*.

Table 3 Results of numerical model

Model index	Displacement at point (cm)				The maximum stress on tunnel circumference (MPa)	Safety factor
	1	2	3	4		
A	11.51	26.82	12.25	4.03	36.44	1.04
B	8.92	24.00	11.03	2.08	29.93	1.47
C	1.89	3.72	1.33	0.50	24.75	2.32
D	2.10	3.92	1.02	0.43	23.73	2.44
E	10.30	23.36	8.19	5.11	29.47	1.15
F	4.14	6.35	4.12	3.19	22.82	1.79
G	2.81	3.63	1.30	0.61	25.70	2.13
H	10.62	25.11	11.83	3.29	35.61	1.25
I	8.13	23.91	10.09	2.01	30.04	1.59
J	3.50	4.01	2.61	0.82	25.11	2.28

Since the minimum acceptable factor of safety for the tunnel C_1 is 2 (Hosseini, 2008), based on the results of the numerical modeling, the four support systems of C, D, G, and J are accepted from a technical point of view, one of these will be selected as the optimum support system.

MULTI CRITERIA DECISION MAKING TECHNIQUES

As there are several criteria which affect on the appropriate support system selection, Multi Criteria Decision Making (MCDM) method has been applied in this research. Each criterion has several attributes which finally affect on the achieved priorities amongst the alternatives. Therefore the applied method is developed as a Multi Attribute Decision Making (MADM) method. In this procedure, the Analytical Hierarchy Processing (AHP) method is first applied for creating the overall vector weights of the attributes. Accordingly through other MADM methods as TOPSIS and PROMETHEE, a final evaluation of the priorities will be performed. The TOPSIS method evaluates the alternatives and PROMETHEE identifies the preferences amongst the alternatives.

DECISION MAKING CRITERIA AND DECISION TREE

The criteria for selecting the appropriate support system are defined based on the experiments and judgment of the expertise of a group of experts. *Table 4* shows the criteria which are considered in the support system selection.

Table 4 Decision criteria for choosing the optimum support system

No.	Criterions explanation	Index
1	The vertical displacement at point 1	C1
2	The vertical displacement at point 2	C2
3	The vertical displacement at point 3	C3
4	The horizontal displacement at point 3	C4
5	The support system costs	C5
6	The support system performance	C6
7	Safety factor	C7

A decision making tree for any project is developed by identifying the goal, alternatives and criteria. The goal, which is support system selection, is on the first line of the tree. The criteria are on the second line and the alternatives are on the third. A decision making tree of the support system selection for the C_1 tunnel project is shown in *Figure 3*. Four support systems amongst the ten considered, potentially have the required technical requirements for supporting the given tunnel. Therefore, the four mentioned alternatives are located in the third line of the tree.

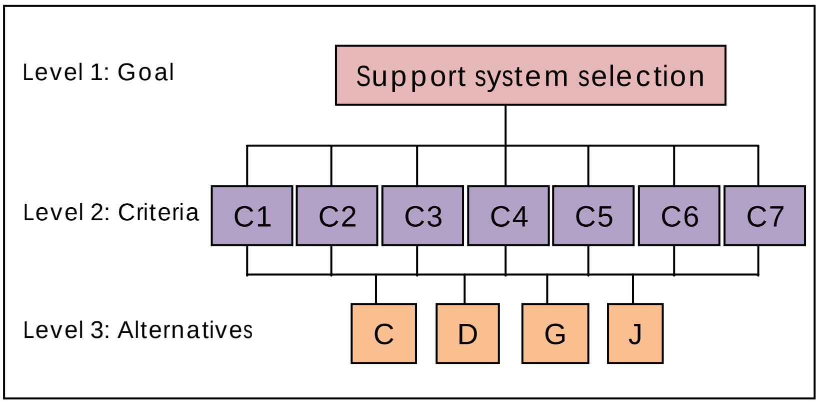

Figure 3 Hierarchy designed for optimum support system selection

ANALYTICAL HIERARCHY PROCESSING (AHP) METHOD

Analytical Hierarch Processing (AHP) is one of the most comprehensive multi criteria decision making methods which has been developed by Saaty (Saaty, 1980). In this technique, the decision making problem is first formulated based on a hierarchy process. Then continues through pair-wise comparison amongst the alternatives and also the criteria and it is finally finished by achieving priorities of the alternatives and calculation of the inconsistency ration amongst them. The implementation steps of the AHP method are as follow:

- *Step 1*, Hierarchy Tree: this step includes creating a hierarchy tree in order to define the goal, criteria and alternatives.
- *Step 2*, Decision Making Matrix: the decision making matrix is generated based on Saaty's nine point scale which is presented in *Table 5*.

