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The development of a novel Model for Mining Method Selection in a Fuzzy Environment; Case study: Tazareh Coal Mine, Semnan Province, Iran

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Fatemeh Asadi Ooriad[1]; Mojtaba Yari[2]; Raheb Bagherpour[2]; Mehrbod Khoshouei[2]

[1] *Faculty of Engineering, Tarbiat Modares University, Tehran, Iran*
[2] *Department of Mining Engineering, Isfahan University of Technology, Isfahan, Iran*

Abstract

Mining method selection (MMS) for mineral resources is one of the most significant steps in mining production management. Due to the high costs involved and environmental problems, it is usually not possible to change the coal mining method after planning and starting the operation. In most cases, MMS can be considered as an irreversible process. Selecting a method for mining mainly depends on geological, geometrical properties of the resource, environmental impacts of exploration, impacts of hazardous activities and land use management. This paper seeks to develop a novel model for mining method selection in order to achieve a stable production rate and to reduce environmental problems. This novel model is illustrated by its implementation in the Tazareh coal mine. Given the disadvantages of the previous models for selecting a coal mining method, the purpose of this research is modifying the previous models and offering a comprehensive model. In this respect, the TOPSIS method is used as a powerful multi attribute decision-making procedure in a Fuzzy environment. After implementation of the presented model in the Tazareh coal mine, the long wall mining method has been selected as the most appropriate mining method.

Keywords

Intelligent Model; Mining Method Selection (MMS); Multi Criteria Decision Making (MCDM); Fuzzy Environment.

1. Introduction

One of the most substantial decisions, for reliable production in mining engineering, is selecting the most appropriate mining method (**Namin et al., 2003**). Due to the complexities of geological and geometrical characteristics of mineral resources, one specific mining method cannot be employed for all mineral resources and any mine needs an intelligent model for selecting a mining method. Therefore, a particular method must be used for a specific resource (**Nicholas, 1981**). In order to choose the correct mining method, economical, technical and safety parameters should be considered (**Namin et al., 2008**). After mining method selection (MMS) and the beginning of extraction using the chosen method, replacement of a method is not usually possible because this replacement is so costly that the entire project would be uneconomical. Therefore, MMS is approximately an irreversible process (**Azadeh et al., 2010**). Implementing the most suitable mining method enhances the profit, along with the maximization of mining recovery and improvement of safety. Sometimes, by considering similar resources and mining operations in a particular area, a mining method can be selected. This method selection cannot always be correct, because each mineral resource has its unique properties. Experts and designers, according to their experience and skills and mineral resource conditions, are able to make logical decisions on method selection (**Bitarafan and Ataei, 2004**).

In 1973, Boshkov and Wright presented a system for the classification of mining methods. This was the first qualitative classification system (**Boshkov and Wright, 1973**). In 1976, Morrison suggested a chart for mining method selection (**Morrison, 1976**). In 1981, Lubscher, based on a rock mass classification system, presented a system to select an appropriate method for underground mines (**Laubscher, 1981**).In 1981, Nicholas provided a classification system for mining. It was the first quantitative system (**Nicholas, 1993**).

In 1987, Hartman proposed a model that was based on the geometrical factors and ground conditions (**Hartman, 1987**). In 1995, Miller-Tait et al. modified the Nicholas system and suggested an UBC classification system (**Miller-Tait et al. , 1995**). Since 1999, decision making techniques have been used for mining method selection (**Bascetin and Kesimal, 1999**). In 2001, Karadogan et al. using the Yager system and Saaty's analytic hierarchy process (AHP) method and considering paired comparisons, introduced a model for mining method selection (**Karadogan et al., 2001**). In 2004, Bitarafan and Ataei used Yager and Saaty's AHP and fuzzy method for deciding on the mining method (**Bitarafan and Ataei, 2004**).

