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Technical Note

Determination of a suitable extraction equipment in mechanized longwall mining in steeply inclined coal seams using fuzzy analytical hierarchy method (Case study: Hamkar coal mine, Iran)

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Abstract

The longwall mining method is one of the most applied methods in extracting low-inclined to high-inclined coal seams. Selection of the most suitable extraction equipment is very important in the economical, safety, and productivity aspects of mining operations. There are a lot of parameters affecting the selection of an extraction equipment in mechanized longwall mining in steeply inclined coal seams. The important criteria involved are the geometric properties of coal seam (dip, thickness, and uniformity of coal seam), geological and hydraulic conditions (faults, fractures, joints, and underground water), and geomechanical properties of coal seam and surrounding rocks. Extraction of inclined coal seams with gradients greater than 40 degree is different from low-inclined seams, and requires a special equipment. Therefore, the influence of the above-mentioned parameters must be considered simultaneously in the selection of extraction equipment for steeply inclined seams. This paper presents an application of the Fuzzy Analytical Hierarchy Process (FAHP) method in order to select a suitable extraction equipment in the Hamkar coal mine. In the proposed FAHP model, fifteen main criteria are considered, as follow: dip of coal seam, thickness of coal seam, seam uniformity, expansion of coal seam, faults, fractures and joints, underground waters, hangingwall strength, footwall strength, coal strength, *in-situ* stress, equipment salvage, dilution, system flexibility, and operational costs. Among the 6 considered longwall extraction equipment system alternatives, the findings show that the most suitable extraction equipment system is shearer on footwall and a support system using hydraulic props and the transport of coal with the force of gravity.

Keywords: *Steeply Inclined Coal Seams, Fuzzy Analytical Hierarchy Process, Extraction Equipment.*

1. Introduction

Longwall mining is a highly productive process in coal extraction with a high recovery rate. High-tech equipment, high efficiency, mechanizability, and extraction of coal seams with high inclination and depth have made this process attractive for mining engineers [1]. In general, coal seams with a low dip between 0 and 35 degrees are more suitable for mechanization. More commonly, seams up to 35 degree of inclination can be mechanized by power supports. The best operational conditions are on level seams [2]. When the coal seam gradient is more than 40 degrees, the extraction equipment is limited, and it is difficult to determine the most suitable one. Therefore, selection of a suitable equipment that can extract and transport a considerable volume of mineral is important. There are a lot of parameters that influence the selection of an extraction equipment in longwall mining for inclined coal seams. These parameters are geometric properties of coal seam, discontinuity properties, water condition, geomechanical properties of the coal and country rock, dilution, salvage, etc [2-8].

Decision-making methods can help engineers to find their optimum set of equipment for a particular application in a scientific way. The Fuzzy Analytical Hierarchy Process (FAHP) is a suitable method for multi-criteria decision-making problems, where the comparisons between selection criteria are confusing. Using FAHP, decision errors in evaluating decision criteria could be decreased. This methodology is strongly advised to underground mines as it is both fast and cheap [9]. Numerous researchers have attempted to use decision-making methods for this mining activity. Bitarafan and Ataei have used the multiple criteria decision-making tools for the selection of an optimal mining method in anomaly No. 3 of Gol-Gohar Iron mine, Iran [10]. Basicetin (2004) have used the AHP method to select a loading-hauling system for coal production in an open pit coal mine located in Orhaneli in western Turkey [11]. Acaroglu et al. have tried to identify the most appropriate roadheader for Cayirhan coal basin using the analytical hierarchy process (AHP), which is one of the multiple criteria decision-making methods [12]. Ataei et al. have used the AHP method with 13 criteria to develop a suitable mining method for the Golbini No. 8 deposit in Jajarm, Iran. According to the AHP method, the results obtained show that a suitable mining method for this deposit in the present situation is the conventional cut and fill method [13]. Alpay and Yavuz have developed a computerized program (UMMS) based on AHP and the Yager's method to analyze the underground mining method selection problems and produce the best underground mining method swiftly for different deposit shapes and ore bodies [14]. Naghadehi et al. (2009) have used the AHP and FAHP methods for selection of an optimum underground mining method for Jajarm Bauxite mine, Iran. For this purpose, they considered thirteen criteria and five extraction mining methods such as the conventional cut and fill, mechanized cut and fill, shrinkage stoping, stull stoping, and bench mining. FAHP was used in determining the weights of the criteria by decision-makers, and then rankings of the methods were determined by AHP [15]. Ertugrul and Karakasoglu have utilized both the FAHP and TOPSIS methods for performance evaluation of Turkish cement plants [16]. Sun have developed an evaluation model based on the fuzzy analytic hierarchy process and the technique for order performance by similarity to ideal solution and fuzzy TOPSIS to help the industrial practitioners to evaluate the performance in a fuzzy environment [17]. Ozfirat has grouped the underground mechanization factors under four main items. These items are the production, geology, rock mechanics, and work safety factors. According to fuzzy evaluations (FAHP method), underground mechanization is analyzed whether it can be applied in the Amasra coal mine, Turkey. Moreover, among the selection criteria, geology and work safety have been found to be the most important factors affecting the selection of a production method [9]. Finally, Rafiee et al. have considered six main criteria: displacement, factor of safety (FOS), costs, time, mechanization, and applicability factor for the selection of a support system design. According to the FAHP method, among the 6 considered support system alternatives, the best support system for a water transporting tunnel in Naien, Iran was selected [18].

It is clear that in the previous studies, selection of mining methods for underground mining has already been done by the AHP or FAHP methods. However, selection of a suitable extraction equipment for mechanized longwall mining in steeply inclined coal seam has not been carried out yet.

