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A Fuzzy AHP Approach to Select the Proper Roadheader in Tabas Coal Mine Project of Iran

İran Tabas Kömür Madeni Projesinde Uygun Tünel Açma Makinası Seçimi için Bulanık AHP Yaklaşımı

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ABSTRACT

Machinery equipment selection, particularly mechanical excavators in mechanized mining operations, is one of the most important issues through a mine project planning and design, and has a remarkable effect on speed and cost of excavating operation. Therefore, it is an essential matter and needs to be concerned and managed appropriately. Alike other mechanized projects, mechanized coal mining is very machinery-intensive so that appropriate equipment selection plays a key role in project's success and productivity. In this respect, it is crucial to consider the basic parameters such as geological and geotechnical properties of ore deposit, its surrounding strata, economic and technical parameters, etc through the selection process; hence, choosing the major equipment and mechanical miners such as roadheaders in mechanized coal mining is a multi-criteria decision making problem. A multi-criteria decision making method is used to rank available roadheaders based on a set of criteria, ultimately leading to suggest the high-ranked one as the best option.This paper presents an evaluation model based on Fuzzy Analytic Hierarchy Process (Fuzzy AHP) approach to select the proper roadheading machine in Tabas coal mine project; the largest and the only fully mechanized coal mine in Iran. This method assists mine designers and decision makers in the process of roadheader selection under fuzzy environment where the vagueness and uncertainty are taken into account with linguistic variable parameterized by triangular fuzzy numbers. The broad issue includes three possible roadheading machines and five criteria to evaluate them. The suggested method applied to the mine and the most appropriate roadheader, among three candidate roadheaders, has been ranked and selected as DOSCO MD1100 roadheader with the highest weight of 0.435. The weights of other options namely KOPEYSK KP21 and WIRTH T2.11 found as 0.323 and 0.242, respectively.

Keywords: Multi-Criteria Decision Making; Fuzzy Analytic Hierarchy Process; Roadheader Selection; Tabas Coal Mine Project

ÖZ

Özellikle mekanize madencilik işletmelerinde kullanılan mekanik kazıcılarda olduğu gibi makina techizat seçimi,bir maden projesi planlaması ve dizaynındaki en önemli konudur ve kazma işleminin hızı ve maliyeti üzerinde belirgin etkisi bulunmaktadır. Bu nedenle, önemli bir konu olup uygun şekilde ilgilenilmesi ve işletilmesi gerekmektedir.Tıpkı diğer mekanize projelerdeki gibi, mekanize kömür madenciliği makina yoğunluğunun çok fazla olduğu bir alan olup, uygun ekipman seçimi projenin başarısında ve üretimde anahtar rol oynar.Bu bağlamda, maden yatağının jeolojik ve jeoteknik temel parametreleri, çevreleyen seviyelerin özellikleri ile ekonomik ve teknik parametrelerin hesaba katılmasıçok önemlidir. Dolayısıyla, mekanize kömür madenciliğindeki tünel açma makinaları gibi ana ekipman seçimi, mekanize kömür madenciliğinde çok-kriterli karar almayı gerektiren problem oluşturur.

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Çok-kriterli karar alma yöntemi bir dizi kriter baz alınarak en çok opsiyonda en yüksek dereceyi alabilen tünel açma makinalarını derecelendirmekte kullanılır. Bu makale, İran'ın en büyük ve tek tam mekanize olarak çalışan Tabas kömür madeni projesine uygun tünel açma makinasını Bulanık Analitik Hiyerarşi İşlemi (Fuzzy AHP) yöntemine dayalı değerlendirme modeli sunmaktadır.Bu yöntem, tünel açma makinası seçiminde maden ocağı tasarımcılarına ve karar mercilerine belirsiz koşulların olduğu durumda destek olacaktır. Piyasada yaygın olan üç olası tünel açma makinası ile değerlendirme aşamasında kullanılan beş kriter çalışma kapsamında ele alınmıştır.Önerilen yöntem madene uygulanmış ve üç aday arasından en uygun tünel açma makinası olan, 0.435 ağırlıkla DOSCO MD1100 seçilmiştir. Diğer seçeneklerden olan KOPEYSK KP21 ve WIRTH T2.11 sırasıyla 0.323 ve 0.242 ağırlık notu almıştır.