Corresponding author: Fatemeh Asadi Ooriad
f.17.asadiooriad@gmail.com

In 2006, Bascetin et al. using the Yager system, presented a computer program to select mining equipment and mining methods (**Bascetin et al., 2006**). In 2009, Naghadehi and Mikaeil, using FAHP and considering 13 parameters, developed a model for the MMS process. Their model had underground mining methods as candidates of the process; additionally this model had been proposed for Jajarm bauxite mine and it was not extended to other mines (**Naghadehi et al., 2009**). In 2008, Samimi Namin and Shahriar presented a model that was based on fuzzy decision making methods. The Fuzzy TOPSIS method had been used in their model (**Namin et al., 2008**). In 2010, Azadeh and Osanloo, in order to select a mining method, proposed a model by modifying the Nicholas technique in which only five mining methods had been considered **(Azadeh et al., 2010**).

As mentioned before, many models have been proposed for MMS, but each of them has undeniable failures. In some of them, only technical aspects have been considered. Some of them have also brought certain parameters in calculations. Most of these models consider the limited number of methods and the influencing parameters. Thus, these models are not adequate and only applicable for a specific resource.

Mining method selection is one of the most critical and problematic activities in mining engineering. The ultimate goals of mining method selection are maximizing company profit, maximizing recovery of the mineral resources and providing a safe environment for the miners by selecting the method with the least amount of problems among the feasible alternatives. Selection of an appropriate mining method is a complex task that should address many technical, economic, political, social, and historical factors. The appropriate mining method is the method technically feasible for the ore geometry and ground conditions, while also being a low-cost operation. This means that the best mining method is the one presenting the cheapest problem.

There is no single appropriate mining method for a deposit. Two or more feasible methods are usually possible. Each method entails some inherent problems. Consequently, the optimal method should offer the least amount of problems. The approach adopting the same mining method as that of a neighboring operation is not always appropriate. However, this does not mean that it is not possible to learn from comparing mining plans of existing operations in the district, or of similar deposits. Each ore body is unique, with its own properties. Engineering judgment has a great effect on the decision in the versatile job of mining; therefore, it seems clear that only an experienced engineer with good experience in working in several mines and skills in different methods can make a logical decision on mining method selection. Although experience and engineering judgment still provide major input into the selection of a mining method, subtle differences in the characteristics of each deposit can usually be understood only through a detailed analysis of the available data. It becomes the responsibility of the geologist and engineer to work together to ensure that all factors are addressed in the mining method selection process. Characteristics with a major impact on the mining method selection include:

- Physical and mechanical characteristics of the deposit such as ground conditions of the ore zone, hanging wall, and footwall, ore thickness, general shape, dip, plunge, depth below the surface, grade distribution, the quality of the resource, etc. The basic components defining the ground conditions are: rock material shear strength, natural fractures and discontinuities shear strength, orientation, length, spacing, and location of major geological structures, in situ stress, hydrologic conditions, etc.
- Economic factors such as capital cost, operating cost, mineable ore tonnage, ore body grades and mineral value.
- Technical factors such as mine recovery, flexibility of methods, machinery and mining rate.
- Productivity factors such as annual productivity, equipment, efficiency and environmental considerations.

Each of these criteria can become the principal determining factor in method selection, but the obvious predominance of one consideration should not preclude careful evaluation of all the parameters. In order to determine the appropriate mining method, it is necessary to evaluate using defined standards technically and economically.

Several methodologies have been developed to evaluate suitable mining methods for an ore deposit, based on the physical and mechanical characteristics of the deposit such as shape, grade, and geomechanical properties of the rock. Following mentioned scientists suggested a series of approaches for suitable mining methods. These studies neither were enough nor comprehensive. It is not possible to design a methodology that will automatically choose a mining method for the ore body studied. The uses of numerical systems to evaluate the appropriateness of a mining method for a particular ore deposit have been popular for some time. In 1981, for the first time, Nicholas suggested a numerical approach for mining method selection. The Nicholas methodology follows a numerical approach to rate different mining methods based on the rankings of specific input parameters. A numerical rating for each mining method is obtained by summing these rankings. The higher the rating, the more suitable the mining method. One of the problems with this approach was that all the selection criteria had the same relevance. A recent modification involves the weighting of various categories, such as that of ore geometry, ore zone, hanging wall, and footwall (**Nicholas 1992**). The wrong definition of some scores and the small domain between favorable and unfavorable scores encouraged Miller, Pakalnis and Paulin in1995 to investigate the UBC approach. The UBC mining method selection, a modification of the Nicholas approach, places more emphasis on the stoping method, better representing typical Canadian mining design practices. Unfortunately, in the UBC approach, the importance of each selection criteria were not considered. In addition, neither of these methods considers the uncertainty associated with boundary conditions of the categories used to describe input variables.