The main purpose of this research work is to determine a suitable extraction equipment for longwall mining in steeply inclined seams (a case study: Hamkar coal mine) using the FAHP method. Therefore, according to the authors' knowledge, it is a unique research work.

2. Longwall extraction equipment in steeply inclined coal seams

The most common extraction equipment used for longwall mining in steeply inclined coal seams is cutting coal with a shearer on the floor, cutting with a plow system, and support with power roof or wooden supports. The thickness of coal seam is an important parameter involved in selection of the cutting machine and roof support equipment. Therefore, a good survey of the seam would be required before choosing the correct cutting machine and roof support equipment.

The seam thickness that can be extracted variable from 0.6 to 6 m. In seams thicker than 3 m or thinner than 0.6 m, the possibility of mechanization will be reduced [2]. In thicknesses more than 2.3 m, the shearer is preferred. In coal seams with a thickness between 1.8 and 2.3 m, choosing between plow and shearer depends on the geological conditions but for seams with a thickness less than 1.8 m, the plow surpasses the shearer in productivity. When the thickness of the seam increases, the imported load to roof supports increases, and it is recommended to use power roof [19].

2.1. Cutting coal with shearer over floor

Shearer over the floor with double cutting drums suitable for working in steeply inclined coal seams. The operation method with shearer in inclined coal seams is shown in Figure 1. Extracting coal is done always upwards, and in the following strips, depth equals the length of the machine drums that is about 0.9 m. Extracted coal falls down by gravity into the charge pits placed in the lower side of the gallery. Displacing the shearer along the stope is done by one twin drum winch, placed in the main gallery, with two cables bolted to the machine, one for pulling and one for safety that hauls the shearer against the coal seam. The power cable and the water hose in the face line move together with the shearer.

The mobile parts of the shearer (drums) destroy the lower and upper parts of the coal seam, and they can be used in two ways, single drum and doube drum, according to the coal seam strength and the type of machine. After extracting one row of coal, the shearer goes down to the lower part of the face and enters inside the hollow. The pulleys frame, installed in the head gallery, displaces in the way of advance of the stope according to the depth of cut of the shearer.

The powered roof support is designed for supporting the exposed area after coal extraction with shearer. Gravity stowing or with caving of the roof can be utilized in the waste area. Under the above-mentioned conditions, the powered roof support is adapted to work with AFC (Armored Flexible Conveyor) for inclined seams or without the conveyor (for steeply inclined seams).

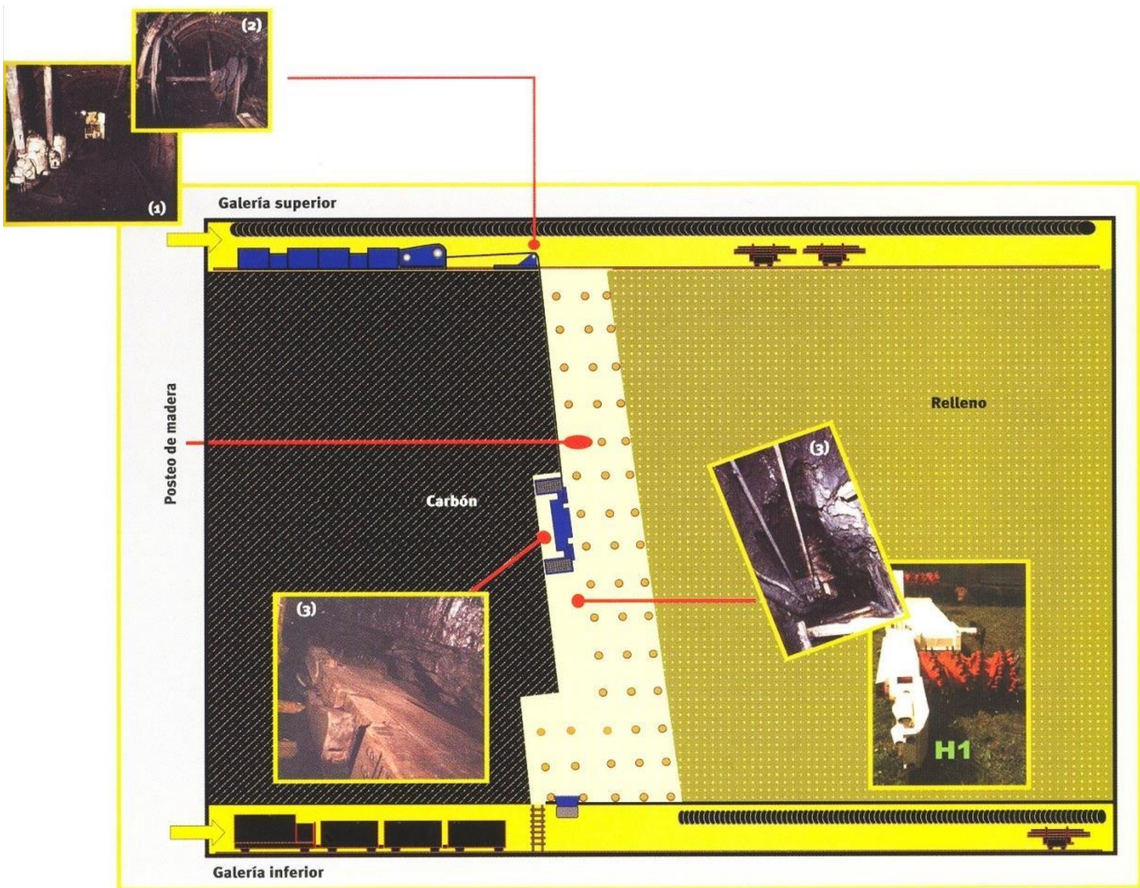

Figure 1. Operation method with shearer in inclined coal seams [20].