Anahtar Kelimeler: *Çok-kriterli karar verme, bulanık analitik hiyerarşi işlemi, tünel kazma makinası seçimi, Tabas kömür madeni projesi*

INTRODUCTION

Once an ore body has been probed and outlined and sufficient information has been collected to warrant further analysis, the most appropriate mining method is then chosen (Hamrin, 1986; Hartman, 1992). Afterwards and at the next step, due to machinery-intensity of most of mining methods particularly in long-wall mining method, the important process of selecting the most proper excavator can begin. At this stage, the selection is preliminary, serving only as the basis and later it may be found necessary to revised details, but the basic principles for selecting the major excavator should remain a part of the final planning. Selection of an appropriate mining machine is a complex task that requires consideration of many factors such as geotechnical, economic and operational factors. The appropriate miner is the excavator which is technically capable of cutting the ore and rock in various ground conditions, while also being a low-cost operation. This means that the best machine is the one which presents the cheapest problem.

Currently, the mining companies are moving toward more profitable, productive and competitive arenas and therefore, mechanization is becoming an inevitable alternative to gain these objectives; hence, the ever-increasing applications of mechanical miners such as roadheaders and other boom-type tunnelling machines are some of the outcomes of project mechanizations, leading to their more extensive use in the mining and civil construction industries in recent years. Among machines employed in mining activities, roadheaders are very popular particularly in underground coal mining. Roadheaders have remarkable advantages including high productivity, reliability, mobility, flexibility, safety, selective excavation, less strata disturbances, fewer personnel and lower capital and operating costs. To achieve these benefits as well as successful roadheader application, proper selection of the machine needs to be accomplished appropriately. This generally deals with geotechnical properties of rock formation to be excavated, machine performance, machine size and flexibility, machine price and total costs (Rostami et al, 1994). Moreover, main aspects influencing on the roadheader type selection include physical and mechanical characteristics, economic, technical and productivity factors (Ebrahimabadi et al., 2012).

For a successful roadheader selection, some alternative machines are primarily chosen in accordance with existing technical and economic condition. Afterward, the proper type needs to be appropriately selected through judicious decision making. Decision-making involves identifying and choosing alternatives based on their performance values and the preferences of the decision maker. Multi-criteria decision making (MCDM) methods, such as AHP and Fuzzy AHP, which are used for mining related problems in the literature especially mining method selection, make the evaluations using the same evaluation scale and preference functions on the criteria basis.

Fuzzy multiple criteria decision-making methods have been developed owing to the imprecision in assessing the relative importance of attributes and the performance ratings of alternatives with respect to attributes. Imprecision may arise from a variety of reasons: unquantifiable information, incomplete information, unobtainable information and partial ignorance. Conventional multiple attribute decision making methods cannot effectively handle problems with such imprecise information.Basically AHP is a method of breaking down a complex, unstructured situation into its components parts; arranging these parts, or variables, into a hierarchic order; synthesize the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation. It uses a hierarchical structure to abstract, decompose, organize and control the complexity of decision involving many attributes, and it uses informed judgment or expert opinion to measure the relative value or contribution of these attributes and synthesize a solution (Oguzitimur, 2011).The analytic hierarchy process (AHP), first proposed by Saaty (1980), along with its extensions is one of the most effective methods for multiple criteria decision making problems and has been used in many disciplines such as mining-related issues. In many cases, application of AHP method can be combined with some other methodologies such as optimization, quality function deployment, and fuzzy logic. Combining an AHP with fuzzy set theory through the process of roadheader selection permits greater flexibility in the selection criteria and the appropriate decision making. A fuzzy-AHP (FAHP) retains many of the advantages enjoyed by conventional AHPs, in particular the relative ease with which it handles multiple criteria and combinations of qualitative and quantitative data. As with an AHP, it provides a hierarchical structure, facilitates decomposition and pairwise comparison, reduces inconsistency, and generates priority vectors. Finally, an FAHP is able to reflect human thought in that it uses approximate information and uncertainty to generate proper decisions (Kahraman et al., 2003, 2004; Feizizadeh et al., 2014). These characteristics qualify the use of an FAHP as an appropriate and efficient tool to assist with making complex decisions for choosing roadheading machines in mining and tunnelling projects. It should be stated that few works have been conducted yet in which FAHP to be applied to choose rodheaders.