In hazardous engineering fields, such as mining engineering, novel decision making methods such as MADM could play the main role. Implementation of this method in mining engineering can be noted as: ranking of risks in mines and tunnels, selecting mineral machinery and equipment, ranking hazards of underground mines, blasting management, selecting suitable place for damping mineral and waste (**Ataei et al., 2008; Asadi Ouriad et al.,2017; Bazzazi et al., 2011; Bazzazi et al., 2008; Bejari et al., 2010; Guoliang and Sijing, 2010; Ibrahimov et al., 2014; Lashgari et al., 2011; Lashgari et al., 2012; Lashgari et al., 2010; Mikaeil et al., 2009; Monjezi et al., 2007; Peijie and Baozhu, 2011; Sadollah et al., 2014; Asadi Ouriad et al.,2017; WU et al., 2007; Yari et al., 2015a; Yari et al. , 2015b; Yari et al., 2015c; Yari et al., 2013; Yari et al., 2014a; Yari et al., 2014b; Yari et al., 2014c; Yari et al., 2015d; Yazdani-Chamzini and Yakhchali, 2012**).

In this study, the number of parameters and mining methods has been enhanced. This model has considered the most effective parameters (operational, technical, and economical). In addition, by increasing the number of mining methods, the decision maker has more choices. Finally, by using Multi Attribute Decision Making (MADM) models and considering all the affecting parameters, a comprehensive and applicable model has been provided. In this model, the TOPSIS method has been implemented for the MMS process.

2. TOPSIS

TOPSIS is one of the most widely used techniques of MADM. Yoon and Hwang proposed this method in 1981 for the first time. In TOPSIS method, the Concepts of the "ideal solution" and "ideal similarity" are used and alternatives are ranked based on similarity to the ideal solution. Thus, the alternative more similar to the ideal solution is more acceptable.

At the similarity ideal, the alternative distance from the positive ideal and negative ideal solution is measured and alternatives based on the distance from the anti-ideal solution to the total distance from positive ideal and negative ideal solution are evaluated and ranked (**Yari, 2016;Yoon and Hwang, 1995**). In order to select the most suitable alternatives using the TOPSIS method, the steps of this method are described here **(Yoon and Hwang, 1995**).

2.1. Forming decision matrix

Decision matrix is formed by considering the number of criteria and alternatives as in **Equation (1)**.

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & C_3 & \dots & C_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & x_{13} & \dots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \dots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \dots & x_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m22} & x_{m3} & \dots & x_{mn} \end{bmatrix} \end{array} \tag{1}$$

Where:

A_i: i'th alternative (i=1, 2, 3… m)

C_j: j'th criteria (j=1, 2, 3… n)

X_{ij}: value of i'th alternative in j'th criteria

2.2. Decision matrix normalization

Often criteria have different units and are not comparable with each other. Therefore, it is necessary to normalize all attributes in order to compare them. There are various methods used for normalization, but in the TOPSIS method, Norm normalization has been usually used as in **Equation 2**.

$$n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \tag{2}$$

Where:

n_{ij}: normalized value of i'th alternative in j'th criteria

2.3. Weighted normalized matrix

For comparison, one should consider diverse weights of attributes and form weighted normalized matrix.