2.2. Cutting with plow (plough)

In contrast to the shearer on the floor, in this system, face cutting is carried out in two directions. When this system is used in the operation of coal seams with high slopes, coal falls down by gravity and descents over the wall of the coal seam until one chain conveyor is installed in the lower gallery to charge the mine cars. The charge of the mine cars may be authomatized by means of change and authomatical advancer–puller in the same way over the chain conveyor. also, one crusher can be also installed to reduce the grain sizes of the coal and to reduce the abrasiveness of them over the belt conveyors that transport the coal outside the mine. The operation method with plough in inclined coal seams is shown in Figure 2.

Propping can be done with props and keys made of wood as well as using wire clothing for supporting refilling or cave in and to avoid that it is accumulated over the operation face.

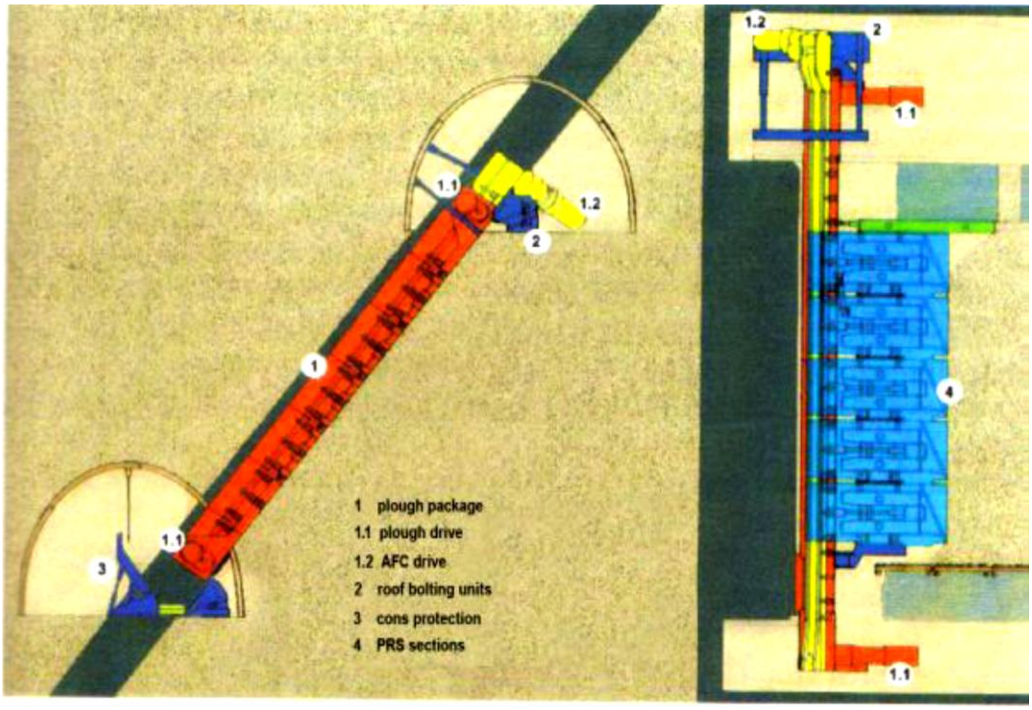

Figure 2. Operation method with plough in inclined coal seams [20].

3. Fuzzy Analytic Hierarchy Process (FAHP)

AHP is a multi-criteria decision-making (MCDM) method, helping a decision-maker to face a complicated problem with conflicting and subjective multiple criteria [21].Among different contexts in which AHP can be applied, mention can be made from creation of the priorities list, choice of the best policy, optimal allocation of resources, prevision of results and temporal dependencies, and assessment of risks and planning. Although AHP is used to capture the experts knowledge, the traditional AHP still cannot really reflect the human thinking style. The traditional AHP method is problematic for using an exact value to express a decision-maker's opinion in a comparison of alternatives [18, 22-24]. Also the 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 adequate pairwise comparison process. To overcome all the shortcomings, FAHP was developed to solve the hierarchical problems. Decision-makers usually realize that it is more confident to give an interval judgment instead of a fixed value judgment. This is because usually he/she is unable to explicit his/her preference to explicit about the fuzzy nature of the comparison process [25].

There are various methods proposed for FAHP in the literature [26-28]. In this study, the extended FAHP, which was introduced by Chang (1996), was used, where $X = \{x_1, x_2, x_3, ..., x_n\}$ is the object set and $G = \{g_1, g_2, g_3, ..., g_n\}$ is a goal set. According to the Chang's extent analysis method, each object is taken, and extent analysis for each goal is performed, respectively. Therefore, "m" extent analysis values for each object can be obtained by the following equation:

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

where $M_{gi}^j = (j-1, 2, ..., m)$ all are TFN_s (Triangular fuzzy numbers). The steps involved in the Chang's extent analysis (Chang, 1996) can be given as follow:

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

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{2}$$

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:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \quad (3)$$

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 as:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \quad (4)$$

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

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (5)$$

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:

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left[\min(\mu_{M_1}(x), \mu_{M_2}(y)) \right] \quad (6)$$

And can be explained as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \quad (7)$$

$$V(M_2 \geq M_1) = \begin{cases} 1 & \text{if } m_2 \geq m_1 \\ 0 & \text{if } l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (8)$$

Figure 3 illustrates Eq. (8), where “d” is the ordinate of the highest intersection point “D" between μ_{M_1} and μ_{M2}. To compare M_1 and M_2, we need both the $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$values.