The main reasoning for using fuzzy AHP has also been that the conventional AHP with crisp input data might not properly model actual human thinking in decision scenarios under uncertainty, especially for qualitative criteria. In the fuzzy AHP, calculations are performed using fuzzy numbers as opposed to the crisp numbers used in the conventional AHP. For the second category of classification, the chosen application areas by different researchers and practitioners have been personal, social, manufacturing sector, political, engineering, education, industry, government, management, etc. Bitarafan and Ataei (2004) have used different fuzzy methods as an innovative tool for criteria aggregation in mining decision problems.Tutmez and Tercan (2007) used fuzzy modelling to estimate mechanical properties of rocks. Tutmez and Kaymak (2008) applied a fuzzy methodology for optimization of slab production. Acaroglu et al. (2006) used conventional AHP approach for selection of roadheaders. Ataei et al. (2008) have used the AHP method for mining method selection. Also, Alpay and Yavuz (2009) have suggested a combination of AHP and fuzzy logic methods for underground mining method selection. Yazdani-Chamzini and Yakhchali (2012) have applied multi-criteria decision making methods in order to select Tunnel Boring Machine.

The aim of the present work is to select the proper roadheader through a fuzzy AHP solution procedure. With that regard, Tabas coal mine is considered as case study. In the following sections, a description of study area is firstly presented. In the next section, the concepts of Fuzzy sets and Fuzzy AHP are illustrated. Afterward, the procedure and calculations of machine selection using Fuzzy AHP approach is well demonstrated step by step. And finally, a discussion on the used method and conclusions of the paper are presented respectively.

MATERIALS AND METHODS

Description of Tabas coal mine

Tabas coal mine, the largest and unique fully mechanized coal mine in Iran, is located in central part of Iran near the city of Tabas in Yazd province and situated 75 km far from southern Tabas. The mine area is a part of Tabas-Kerman coal field. The coal field is divided into 3 parts in which Parvadeh region with the extent of 1200 Km^2 and 1.1 billion tones of estimated coal reserve is the biggest and main part to continue excavation and fulfillment for future years. The coal seam has eastern-western expansion with reducing trend in thickness toward east. Its thickness ranges from 0.5 to 2.2 m but in the majority of conditions it has a consistent 1.8 m thickness. Room and pillar and also long wall mining methods are considered as the main excavation methods in the mine. The use of roadheaders in Tabas coal mine project was a consequence of mechanisation of the work. Coal mining by the long-wall method with powered roof supports makes rapid advance of the access roads necessary. On the other hand, the two alternatives for mining very thick coal seams, i.e. room-and-pillar and long wall in flat seams, also make the use of roadheader driving galleries in the coal seams necessary (Ebrahimabadi et al., 2011a; 2011b; 2012).

Fuzzy theory

Adequate knowledge and comprehensive database on a number of different problems are requested to analyse critical infrastructures. There are a close relationship between complexity and certainty, so that; increasing the complexity lead to decrease the certainty. Fuzzy logic, introduced by Zadeh (1965), can consider uncertainty and solve problems where there are no sharp boundaries and precise values. Fuzzy logic provides a methodology for computing directly with words (Klir and Yuan, 1995).

Fuzzy set theory is a powerful tool to handle imprecise data and fuzzy expressions that are more natural for humans than rigid mathematical rules and equations (Klir and Yuan, 1995; Vahdani and Hadipour, 2010; Ertugrul, 2011).