Table 5 Preference values for pair-wise comparison (Saaty, 1980)

Oral judgments	**Numeral value**
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Intermediate values	2, 4, 6 and 8

- *Step 3*, Pair-wise Comparison Matrix: in this step, a pair-wise comparison is performed between the members of the decision making matrix. Pair-wise comparisons are done in order to determine relative importance of the attributes with respect to each other. A pair-wise comparison matrix for *n*-attributes is presented as *Equation 4*.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}; a_{ij} = \frac{1}{a_{ji}};\ a_{ii} = 1;\ i, j = 1,2,...,n \qquad (4)$$

where, the element a_{ij} can be interpreted as the degree of preference of *i*th attribute over *j*th attribute and vice versa.

- *Step 4*, Normalized Matrix: in this step, the pair-wise comparison matrix should be normalized. A normalized matrix is achieved by dividing each member of a column by the total amount of all members in that column. The normalized matrix which is created by such calculations has a total amount of each column's members equal to 1. A normalized pair-wise matrix is shown in *Equation 5*.

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1J} \\ r_{21} & r_{22} & \cdots & r_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nJ} \end{bmatrix}; i = 1,2,...,n; \ j = 1,2,...,J \tag{5}$$

- *Step 5*, Relative Weights: to achieve the relative weights of each attribute, the arithmetic average of each row is calculated.
- *Step 6*, Attributes Weights Vector: The amount of relative weights of attributes multiplied by the weight of the criteria of the higher levels and hence the overall weighting vector is obtained. This vector is presented in *Equation 6*.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}; \ \sum_{i=1}^{n} w_i = 1; \ i = 1,2,...,n \tag{6}$$

where w_i is the weight of the *i*th attribute.

An inconsistency ratio for defining the level of the consistency of judgments of the decision makers is calculated in AHP method. *Equation 7* shows the inconsistency ratio:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{7}$$

where $\lambda_{\max}$ is highest eigenvalueof the pair-wise comparison matrix. The closer the inconsistency index is to zero, the greater the consistency so the relevant index should be lower than 0.10 to accept the AHP results as consistent.

To select the support system based on AHP, the *Expert Choice* software (Expert Choice, 2010) is used. In the first step, decision making tree is created, then pair-wise comparison matrix of alternatives based on each criterion and finally, pair-wise comparison matrix of criterion is generated. After data entry, the software ranks the alternatives based on the AHP method. In *Figure 4*, ranking of the support system for tunnel C_1 is shown.

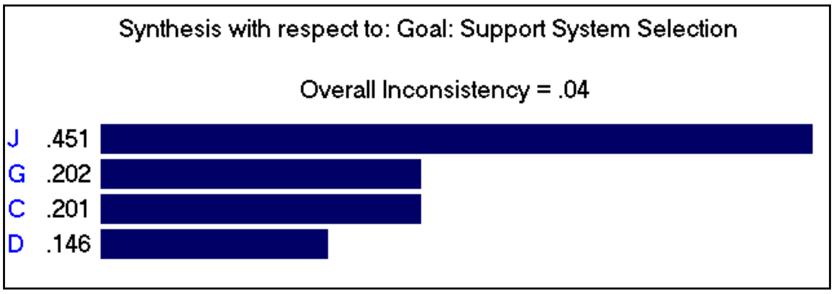

Figure 4 The ranking of support systems based on the AHP method

TECHNIQUE FOR ORDER PREFERENCE BY SIMILARITY TO IDEAL SOLUTION (TOPSIS) METHOD

The TOPSIS method is presented by Hwang and Yoon (Hwang, and Yoon, 1981; Yoon, and Hwang, 1995). TOPSIS is a multi-criteria method to identify the solutions from a finite set of alternatives. The concept of this technique is that the chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. Steps for implementation of the TOPSIS method are as follow:

- *Step 1*, Weighted Normalized Matrix: in the TOPSIS algorithm, the inputs are in the form of weighted normalized matrix v_{ij}, according to *Equation 8*. This matrix is the result of multiplication of the normalized matrix R_{ij} (*Equation 5*), in the diagonal matrix of total weighting of criteria, w_i (*Equation 6*).

$$v_{ij} = R_{ij} \times w_i = \begin{bmatrix} r_{11}w_1 & \cdots & r_{1J}w_n \\ \vdots & \ddots & \vdots \\ r_{n1}w_1 & \cdots & r_{nJ}w_n \end{bmatrix}; i = 1,\dots,n;\ j = 1,\dots,J \qquad (8)$$