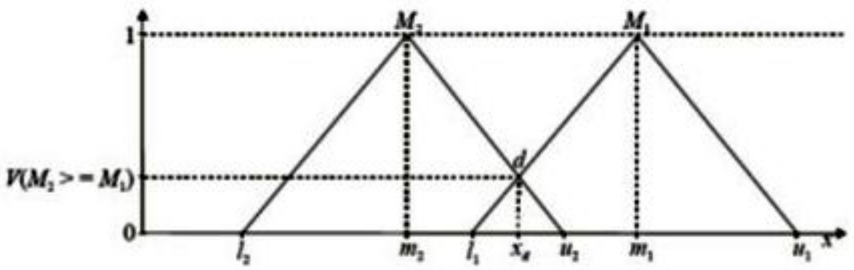

Figure 3. Intersection between M1 and M2 [29].

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

$$\begin{aligned} & V(M \geq M_1, M_2 ..., M_k) = \\ & V[(M \geq M_1) \text{and} (M \geq M_2) .... \text{and} (M \geq M_k)] \\ & = \min V(M \geq M_i) \qquad i = 1, 2, 3, ..., k \end{aligned} \quad (9)$$

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

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^T \quad (10)$$

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

Step 4. Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), ..., d(A_n))^T \quad (11)$$

where W is a non-fuzzy number.

4. Case study

Hamkar coal mine is located 50 km west of the Ravar city and 185 km NW of the Kerman city. The mine area is about 4 k m^2, and its coal reservoir is approximately 34 million tons. The mine has two series of seams: zone E seams that have a 45 to 65 degrees incline and zone D seams that have a 50 to 90 degrees incline. E zone has minable seams like E1, E2, and E4; the E1 seam is the main and most economic one. Thickness of the E1 seam is 0.63 to 1.93 m, and its gradient is 45 to 60 degrees. Gradient and thickness of this seam are the best for a mechanized and semi-mechanized extraction. Currently, this seam is planned to be extracted using the mechanized longwall mining method. The most important properties of the E1 coal seam are summarized in Table 1.

As mentioned earlier, the purpose of this paper is the selection of a suitable extraction equipment for steeply inclined seams in the Hamkar coal mine using the FAHP method. The proposed algorithm can be seen in Figure 4. In the first step, which is problem structuring, the decision-maker states the objectives, defines the selection criteria and picks the alternative choices to be selected from. In the second step, the fuzzy techniques are employed and the local priorities of the selection criteria and alternatives are determined. Finally, in the third step, the global priorities of each alternative are computed.

In this research work, we tried to consider all the effective factors that influence selection of the extraction equipment in the mechanized longwall mining in steeply inclined coal seams. Therefore, 15 criteria including dip of coal seam (C1), thickness of coal seam (C2), seam uniformity (C3), expansion of coal seam (C4), faults (C5), fractures and joints (C6), underground waters (C7), roof strength (C8), floor strength (C9), coal strength (C10), *in-situ* stress (C11), equipment salvage (C12), dilution (C13), system flexibility (C14), operational costs (C15) were considered.

To select a suitable extraction equipment using the FAHP method, the first step is to build the FAHP diagram shown in Figure 5, which includes the purpose, criteria, and alternatives. Six alternatives were considered for the extraction equipment in the Hamkar coal mine, which were represented in Table 2. The hierarchy design for extraction equipment selection process was shown in Figure 5.

Different kinds of fuzzy numbers can be utilized for taking the experts' opinions. In this research work, triangle fuzzy numbers (TFN) were used. A TFN is denoted simply as (l, m, u). The parameters l, m, and u denote the smallest possible value, the most promising value, and the largest possible value, respectively, that describe a fuzzy event.

The first step is to provide a questionnaire, which includes the main criteria and alternative. This questionnaire was sent to some experts who were highly experienced in the incline coal mines. According to the data for the Hamkar coal mine, the experts evaluated the importance of the criteria based on the Saaty's scale [30].

In the next step, the FAHP method was used to calculate the criteria weight and alternatives. By this way, the ranking of the considered extraction equipment was obtained based on its overall efficiency for the Hamkar coal mine.

4.1. Determination of criteria weights

Decision-makers from different backgrounds may define different weight vectors. They usually cause not only an imprecise evaluation but also a serious persecution during the decision process. For this reason, we proposed a group decision based on FAHP to improve a pair-wise comparison. Firstly, each decision-maker individually carried out a pair-wise comparison using the Saaty scale [30]. One of these pair-wise comparisons is shown in Table 3.

Then a comprehensive pair-wise comparison matrix was built by integrating nine decision-makers numbers through Eq. (11) [31]. By this way, the decision makers' pair-wise comparison values were transformed into triangular fuzzy numbers (Table 4).

After forming the fuzzy pair-wise comparison matrix, the weights of criteria and sub-criteria were determined using FAHP. According to the FAHP method, the synthesis values must firstly be calculated. From Table 4, a synthesis value related to the main goal was calculated using Equation 3.

S_{C1}= (17.38, 24.85, 34.34) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.046, 0.095, 0.198)

S_{C2}= (17.11, 24.12, 34.68) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.045, 0.093, 0.200)

S_{C3}= (13.09, 19.09, 27.46) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.035, 0.073, 0.158)

S_{C4}= (10.27, 16.55, 22.79) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.027, 0.064, 0.131)

S_{C5}= (12.26, 17.37, 25.73) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.032, 0.067, 0.148)

S_{C6}= (11.81, 16.64, 24.13) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.031, 0.064, 0.139)

S_{C7}= (10.28, 15.07, 22.24) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.027, 0.058, 0.128)

S_{C8}= (12.88, 20.38, 30.23) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.034, 0.078, 0.174)

S_{C9}= (13.83, 19.40, 26.78) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.036, 0.074, 0.155)

S_{C10}= (10.45, 16.08, 23.67) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.028, 0.062, 0.137)

S_{C11}= (9.722, 14.84, 23.74) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.026, 0.057, 0.137)

S_{C12}= (11.84, 17.67, 25.55) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.031, 0.063, 0.147)

S_{C13}= (3.176, 6.836, 12.19) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.008, 0.026, 0.070)

S_{C14}= (7.904, 14.44, 21.37) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.021, 0.055, 0.123)

S_{C15}= (11.35, 17.31, 24.21) $\otimes$ (1/379.1, 1/260.6, 1/173.3) = (0.030, 0.066, 0.140)

These fuzzy values were compared using Equation 8, and these values were shown in Table 5.