A fuzzy set is general form of a crisp set. A fuzzy number belongs to the closed interval 0 and 1, which 1 addresses full membership and 0 expresses non-membership. Whereas, crisp sets only allow 0 or 1. There are different types of fuzzy numbers that can be utilised based on the situation. It is often convenient to work with triangular fuzzy numbers (TFNs) because they are computed simply, and are useful in promoting representations and information processing in a fuzzy environment (Van Laarhoven and Pedrycz, 1983; Bojadziev and Bojadziev, 1998; Deng, 1999; Ertugrul and Tus, 2007).

A fuzzy number on can be a TFN if its membership function be defined as equation 1:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \le a \\ (x-a)/(b-a), & a \le x \le b \\ (c-x)/(c-b), & b \le x \le c \\ 0, & otherwise \end{cases} \quad (1)$$

Let $\tilde{A} = (a_1, a_2, a_3)$, $\tilde{B} = (b_1, b_2, b_3)$ be two fuzzy numbers, so their mathematical relations expressed as equations 2-5:

$$\tilde{A}(+)\tilde{B} = (a_1, a_2, a_3)(+)(b_1, b_2, b_3) = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \quad (2)$$

$$\tilde{A}(-)\tilde{B} = (a_1, a_2, a_3)(-)(b_1, b_2, b_3) = (a_1 - b_3, a_2 - b_2, a_3 - b_1) \quad (3)$$

$$\tilde{A}(\times)\tilde{B} = (a_1, a_2, a_3)(\times)(b_1, b_2, b_3) = (a_1 b_1, a_2 b_2, a_3 b_3) \quad (4)$$

$$\tilde{A}(\div)\tilde{B} = (a_1, a_2, a_3)(\div)(b_1, b_2, b_3) = (a_1/b_3, a_2/b_2, a_3/b_1) \quad (5)$$

Fuzzy AHP methodology

Analytical hierarchy process (AHP) was developed primarily by Saaty (1980) and is able to solve the decision making problems (Vaida and Kumar, 2006). AHP can decompose any complex probleminto several sub-problems in terms of hierarchical levels where each level represents a set of criteria or attributes relative to each sub-problem. AHP utilizes three principles to solve problems (Aydogan, 2011): (a) structure of the hierarchy, (b) the matrix of pairwise comparison ratios, and (c) the method for calculating weights. AHP summarises the results of pair-wise comparisons in a matrix of pair-wise comparisons (Kahraman, 2008).

Different fuzzy AHP methods are proposed by various authors (Van Laarhoven and Pedrycz, 1983; Buckley, 1985; Boender et al., 1989; Chang 1992, 1996).These methods apply a systematic procedure to prioritize the criteria and alternatives by using the concepts of fuzzy set theory and hierarchical structure analysis. In this paper, Chang's extent analysis method (Chang, 1996) is utilized because the steps of this approach are relatively easier than the other fuzzy AHP techniques.

Assume X = {x_1, x_2, x_3,..., x_n} be an object set, and G = {g_1, g_2, g_3,......., g_n} be a goal set. According to the method of Chang's extent analysis, each object is taken and extent analysis for each goal, , is performed, respectively. Therefore, extent analysis values for each object can be obtained, with the equation 6 (Chang, 1996):

$$M_{gi}^1, M_{gi}^2, \dots, M_{gi}^m, \qquad i=1,2,3,\dots,n \tag{6}$$

where all the M_{gi}^j (j=1, 2, 3,…, m) are TFNs.