- *Step 2*, Determination of Positive-Ideal and Negative-Ideal Solutions: using weighted normalized matrix in which the criteria are specified. Positive-ideal solution A^*, and negative-ideal solution A^-, are determined by *Equation 9* and *10* respectively.

$$A^* = \{v_1^*, v_2^*, \dots, v_n^*\} = \{(\max v_{ij} \mid j \in I'), (\min_i v_{ij} \mid j \in I'')\} \qquad (9)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} = \{(\min v_{ij} \mid j \in I'), (\max_i v_{ij} \mid j \in I'')\} \qquad (10)$$

where I' is associated with benefit criteria, and I'' is associated with cost criteria.

- *Step 3*, determination of alternative's distance from positive and negative ideals: the Euclidean distance of each alternative from positive ideal d_j^+ and from negative ideal d_j^- are calculated by *Equation 11* and*12*, respectively.

$$d_j^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \; ; i = 1,2,...,m \tag{11}$$

$$d_j^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \; ; i = 1,2,...,m \tag{12}$$

- *Step 4*, determination of relative closeness of each alternative to ideal solution: the relative closeness CL_j^* calculated by *Equation 13*.

$$CL_j^* = \frac{d_j^-}{d_j^- + d_j^+} \tag{13}$$

Since $d_j^- \geq 0$ and $d_j^+ \geq 0$, then clearly $CL_j^* \in [0,1]$.

- *Step 5*, ranking: finally, the alternative that has maximum CL_j^* is the appropriate alternative. Similarly, in such a way all the alternatives will be ranked.

The weight of each criterion is obtained by AHP. The input to the TOPSIS algorithm requires a weighted normalized matrix. In this research, these have been determined by the use of *Equation 8*, the weighted normalized matrix, according to *Table 6*.

Table 6 Weighted normalized matrix

	C	**D**	**G**	**J**
C1	0.0477	0.0252	0.0117	0.0045
C2	0.0084	0.0210	0.0336	0.0756
C3	0.0546	0.0168	0.0294	0.1092
C4	0.0574	0.0246	0.0984	0.2296
C5	0.0044	0.0216	0.0120	0.0020
C6	0.0203	0.0378	0.0035	0.0084
C7	0.0036	0.0021	0.0162	0.0081

The positive ideal solution A^* and the negative ideal solution A^- are then calculated by equations 9 and 10, respectively. The weighted normalized matrix and the positive and negative ideal solution for each criterion are presented in *Table 7*.

Table 7 Positive and negative ideal solutions

	A^*	A^-
C1	0.0477	0.0045
C2	0.0756	0.0084
C3	0.1092	0.0168
C4	0.2296	0.0246
C5	0.0216	0.0020
C6	0.0378	0.0035
C7	0.0162	0.0021

Having obtained the positive and negative ideal solutions, the distance of each alternative from positive ideal d_j^+ and negative ideal d_j^- are calculated by using *Equations 11* and *12*, respectively. Finally, using *Equation 13*, the relative closeness of each alternative CL_j^* is calculated. In *Table 8* the distance of each alternative from positive and negative ideals, the closeness of each alternative and hence the final ranking of alternatives are presented.

Table 8 Positive and negative distance / Relative closeness and ranking

	C	**D**	**G**	**J**
d_j^+	0.195	0.233	0.167	0.056
d_j^-	0.068	0.046	0.081	0.235
CL_i^*	0.260	0.166	0.327	0.806
Rank	3	4	2	1

PREFERENCE RANKING ORGANIZATION METHOD FOR ENRICHMENT EVALUATIONS (PROMETHEE)

The PROMETHEE method is presented by Brans and Vincke (Brans, and Vincke, 1985; Brans, and Mareschal, 1992). This method considers a preference between alternatives individually. Steps of implementation of PROMETHEE method are as follow:

- *Step 1*, the amplitudes of deviation d_i between the evaluation of each alternatives *k* and *l*, within each attribute *i*, is calculated by *Equation 14*.

$$d_i(k,l) = r_{ki} - r_{li},\ k,l = 1,2,...,J \ and \ i = 1,2,...,n \tag{14}$$

Thus, the deviation amplitude matrix for an alternative *j* within *n* attributes is obtained by *Equation 15*.

$$D_j = \begin{bmatrix} d_1(j,1) & d_2(j,1) & \cdots & d_n(j,1) \\ d_1(j,2) & d_2(j,2) & \cdots & d_n(j,2) \\ \vdots & \vdots & \ddots & \vdots \\ d_1(j,J) & d_2(j,J) & \cdots & d_n(j,J) \end{bmatrix}, \quad j = 1,2,\dots,J \tag{15}$$

- *Step 2*, preference functions: in this paper, the Gaussian function (*Equation 16*) is used as a preference function, $P_i(d)$ for each criterion *i*.

$$P_i(d) = \begin{cases} 0, & if\ d_i \le 0 \\ 1 - \exp(\dfrac{-d_i^2}{2\sigma^2}) & if\ d_i > 0 \end{cases} \tag{16}$$

In Gaussian function, the distance between the origin and the inflexion point of the graph $P_i(d)$, is shown by σ.