For example, $V(Sc_3 \geq Sc_1, c_2, \dots, c_n)$

V($S_3 \geq S_1$) $= \frac{(\mathbf{U_3-L_1})}{(\mathbf{U_3-L_1})+(\mathbf{m_1-m_3})} = \mathbf{0.84}$

V($S_3 \geq S_2$) $= \frac{(\mathbf{U_3-L_2})}{(\mathbf{U_3-L_2})+(m_2-m_3)} = \mathbf{0.85}$

V($S_3 \geq S_4$) $= (\mathbf{m_3 \geq m_4}) = \mathbf{1}$

V($S_3 \geq S_5$) $= (\mathbf{m_3 \geq m_5}) = \mathbf{1}$

V($S_3 \geq S_6$) $= (\mathbf{m_3 \geq m_6}) = \mathbf{1}$

V($S_3 \geq S_7$)$= (\mathbf{m_2 \geq m_7}) = \mathbf{1}$

V($S_3 \geq S_8$) $= \frac{(\mathbf{U_3-L_8})}{(\mathbf{U_3-L_8})+(\mathbf{m_8-m_3})} = \mathbf{0.96}$

V($S_3 \geq S_9$)$= \frac{(\mathbf{U_3-L_9})}{(\mathbf{U_3-L_9})+(\mathbf{m_9-m_3})} = \mathbf{0.99}$

V($S_3 \geq S_{10}$) $= (\mathbf{m_3 \geq m_{10}}) = \mathbf{1}$

V($S_3 \geq S_{11}$)$= (\mathbf{m_3 \geq m_{11}}) = \mathbf{1}$

V($S_3 \geq S_{12}$) $= (\mathbf{m_3 \geq m_{12}}) = \mathbf{1}$

V($S_3 \geq S_{13}$)$= (\mathbf{m_3 \geq m_{13}}) = \mathbf{1}$

V($S_3 \geq S_{14}$) $= (\mathbf{m_3 \geq m_{14}}) = \mathbf{1}$

V($S_3 \geq S_{15}$)$= (\mathbf{m_3 \geq m_{15}}) = \mathbf{1}$

The priority weights were calculated using Equation 9.

$d'(C_1)$ =min(1,1,1,1,1,1,1,1,1,1,1,1,1,1)=1

$d'(C_2)$ = min(0.98,1,1,1,1,1,1,1,1,1,1,1,1,1)=0.98

$d'(C_3)$ = min(0.84,0.85,1,1,1,1,0.69,0.99,1,1,1,1,1,1)=0.84

$d'(C_4)$ =min(0.73,0.74,0.90,0.96,0.99,1,0.86,0.89,1,1,0.95,1,1,0.97) = 0.73

$d'(C_5)$ =min(0.78,0.79,0.94,1,1,1,0.90,0.93,1,1,0.99,1,1,1,)0.78

$d'(C_6)$ = min(0.75,0.76,0.91,1,0.97,1,10.88,0.90,1,1,0.96,1,1) = 0.75

$d'(C_7)$ =min(0.69,0.70,0.85,0.94,0.91,0.94,0.82,0.84,0.96,1,0.90,1,1,0.91) = 0.69

$d'(C_8)$ = min(0.88,0.90,1,1,1,1,1,1,1,1,1,1,1,1) = 0.88

$d'(C_9)$ = min(0.84,0.85,1,1,1,1,1,0.96,1,1,1,1,1,1) = 0.84

$d'(C_{10})$ = min(0.73,0.74,0.89,0.98,0.95,0.97,1,0.86,0.88,1,0.94,1,1,0.95) = 0.73

$d'(C_{11})$ =min(0.70,0.72,0.86,0.94,0.91,0.93,0.99, 0.82,0.85,0.95,0.90,1,1, 0.91) = 0.70

$d'(C_{12})$ = min(0.79,0.80,0.95,1,1,1,1,0.91,0.94,1,1,1,1,1) = 0.79

$d'(C_{13})$ =min(0.26,0.27,0.43,0.53,0.48,0.51,0.57, 0.41,0.41,0.54,0.59,0.48,0.62,0.50) = 0.26

$d'(C_{14})$ =min(0.66,0.67,0.83,0.92,0.89,0.91,0.97, 0.79,0.82,0.93,0.98,0.88,1,0.89) = 0.66

$d'(C_{15})$ = min(0.76,0.78,0.93,1,0.99,1,1,0.89,0.92,1,1,0.98,1,1) = 0.76

Priority weight form W' = (1,0.98,0.84,0.73,0.78,0.75,0.69,0.88,0.84,0.73,0.70,0.79,0.26,0.66,0.76) vector.

This value had to be normalized using Equation 12.

$$W_i = \frac{W'(C_i)}{\sum_{i=1}^{k} W'(C_i)} \qquad (12)$$

After normalization of these value priorities, weights related to the main goal were calculated as (0.088, 0.086, 0.073, 0.064, 0.069, 0.066, 0.060, 0.077, 0.074, 0.064, 0.062, 0.069, 0.023, 0.058, 0.067). The mentioned priority weights and ranking were indicated for each criterion in Table 6.