Weighted normalized matrix= ND.Wn*n (3)

Where:

ND: normalized matrix

Wn*n: is a diagonal matrix in which only arrays of the main diagonal are non-zero (the relative weights of criteria are located on the main diagonal.)

2.4. Determining the positive ideal solution and negative ideal solution

Positive ideal alternative (V^+) and negative ideal alternative (V^-) are defined as follows:

$$v^+ = \left\{ \left(\max_i v_{ij} \middle| j \in J' \right), \left(\min_i v_{ij} \middle| j \in J' \right) \middle| i = 1,2,....,n \right\} = \\ = \left\{ v_1^+, v_2^+, ..., v_j^+, ..., v_n^+ \right\} \tag{4}$$

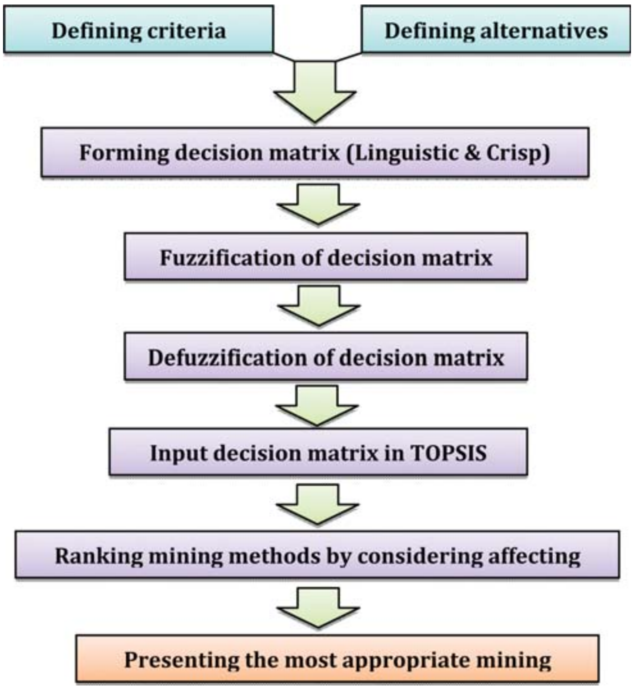

Fig. 1: Flowchart of the proposed model for mining method selection using multi criteria decision making

$$v^- = \left\{\left(\min_i v_{ij} | j \in J'\right), \left(\max_i v_{ij} | j \in J'\right) | i = 1,2,....,m\right\} =$$
$$= \left\{v_1^-, v_2^-, ..., v_j^-, ..., v_n^-\right\} \quad (5)$$

2.5. *Calculating the size of the separation (distance)*

Distance of i-alternative from the ideal alternative using the Euclidean should be calculated in this stage.

Distance of i-alternative of the positive ideal alternative is obtained as in **Equation (6)**.

$$d_{i+} = \left\{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2\right\}^{0/5} ; i = 1,2,....,m \quad (6)$$

Distance of i-alternative from negative ideal alternative is calculated by using **Equation (7)**.

$$d_{i-} = \left\{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2\right\}^{0/5} ; i = 1,2,....,m \quad (7)$$

2.6. *Calculating relative closeness to the ideal solution*

This relative closeness is defined as follows:

$$Cl_{i+} = \frac{d_{i-}}{\left(d_{i+} + d_{i-}\right)}; 0 \le Cl_{i+} \le 1; i = 1,2,.....,m \quad (8)$$

If, $\upsilon_i = \upsilon^+$ then $d_{i+} = 0$ and we have $Cl_{i+} = 1$ and if $\upsilon_i = \upsilon^-$, then $d_{i-} = 0$ and we have $Cl_{i+} = 0$. Thus, when an alternative of υ_i is closer to the ideal solution (υ^+), the value of Cl_{i+} is closer to the unit.

2.7. *Ranking of alternative:*

Based on descending order of Cl_{i+}, alternatives can be ranked and the most appropriate alternative can be selected.