The preference function $P_i(k,l)$ for each criterion *i* and alternatives *k* and *l*, therefore denotes the preference of alternative A_k to alternative A_l that is represented in *Equation 17*.

$$P_i(k,l) = \begin{cases} if\ r_{ki} \le r_{li} \Rightarrow d_i(k,l) \le 0 \rightarrow P_i(k,l) = 0 \\ if\ r_{ki} > r_{li} \Rightarrow d_i(k,l) > 0 \rightarrow P_i(k,l) = 1 - \exp(\dfrac{-d_i^2}{2\sigma^2}) \end{cases} \tag{17}$$

If the alternative *k,* based on criterion *i*, is similar or worse than alternative *l*, the preference function is equal to zero. But, if the alternative *k* based on criterion *i*, is better than alternative *l*, the preference function will be between 0 and 1. Wherever, the preference function is near 1, the distance between normalized values of r_{ki} and r_{li} increases.

Based on the Gaussian preference function, for determination of the inflexion point of the curve, in other hand for calculation the threshold value parameter σ, the *Equation 18* is used.

$$\sigma_i = \frac{\sum_{\substack{k,l=1 \\ k \ne l}}^{k,l=J} |d_i(k,l)|}{J(J-1)}; \ i = 1,2,\dots,n; \ k,l = 1,2,\dots,J \tag{18}$$

- *Step 3*, preference index and to constitute the preference index matrix: whenever all the criterion *i* are considering simultaneously, the preference index $\pi(k,l)$ as *Equation 19* is defined which indicate the preference value of alternative A_k over alternative A_l.

$$\pi(k,l)=\sum_{i=1}^{n} w_i.P_i(k,l);\quad k,l\in J \tag{19}$$

The preference index matrix, given by *Equation 20*, is calculated using *Equation 19*.

$$\pi=\begin{bmatrix} 0 & \pi(1,2) & \cdots & \pi(1,J) \\ \pi(2,1) & 0 & \cdots & \pi(2,J) \\ \vdots & \vdots & \ddots & \vdots \\ \pi(J,1) & \pi(J,2) & \cdots & 0 \end{bmatrix};\ i,j=1,2,...,J \tag{20}$$

- *Step 4*, outgoing flows: the outgoing flow is the sum of the value of arcs which leave node *j* and therefore yields a measure of the *outranking character* of alternative *j*. This outgoing flow representing the strength of alternative *j* than other alternatives. The outgoing flow φ_j^+ is calculated by *Equation 21*.

$$\varphi_j^+=\frac{1}{J-1}\sum_{\substack{k=1\\k\neq j}}^{J}\pi(j,k);\ j,k=1,2,...,J \tag{21}$$

- *Step 5*, entering flows: the entering flow φ_j^- which is a measure for the weakness of an alternative *j*, is calculated, measuring the *outranked character* of alternative *j*. The entering flow φ_j^- is calculated by *Equation 22*.

$$\varphi_j^-=\frac{1}{J-1}\sum_{\substack{k=1\\k\neq j}}^{J}\pi(k,j);\ j,k=1,2,...,J \tag{22}$$

- *Step 6*, ranking: finally, the ranking of alternatives by using net flow φ_j^{net} based on difference between outgoing and entering flows of alternative *j*, as *Equation 23* will be accomplished.

$$\varphi_j^{net}=\varphi_j^+-\varphi_j^- \tag{23}$$

Thus the alternative that has the highest net flow is preferable.

The input of PROMETHEE is the normalized matrix which is obtained by AHP. For each alternative *l* and *k*, the deviation amplitude $d_j(k,l)$, is calculated and by arrangement of these, the deviation amplitudes matrix according to *Table 9* will be generated.