According to Table 6, it can be seen that among the selection criteria, the dip of coal seam (C1) and thickness of coal seam (C2) were found to be the most important factors affecting the extraction equipment selection in the Hamkar coal mine. Other criteria were found to be the main roof strength (C8) and floor strength (C9), respectively.

4.2. Ranking of alternatives (selection of extraction equipment)

Similarly, the alternative pair-wise comparison matrix into criteria was constituted, and the final weight of alternative into criteria was obtained (Table 7).

Table 1. E1 coal seam properties of Hamkar coal mine [20].

Parameter	Description	
Dip of coal seam	$45-60^{o}$	
Average dip of coal seam	55^{o}	
Thickness of coal seam	0.7-1.9 m	
Average thickness of coal seam	1.3 m	
Structure of footwall	Shale-Siltstone	
Structure of hanging wall	Shale-Siltstone-Sandstone	
Seam uniformity condition	Semi-uniform	
Uniaxial Compressive Strength	Coal	12 MPa
	Sandstone (Roof)	40 MPa
	Siltstone (Roof)	32 MPa
	Mudstone (Roof)	18 MPa
	Sandstone (Floor)	48 MPa
	Siltstone (Floor)	38 MPa
	Mudstone (Floor)	22 MPa

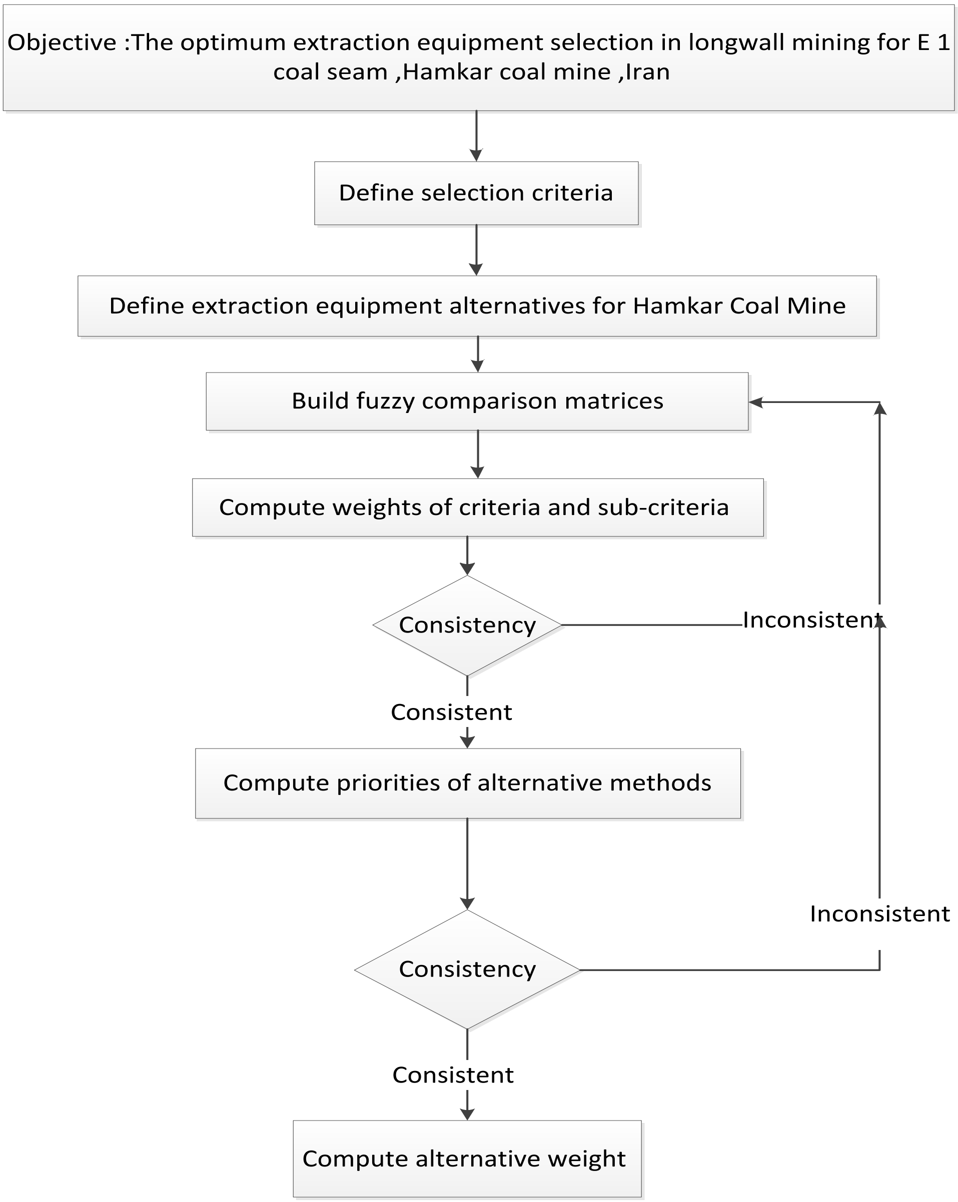

Figure 4. A flow sheet for proposed algorithm.

Table 2. Extraction equipment alternatives for Hamkar coal mine.