3. Methodology and the proposed model

In mentioning models, limiting the number of mining methods and parameters affects the mining method se-

Table 1: Transformation of fuzzy membership functions

Linguistic variable	Membership function
Very low	(0,0,1,2)
Low	(1,2,3)
Medium Low	(2,3,4,5)
Medium	(4,5,6)
Medium high	(5,6,7,8)
High	(7,8,9)
Very high	(8,9,10,10)

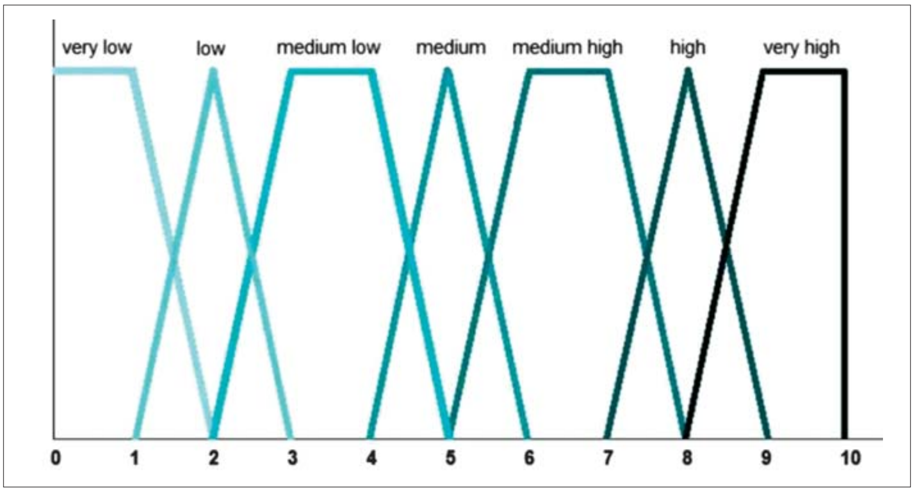

Fig. 2: Yager system for converting linguistic variables to fuzzy numbers

Fig 3: Location of the Tazareh coal mine

Table 2: Tazareh coal mine geological and geometrical characteristic.

	Criteria	Description
Ore zone	Deposit shape Ore thickness Ore dip Depth	Tabular 30 – 70 cm 37 - 50 degrees <100 meters
Hanging wall	Sandstone	
Foot wall	Sandstone	

lection and leads to fewer choices. So, in this paper, the number of alternatives and parameters is enhanced. The AHP method is used for weighting the parameters. The proposed model can be applied to the mining method selection, as shown in **Fig 1**.

In this process, there are linguistic variables. Firstly, linguistic variables must be converted to crisp numbers. For this purpose, fuzzification and defuzzification are used. Fuzzification is performed using triangular and trapezoidal fuzzy numbers in Yager standard (see **Fig. 2)**. Fuzzy numbers corresponding to each of linguistic variables are shown in **Table 1**. Defuzzification has been implemented using the presented formula by Li and Lee (**Lee and Li, 1993**). These formulas are shown in **Equations 9 and 10**.

Triangular fuzzy number

$$M= (a,b,c) \quad \bar{X} = \frac{(a+b+c)}{3} \tag{9}$$

Trapezoidal fuzzy number

$$M= (a,b,c,d) \quad \bar{X} = \frac{(c^2+d^2-a^2-b^2-ab+cd)}{3(c+d-a-b)} \tag{10}$$

Where:

M is a fuzzy number and $\bar{\mathbf{X}}$ is the mean value of fuzzy number that presents the final number.

After defuzzification, only crisp numbers in the data matrix remain and the TOPSIS decision making method can be implemented.

4. Tazareh coal mine

The Tazareh coal mine is one of the coal resources in North East of Iran. It is located 70 km North West of Shahroud and 45 km North East of Damghan in Semnan Province (see **Fig. 3**). This area is spread in the east-west direction by Precambrian, Mesozoic and Cenozonic rock units. The youngest and oldest rock units which have outcrops in this area are Quaternary deposits and Bayandor Formation respectively. Soltanieh, Barut, Zagun, Lalun and Jeyrud Formations are the main rock units of Paleozoic units. Mesozoic rock units contain Elika, Shemshak, Delichay, Lar Formations, Upper Cretaceous rocks. Neogene conglomerates and Quaternary sediments are the fundamental parts of Cenozoic rock units. The main faults of this area have an approximately east-west inclination. There are synthetic faults with a northeast-southwest or a northwest-southeast direction.