The steps of Chang's extent analysis can be given as following:

Step 1: The value of fuzzy synthetic context with respect to th object is define as equation 7:

$$S_i = \sum_{j=1}^m M_{gi}^j \otimes \left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j\right]^{-1} \tag{7}$$

To obtain $\sum_{j=1}^m M_{gi}^j$ (Fuzzy Summation of Row), perform the fuzzy addition operation of extent analysis values for a particular matrix such equation 8:

$$\sum_{j=1}^m M_{gi}^j = \left(\sum_{j=1}^m l_j, \sum_{j=1}^m m_j, \sum_{j=1}^m u_j\right) \tag{8}$$

And to obtain $\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j\right]^{-1}$, perform the fuzzy addition operation of M_{gi}^j (j=1, 2…, m) values such equation 9: (Summation of Column)

$$\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j = \left(\sum_{i=1}^n l_i, \sum_{i=1}^n m_i, \sum_{i=1}^n u_i\right) \tag{9}$$

And then compute the inverse of the vector in equation 10 such that:

$$\left[\sum_{i=1}^n \sum_{j=1}^m M_{gi}^j\right]^{-1} = \left(1/\sum_{i=1}^n u_i, 1/\sum_{i=1}^n m_i, 1/\sum_{i=1}^n l_i\right) \tag{10}$$

Step 2: 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 equation 11:

$$V(M2 \geq M1) = \sup_{y \geq x}\left[\min\left(\mu_{M1}(x), \mu_{M2}(y)\right)\right] \tag{11}$$

And can be equivalently expresses as equations 12-13:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d) \tag{12}$$

$$(M_2 \geq M_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ l_1\text{-}u_2/(m_2\text{-}u_2)\text{-}(m_1\text{-}l_1) & \text{otherwise} \end{cases} \tag{13}$$

where d is the ordinate of highest intersection point D between μ_{M1} and μ_{M2} (see Fig. 1). To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Step 3: The degree of possibility for a convex fuzzy number to be greater than convex numbers $M_i (i = 1,2, \dots, k)$ can be defined by equation 14:

$$\begin{aligned} V(M \geq M_1, M_2, \dots, M_k) &= V[(M \geq M_1) \text{ and } \\ (M \geq M_2) \text{ and} \dots \text{and } (M \geq M_k)] &= \\ \text{Min}(M \geq M_i) \qquad i &= 1, 2, 3, \dots, k \end{aligned} \tag{14}$$

Assume the equation 15 as below:

$$d'(A_i) = \min V(S_i \geq S_k) \tag{15}$$

For $k = 1, 2, \dots, n; k \neq i.$ Then the weight vector is given by equation 16:

$$W'' = (d''(A_1), d''(A_2), \dots, d''(A_n))^T \tag{16}$$

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

Step 4: The normalized weight vectors are obtained through normalization process, as below using equation 17:

$$W' = (d'(A_1), d'(A_2), \dots, d'(A_n))^T \tag{17}$$

where W is a non-fuzzy number.

Step 5: Determination of alternatives of final weight, as below using equation 18:

$$\begin{aligned} A_1 = {} & (A_1 \text{ to } C_1 \times C_1 \text{ to GOAL}) + \\ & (A_1 \text{ to } C_2 \times C_2 \text{ to GOAL}) + (A_1 \text{ to } C_3 \times \\ & C_3 \text{ to GOAL}) + \dots + \\ & (A_1 \text{ to } C_n \times C_n \text{ to GOAL}) \end{aligned} \tag{18}$$

Where n is the number of criteria.

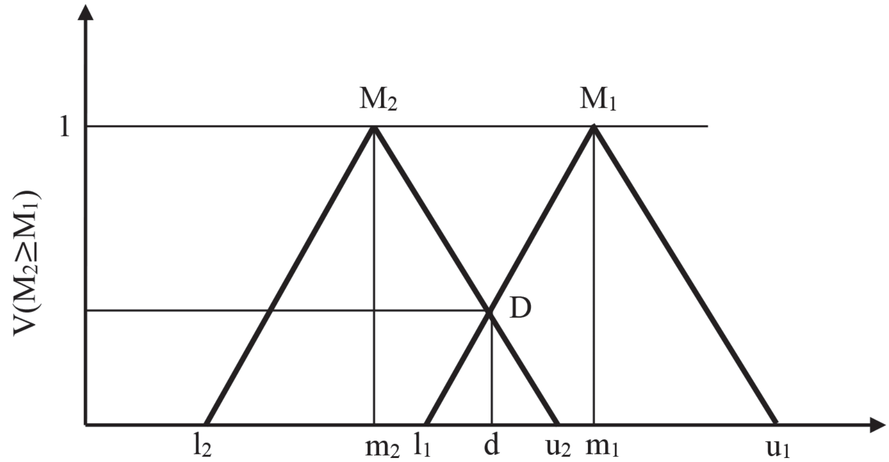

Figure 1.The intersection between M1 and M2 (Chang, 1996)
Şekil 1. M1 ve M2'deki kesişim (Chang, 1996)