Table 9 Matrix of deviation amplitude for normalized values

	C1	C2	C3	C4	C5	C6	C7
C-D:	0.25	-0.09	0.18	0.08	-0.43	-0.25	0.05
C-G:	0.40	-0.18	0.12	-0.10	-0.19	0.24	-0.42
C-J:	0.48	-0.48	-0.26	-0.42	0.06	0.17	-0.15
D-C:	-0.25	0.09	-0.18	-0.08	0.43	0.25	-0.05
D-G:	0.15	-0.09	-0.06	-0.18	0.24	0.49	-0.47
D-J:	0.23	-0.39	-0.44	-0.50	0.49	0.42	-0.20
G-C:	-0.40	0.18	-0.12	0.10	0.19	-0.24	0.42
G-D:	-0.15	0.09	0.06	0.18	-0.24	-0.49	0.47
G-J:	0.08	-0.30	-0.38	-0.32	0.25	-0.07	0.27
J-C:	-0.48	0.48	0.26	0.42	-0.06	-0.17	0.15
J-D:	-0.23	0.39	0.44	0.50	-0.49	-0.42	0.20
J-G:	-0.08	0.30	0.38	0.32	-0.25	0.07	-0.27

Then, as shown in *Table 10*, the threshold value of alternatives are calculated and based on Gaussian preference function, the preference function matrix as shown in *Table 11* will be obtained.

Table 10 Values of threshold

Criteria	C1	C2	C3	C4	C5	C6	C7
Threshold	0.265	0.255	0.240	0.267	0.277	0.273	0.260

Table 11 Preference function

	C1	C2	C3	C4	C5	C6	C7
P(C,D)	0.359	0.000	0.245	0.044	0.000	0.000	0.018
P(C,G)	0.680	0.000	0.118	0.000	0.000	0.320	0.000
P(C,J)	0.806	0.000	0.000	0.000	0.023	0.176	0.000
P(D,C)	0.000	0.060	0.000	0.000	0.701	0.342	0.000
P(D,G)	0.148	0.000	0.000	0.000	0.314	0.799	0.000
P(D,J)	0.314	0.000	0.000	0.000	0.792	0.693	0.000
P(G,C)	0.000	0.221	0.000	0.068	0.210	0.000	0.729
P(G,D)	0.000	0.060	0.031	0.204	0.000	0.000	0.805
P(G,J)	0.045	0.000	0.000	0.000	0.335	0.000	0.417
P(J,C)	0.000	0.830	0.444	0.711	0.000	0.000	0.153
P(J,D)	0.000	0.689	0.814	0.828	0.000	0.000	0.256
P(J,G)	0.000	0.499	0.714	0.513	0.000	0.032	0.000

With calculating and arrangement of preference index $\pi(k,l)$, the preference index matrix according to *Table 12* is generated.

Table 12 Matrix of preference indexes

	C	D	G	J
C	0	0.102	0.108	0.086
D	0.060	0	0.082	0.108
G	0.089	0.123	0	0.030
J	0.505	0.614	0.433	0

Finally, the calculation of all flows and ranking are shown in *Table 13*.

Table 13 All flows and ranking of alternatives

	C	D	G	J
Outgoing flow	0.0988	0.0836	0.0805	0.5175
Entering flow	0.2183	0.2798	0.2076	0.0747
Net flow	-0.1195	-0.1962	-0.1271	0.4428
Ranking	2	4	3	1

The results of these three decision making techniques (AHP, TOPSIS, and PROMETHEE), in support system selection for tunnel C_1 of Tabas coal mine shown in *Table 14*.

Table 14 The ranking of support system selected for tunnel C_1 of Tabas coal mine

Preference	**1**	**2**	**3**	**4**
AHP	J	G	C	D
TOPSIS	J	G	C	D
PROMETHEE	J	C	G	D

CONCLUSION

The selection of the appropriate support system for tunnel C_1 of Tabas coal field by AHP and TOPSIS techniques has shown similar results. Although, the alternatives score are different in ranking, in both techniques the first rank is J (application of steel arches with 1 m spacing together with rock bolts) alternative and G (application of steel arches with 0.5 m spacing), C (supporting by B40 shotcrete 8 cm in thickness together with rock bolts) and D (application of roof piping together with cement injection) alternatives are the other ones preferred, respectively. Based on PROMETHEE technique, the J alternative is the first rank, the other ranked alternatives are C, G and D, respectively. Actually, such a difference is due to different decision making approach of AHP, TOPSIS, and PROMETHEE. However, simultaneous consideration of all the technical, economical, and performance parameters, which are the decision making criteria, the J alternative is selected as the optimum support system for this tunnel. The overall results obtained in this study show that the multi criteria decision making techniques can be useful tools in selection of optimum support systems.

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