Tazareh is located between longitudes **54 18' 48"** and **54 30' 45"** and latitudes of **36 22' 30"** and **36 25' 50"**. The mining history of the region in about 30 years and daily extraction of coal reaches more than 2,000 tons per day. Tazareh coal mine characteristics can be seen in **Table 2**. This area consists of sandstone, coaly shale of Shemshak Formation with narrow thickness and alluvial deposits with gravel marl and quartz. The Alborze

Table 3: decision matrix (linguistic and crisp)

Criteria Alternative	Deposit shape	Grade distribution	safety	Ore dip	Ore thickness	Depth
Attribute Weight	0.0510	0.0814	0.1668	0.1788	0.0638	0.0814
Open-pit mining	H	MH	MH	L	H	MH
Block caving	VL	H	H	VL	H	H
Sublevel stoping	L	H	ML	VL	MH	H
Sublevel caving	L	H	ML	VL	MH	H
Long wall mining	VH	ML	L	H	H	ML
Room & pillar	VH	H	L	H	MH	H
Shrinkage stoping	VL	H	L	H	MH	H
Cut & fill	VL	MH	H	MH	H	MH
Top slicing	VL	ML	H	ML	H	ML
Square set mining	VL	ML	H	H	ML	ML
Vertical Crater Retreat	VL	MH	L	H	MH	MH
Stull stoping	H	H	L	VH	H	H
Short wall mining	VH	ML	L	H	H	ML
Shield mining	VL	H	H	L	H	H

Criteria Alternative	Hang wall RMR	Ore RMR	Footwall RMR	Hang wall RSS	Ore RSS	Footwall RSS
Attribute Weight	0.0451	0.0257	0.0180	0.0406	0.0099	0.0383
Open-pit mining	H	MH	H	MH	H	MH
Block caving	H	H	H	MH	H	MH
Sublevel stoping	H	ML	MH	ML	L	ML
Sublevel caving	H	MH	MH	MH	H	H
Long wall mining	MH	VH	H	VH	VH	H
Room & pillar	VH	VL	MH	L	L	ML
Shrinkage stoping	H	L	MH	ML	L	H
Cut & fill	MH	L	H	VH	L	MH
Top slicing	MH	MH	H	H	MH	H
Square set mining	L	H	L	H	H	H
Vertical Crater Retreat	H	L	MH	ML	L	H
Stull stoping	MH	VL	MH	H	VL	H
Short wall mining	MH	VH	H	VH	VH	H
Shield mining	VL	VL	H	MH	MH	H

Sharghi Coal Company plays the main role in extraction of this mine.

5. Mining method selection using the presented model for the Tazareh coal mine

According to the Flowchart presented in **Fig. 1**, the proposed model is used for the Tazareh coal mine and steps were taken respectively for the flowchart; finally, by using the algorithm of TOPSIS, mining methods were ranked. The decision matrix is shown in **Table 3**.

The ranking of mining alternatives results is shown in **Table 4**. According to this table, the Long wall mining method is introduced as the most appropriate mining method for Tazareh coal.