APPLICATION OF FUZZY AHP APPROACH FOR SELECTING PROPER ROADHEADING MACHINE IN TABAS COAL MINE

The selection process of suitable miner (roadheader) gets started by evaluating given ore deposit, rock formation properties and mining method data. Theselection criteria include geotechnical characteristics of rock formations (C1), machine (roadheader) size (C2), machine performance (C3), machine flexibility (C4), and total costs (C5). At the first stage, a comprehensive questionnaire in accordance with the above mentioned criteria is designed and distributed among decision makers from various areas to qualify and evaluate the dominant factors affecting on selection process. Then, FAHP approach is used to determine the weighs of main criteria. Following to this, the major roadheader type is selected based on experts' opinions. Ranking of considered mining machine for Tabas coal mine is finally carried out utilizing AHP method.

Here, it should be stated that according to working condition and mining method (particularly longwall and room-and-pillar mining methods) and possibly conventional mining machine (here, as roadheaders with medium weight) to excavate coal and coal measure rocks in Tabas deposit, there are only 3 appropriate medium-duty roadheaders for the mine including DOSCO MD1100, KOPEYSK KP21, and WIRTH T2.11roadheaders.Table 1 indicates the basic specifications of these roadheaders (Dosco Ltd, 2008; Kopeysk machine-building plant, 2014; AkerSolutions, 2014).The algorithm of FAHP approach is considered as steps presented and sammarised in the following sections.

Making Hierarchical Structure of the Problem

The criteria and machine alternatives can be ruled as a hierarchical structure of the problem, shown in Fig. 2.

Making Comparison Dual Matrix

Decision-makers prepared questionnaires forms and then with division against other importance carry out pair-wise comparison. Decision-makers use the linguistic variables, to evaluate the ratings of alternatives with respect to each criterion and they converted into triangular fuzzy numbers. Among the various shapes of fuzzy number, triangular fuzzy number (TFN) is the most popular one; hence, these TFNs have been used through the analyses. Fuzzy numbers are defined arbitrarily as very low [0, 1, 3], low [1,3,5], medium [3,5,7], high [5,7,9], very high [7,9,10] that are shown in Table 2.

Then, a comprehensive pair-wise comparison matrix is built. One of these pair-wise comparisons with respect to C5 (machine total costs) is shown below in Table 3 as an example.

Table 1. Typical specifications of available roadheaders
Tablo 1. Uygun olan tünel açma makinalarının tipik özellikleri

Technical data/ Roadheaders	DOSCO MD1100	KOPEYSK KP21	WIRTH T2.11
Machine weight (Base machine)	34 tons	46 tons	85 tons
Total power (Standard machine)	From 157 kW	110 kW	439 kW
Power on cutting boom (Standard machine)	82 kW axial, 112 kW transverse	60 kW	300 kW
Machine length	8060 mm	12500 mm	12780 mm
Machine width	3000 mm	2100 mm	3050 mm
Machine height	1700 mm	4500 mm	3780 mm