Alternative	Cutting machine	Support system	Transport system
A	Shearer on floor	Power support roof	Based on the gravity power
B	Shearer on floor	Hydraulic props	Based on the gravity power
C	Shearer on floor	Wooden support	Based on the gravity power
D	Plow	Power support roof	AFC
E	Plow	Hydraulic props	AFC
F	Plow	Wooden support	AFC

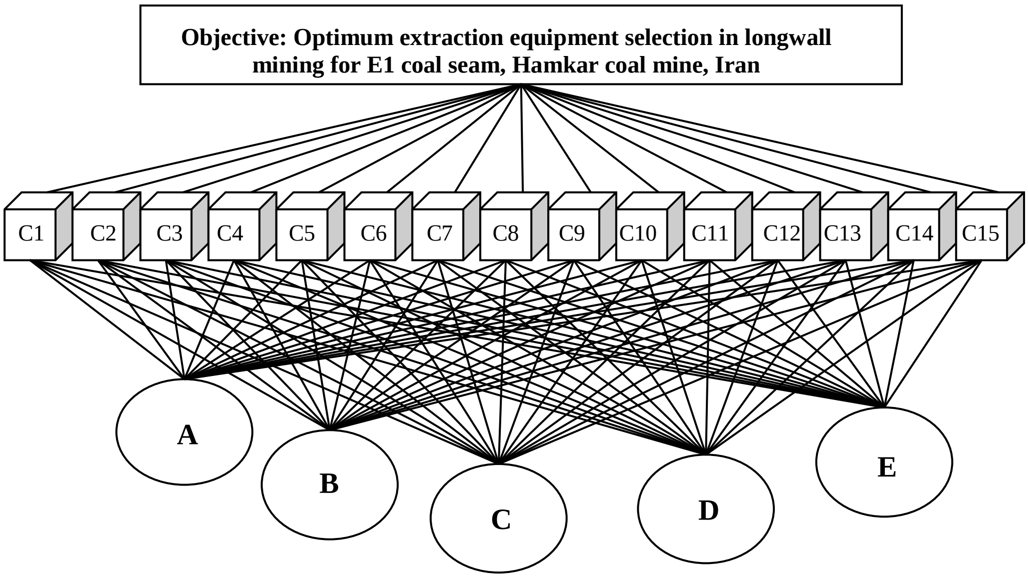

Figure 5. Hierarchy design for extraction equipment selection process.

Table 3. Pair-wise comparison matrix.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1	1.0	1.0	1.3	1.6	1.1	1.1	1.3	1.0	1.0	1.1	1.6	1.1	1.6	1.6	1.3
C2	1.0	1.0	1.3	1.6	1.1	1.1	1.3	1.0	1.0	1.1	1.6	1.1	1.6	1.6	1.3
C3	0.8	0.8	1.0	1.2	0.9	0.9	1.0	0.8	0.8	0.9	1.2	0.9	1.2	1.2	1.0
C4	0.6	0.6	0.8	1.0	0.7	0.7	0.8	0.6	0.6	0.7	1.0	0.7	1.0	1.0	0.8
C5	0.9	0.9	1.2	1.4	1.0	1.0	1.2	0.9	0.9	1.0	1.4	1.0	1.4	1.4	1.2
C6	0.9	0.9	1.2	1.4	1.0	1.0	1.2	0.9	0.9	1.0	1.4	1.0	1.4	1.4	1.2
C7	0.8	0.8	1.0	1.2	0.9	0.9	1.0	0.8	0.8	0.9	1.2	0.9	1.2	1.2	1.0
C8	1.0	1.0	1.3	1.6	1.1	1.1	1.3	1.0	1.0	1.1	1.6	1.1	1.6	1.6	1.3
C9	1.0	1.0	1.3	1.6	1.1	1.1	1.3	1.0	1.0	1.1	1.6	1.1	1.6	1.6	1.3
C10	0.9	0.9	1.2	1.4	1.0	1.0	1.2	0.9	0.9	1.0	1.4	1.0	1.4	1.4	1.2
C11	0.6	0.6	0.8	1.0	0.7	0.7	0.8	0.6	0.6	0.7	1.0	0.7	1.0	1.0	0.8
C12	0.9	0.9	1.2	1.4	1.0	1.0	1.2	0.9	0.9	1.0	1.4	1.0	1.4	1.4	1.2
C13	0.6	0.6	0.8	1.0	0.7	0.7	0.8	0.6	0.6	0.7	1.0	0.7	1.0	1.0	0.8
C14	0.6	0.6	0.8	1.0	0.7	0.7	0.8	0.6	0.6	0.7	1.0	0.7	1.0	1.0	0.8
C15	0.8	0.8	1.0	1.2	0.9	0.9	1.0	0.8	0.8	0.9	1.2	0.9	1.2	1.2	1.0

Table 4. Fuzzy pair-wise comparison matrix.

		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
	L1	1.0	0.9	0.7	0.5	0.6	0.6	0.4	0.6	0.7	0.4	0.4	0.6	0.1	0.4	0.6
C1	M1	1.0	1.0	0.8	0.7	0.7	0.7	0.6	0.8	0.8	0.7	0.6	0.7	0.3	0.6	0.7
	U1	1.0	1.1	0.9	0.8	0.9	0.9	0.9	1.0	1.0	0.9	0.9	0.9	0.6	0.7	0.9
	L2	0.9	1.0	0.7	0.4	0.6	0.6	0.4	0.6	0.7	0.5	0.4	0.6	0.1	0.3	0.6
C2	M2	1.0	1.0	0.8	0.7	0.7	0.7	0.6	0.8	0.8	0.7	0.6	0.7	0.3	0.6	0.7
	U2	1.1	1.0	1.0	0.9	0.9	0.9	0.8	1.0	1.0	0.9	0.8	0.9	0.6	0.8	1.0
	L3	1.1	1.0	1.0	0.7	0.6	0.6	0.6	0.7	0.9	0.6	0.5	0.7	0.1	0.5	0.7
C3	M3	1.3	1.3	1.0	0.9	0.9	0.9	0.8	1.1	1.0	0.9	0.8	0.9	0.4	0.8	0.9
	U3	1.5	1.5	1.0	1.2	1.2	1.2	1.0	1.3	1.3	1.2	1.2	1.2	0.8	0.9	1.3

Table 4. Continued.