6. Conclusion

Mining method selection is one of the most important operations in mining engineering in order to achieve a reliable production rate. Ignoring influential parameters in this process inflicts irreparable damage to extraction and production, because the MMS process is almost always an irreversible operation in mining. This study tried to solve all the problems of previous models and presented a comprehensive and intelligent model for MMS. In this model, the number of impacting parame-

Continuation of Table 3: decision matrix (linguistic and crisp)

Criteria Alternative	Recovery	Skilled man power	Production per man shift	Production rate	Selective mining
Attribute Weight	0.0081	0.0031	0.0221	0.0101	0.0105
Open-pit mining	VH	VH	VH	H	L
Block caving	H	VL	H	H	L
Sublevel stoping	MH	MH	H	H	L
Sublevel caving	H	ML	H	H	L
Long wall mining	H	H	H	H	L
Room & pillar	H	MH	MH	H	L
Shrinkage stoping	H	MH	L	H	ML
Cut & fill	VH	H	H	H	H
Top slicing	VH	H	H	L	VL
Square set mining	VH	VL	L	L	H
Vertical Crater Retreat	H	MH	L	H	VL
Stull stoping	H	VL	L	L	H
Short wall mining	MH	H	H	MH	L
Shield mining	H	L	H	H	ML

Criteria Alternative	Flexibility	Development rate	Mechanization	Capital costs	Operating costs	subsidence	Blending
Attribute Weight	0.0047	0.0103	0.0089	0.0101	0.1258	0.0629	0.0101
Open-pit mining	H	H	MH	H	H	10.00	VL
Block caving	L	L	L	MH	H	10.00	H
Sublevel stoping	L	H	H	MH	H	20.00	L
Sublevel caving	H	H	H	MH	H	15.00	H
Long wall mining	L	H	VH	MH	H	15.00	L
Room & pillar	H	H	VH	MH	H	20.00	L
Shrinkage stoping	H	H	L	H	L	45.00	L
Cut & fill	H	H	H	H	H	55.00	L
Top slicing	L	L	VL	H	H	25.00	H
Square set mining	H	L	VL	L	L	100.00	L
Vertical Crater Retreat	H	L	H	H	ML	40.00	L
Stull stoping	H	H	L	H	L	70.00	H
Short wall mining	H	H	VH	H	MH	40.00	L
Shield mining	L	L	H	H	MH	30.00	H

Table 4: Ranking results using the proposed model

Methods	Cl_{i+}		Methods	Cl_{i+}
Long wall mining	0.54221		Shrinkage stoping	0.46048
Room & pillar	0.52715		Vertical Crater Retreat	0.45657
Stull stoping	0.51265		Top slicing	0.41620
Square set mining	0.50280		Block caving	0.39372
Cut & fill	0.49765		Sublevel stoping	0.37274
Open-pit mining	0.49587		Sublevel caving	0.36141
Short wall mining	0.49196		Shield mining	0.36122

ters and mining methods is enhanced and based on expert opinions, and influencing factors were weighted. Through the TOPSIS model as an applied method of multi criteria decision making models, the final ranking is done in a Fuzzy environment. The final ranking indicated that the Long wall mining method is the most suitable mining method for the Tazareh coal mine in terms of all affecting factors.

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SAŽETAK

Razvoj novoga modela za odabir rudarske metode pomoću neizrazite logike; primjer rudnika ugljena Tazareh, provincija Semnan, Iran

Odabir rudarske metode za bilo koju mineralnu sirovinu najvažniji je korak kod započinjanja i održavanja uspješnoga rudarenja. S obzirom na velike troškove i utjecaj na okoliš odabranu rudarsku metodu pridobivanja obično je nemoguće promijeniti kada pridobivanje započne. Odabir metode uglavnom se temelji na geološkim i geometrijskim svojstvima sirovine, utjecaju na okoliš, mogućim opasnostima te općenito uporabi tla na kojemu se rudari. U radu je prikazan razvoj nove metode kojom se postiže stabilan iznos proizvodnje, ali i smanjuju problemi u okolišu. Njezina uporaba objašnjena je na primjeru rudnika ugljena Tazareh. Istaknuti su nedostatci prethodnih rudarskih metoda te kako su oni riješeni novim pristupom nazvanim TOPSIS. Riječ je o postupku odlučivanja s više varijabli, oblikovanome neizrazitom logikom. Danas je upravo ta metoda u primjeni u navedenome rudniku.

Ključne riječi

inteligentni model, odabir rudarske metode, višekriterijsko odlučivanje, neizrazita logika