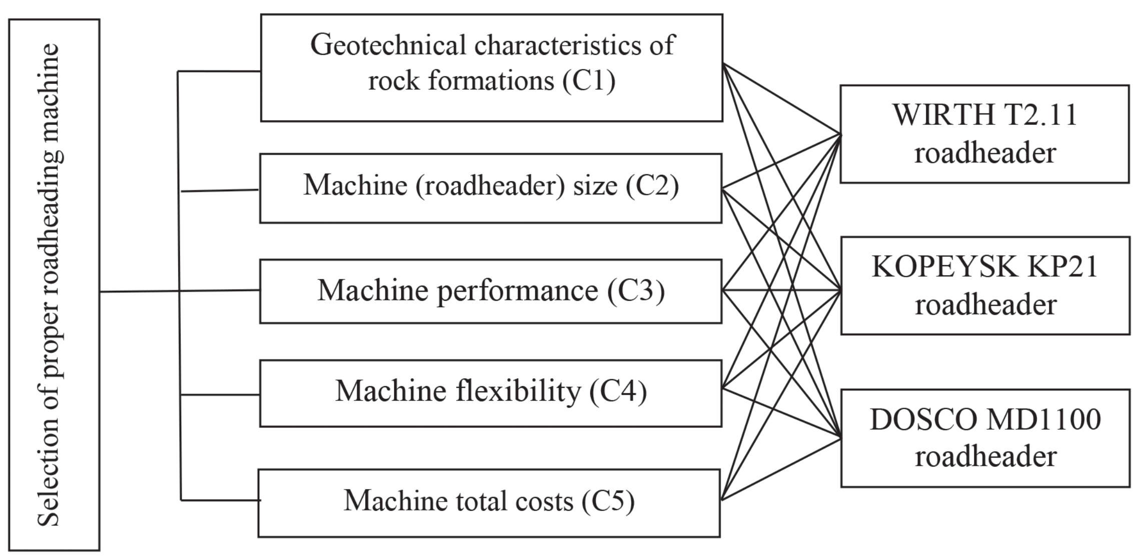

Figure 2.Hierarchical structure of problem
Şekil 2. Problemin hiyerarşik yapısı

Determination of Any Matrix Relative Weight

After making fuzzy pair-wise comparison matrix and according to the FAHP method, synthesis values must firstly be determined. From Table 3, according to extent analysis synthesis values with respect to cost criterion (C5), for example, are calculated like in equation 6: S1= 0.049, 0.072, 0.123, S2=0.274, 0.589, 1.204, S3=0.164, 0.339, 0.723.

These fuzzy values are compared by using equation 12, and next values are obtained. Then priority weights (Min) are calculated by using equations 13,14, as seen in Tables 4 and 5.

After the normalization of these values, priority weights respect to cost criterion are calculated in Table 5.

After determining the priority weights of the criteria, the priority of the alternatives will be determined for each criterion. From the pair-wise comparisons matrixes based on decision-makers' opinion for three alternatives, evaluation matrixes are also formed. Then, priority weights of alternatives for each criterion are determined by making the same calculation.

Table 2. Preference values for the questionnaires
Tablo 2. Anketlerdeki tercih değerleri

Quality Judge	Fuzzy Numbers
Very low	0,1,3
low	1,3,5
Average	3,5,7
High	5,7,9
Extreme	7,9,10

Table 3. The alternatives fuzzy dual comparison matrix toward together, with respect to C5
Tablo 3. C5'e göre seçenekler arasında karşılıklı karşılaştırma matrisi

C5	WIRTH T2.11	KOPEYSK KP21	DOSCO MD1100
WIRTH T2.11	1,1,1	0.111,0.142,0.2	0.142,0.2,0.333
KOPEYSK KP21	5,7,9	1,1,1	1,3,5
DOSCO MD1100	3,5,7	0.2,0.333,1	1,1,1

Table 4. The degree of possibility in Table 3
Tablo 4. Tablo 3'teki olasılık derecesi

V(s1>=s2)=	0.000	v(s1>=s3)=	0.000
V(s2>=s1)=	1.000	V(s2>=s3)=	1.000
V(s3>=s1)=	1.000	V(s3>=s2)=	0.640

Determination of Alternatives Final Weight (Selection of Roadheading Machine)

In the last part, final weights of alternatives are determined by conflation of scores. By using of equation 16, alternative DOSCO MD1100 roadheader which has the highest priority weight is selected as an appropriate roadheader for Tabas coal mine. The ranking order of the alternatives with fuzzy AHP method is DOSCO MD1100>KOPEYSK KP21>WIRTH T2.11 that are shown in Fig. 3.

DISCUSSION

Fuzzy AHP approach is an appropriate method for selecting coal mining machinery or other multi-criteria decision-making problems. However, this method has some limitations as mentioned below:

– Through fuzzy AHP, the decision-maker is only asked to give judgments about either the relative importance of one criterion against another or its preference of one alterative on one criterion against another. However, when the number of alternatives and criteria grows, the pair-wise comparison process becomes cumbersome, and the risk of inconsistencies grows.

– In the extent analysis of fuzzy AHP, the priority weights of criterion or alternative can be equal to zero. In this situation, we do not take this criterion or alternative into consideration. This is the one of the disadvantages of this method.

Companies should choose the appropriate method for their problem according to the situation and the structure of the problem they have. In future studies, other modern multi-criteria methods such as Electre and Paprika can be used to handle machine selection process.

Table 5. Un-normalized weight and normalized weight respect to cost criterion
Tablo 5. Maliyet kriterine dayalı normalize edilmemiş ve normalize edilmiş ağırlık

$d'(A_I)$	$\acute{W}$
Minimum	normalized
0.000	0.000
1.000	0.609
0.640	0.391
Sum= 1.640	

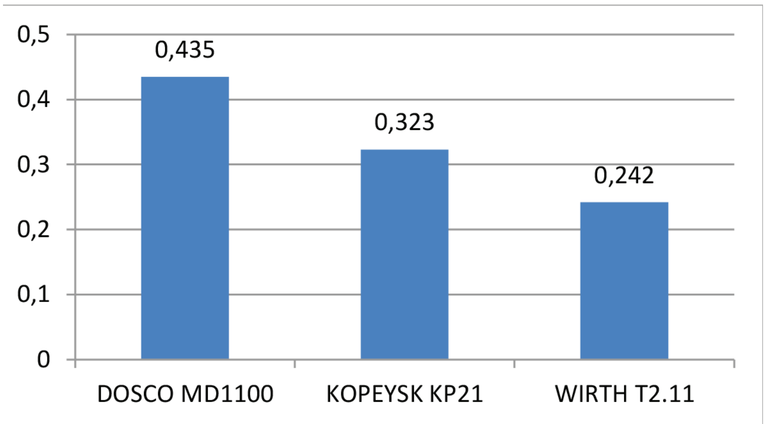

Figure 3. Priority of roadheaders for Tabas coal mine using FAHP approach
Şekil 3. FAHP yaklaşımı kullanılarak Tabas kömür madeni için roadheaderların önemi

CONCLUSIONS

The selection of optimum roadheading machine (roadheader) is one of crucial issues in underground mining methods such as longwall and room-and-pillar mining and plays a major role in mining projects from both technical and economic point of view. Hence, the convenient roadheading machine for each mine should appropriately be chosen from among relevant roadheader alternatives. In this respect, some parameters such as geological and geotechnical properties of ore deposit and its surrounded strata (hangingwall and footwall), economic and technical parameters, and operational factors should be taken into account. The aim of this research work is to select proper roadheader for Tabas coal mine of Iran using Fuzzy Analytic Hierarchy Process (Fuzzy AHP) approach. FAHP is a multi-criteria decision making method which can be successfully used to rank alternative roadheading machines based on a set of criteria. In fuzzy AHP, decision-makers made pair-wise comparisons for the criteria and alternatives under each criterion. Then these comparisons integrated and decision-makers' pairwise comparison values are transformed into triangular fuzzy numbers. The priority weights of criteria and alternatives are determined by Chang extent analysis. According to the combination of the priority weights of criteria and alternatives, the best alternative is determined. According to the fuzzy AHP, the appropriate roadheader for Tabas coal mine found as DOSCO MD1100 roadheader and the ranking order of the alternatives is DOSCO MD1100, KOPEYSK KP21 and WIRTH T2.11 roadheaders, respectively.

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