	L4	1.3	1.1	0.9	1.0	0.8	0.8	0.7	0.9	1.0	0.7	0.7	0.8	0.2	0.7	0.8
C4	M4	1.5	1.5	1.2	1.0	1.1	1.1	1.0	1.3	1.2	1.0	0.9	1.1	0.5	0.9	1.1
	U4	2.0	2.3	1.5	1.0	1.5	1.5	1.4	2.0	2.0	1.8	1.8	1.5	1.0	1.0	1.3
	L5	1.1	1.1	0.9	0.7	1.0	0.7	0.7	0.8	0.9	0.6	0.7	0.7	0.1	0.5	0.7
C5	M5	1.4	1.4	1.1	1.0	1.0	1.0	0.9	1.2	1.1	1.0	0.9	1.0	0.4	0.8	1.0
	U5	1.8	1.6	1.6	1.2	1.0	1.2	1.2	1.6	1.4	1.2	1.2	1.2	0.7	1.0	1.4
	L6	1.1	1.1	0.9	0.7	0.8	1.0	0.8	0.7	0.9	0.7	0.7	0.7	0.2	0.5	0.7
C6	M6	1.5	1.5	1.2	1.0	1.1	1.0	0.9	1.2	1.2	1.0	0.9	1.1	0.4	0.9	1.1
	U6	1.8	1.8	1.6	1.2	1.4	1.0	1.2	1.6	1.4	1.2	1.2	1.4	0.7	1.2	1.4
	L7	1.1	1.3	1.0	0.7	0.8	0.8	1.0	0.7	0.9	0.8	0.7	0.7	0.2	0.6	0.7
C7	M7	1.7	1.6	1.3	1.1	1.2	1.1	1.0	1.4	1.3	1.1	1.0	1.2	0.5	1.0	1.2
	U7	2.3	2.3	1.8	1.5	1.5	1.3	1.0	1.8	1.6	1.4	1.4	1.8	0.8	1.5	1.6
	L8	1.0	1.0	0.8	0.5	0.6	0.6	0.6	1.0	0.8	0.5	0.6	0.6	0.1	0.4	0.6
C8	M8	1.3	1.2	1.0	0.8	0.9	0.9	0.8	1.0	1.0	0.8	0.7	0.9	0.4	0.7	0.9
	U8	1.6	1.8	1.4	1.2	1.2	1.4	1.4	1.0	1.2	1.4	1.0	1.2	0.6	1.0	1.2
	L9	1.0	1.0	0.8	0.5	0.7	0.7	0.6	0.8	1.0	0.7	0.6	0.8	0.2	0.4	0.6
C9	M9	1.3	1.2	1.0	0.9	0.9	0.9	0.8	1.0	1.0	0.8	0.8	0.9	0.4	0.7	0.9
	U9	1.5	1.5	1.2	1.0	1.2	1.2	1.2	1.3	1.0	1.2	1.0	1.2	0.6	1.0	1.0
	L10	1.1	1.1	0.9	0.6	0.8	0.8	0.7	0.7	0.9	1.0	0.7	0.7	0.2	0.4	0.7
C10	M10	1.6	1.5	1.2	1.1	1.1	1.1	1.0	1.3	1.2	1.0	0.9	1.1	0.4	0.9	1.1
	U10	2.3	2.0	1.8	1.5	1.8	1.5	1.3	2.0	1.5	1.0	1.5	1.5	0.7	1.5	1.5
	L11	1.1	1.3	0.9	0.6	0.8	0.9	0.7	1.0	1.0	0.7	1.0	0.9	0.2	0.4	0.7
C11	M11	1.7	1.7	1.3	1.1	1.2	1.2	1.1	1.4	1.3	1.1	1.0	1.2	0.5	1.0	1.2
	U11	2.3	2.3	2.0	1.5	1.5	1.4	1.5	1.8	1.8	1.5	1.0	1.8	1.0	1.5	1.8
	L12	1.1	1.1	0.9	0.7	0.8	0.7	0.6	0.9	0.9	0.7	0.6	1.0	0.1	0.5	0.8
C12	M12	1.4	1.4	1.1	0.9	1.0	1.0	0.9	1.2	1.1	0.9	0.9	1.0	0.4	0.8	1.0
	U12	1.8	1.8	1.4	1.2	1.4	1.4	1.4	1.6	1.3	1.4	1.2	1.0	0.7	1.2	1.2
	L13	1.6	1.6	1.2	1.0	1.4	1.4	1.2	1.6	1.6	1.4	1.0	1.4	1.0	0.8	1.2
C13	M13	4.9	4.6	3.7	3.3	3.3	3.1	2.8	4.0	3.6	2.8	2.8	3.4	1.0	2.9	3.3
	U13	9.0	9.0	7.0	6.0	7.0	6.0	5.0	8.0	6.0	5.0	6.0	7.0	1.0	6.0	6.0
	L14	1.5	1.3	1.2	1.0	1.0	0.8	0.7	1.0	1.0	0.7	0.7	0.8	0.2	1.0	0.8
C14	M14	1.8	1.8	1.4	1.2	1.3	1.2	1.1	1.5	1.5	1.2	1.1	1.3	0.6	1.0	1.3
	U14	2.7	3.0	2.0	1.5	2.0	2.0	1.7	2.7	2.7	2.3	2.3	2.0	1.3	1.0	1.8
	L15	1.1	1.0	0.8	0.8	0.7	0.7	0.6	0.9	1.0	0.7	0.6	0.9	0.2	0.6	1.0
C15	M15	1.4	1.4	1.1	1.0	1.0	1.0	0.9	1.2	1.1	1.0	0.9	1.0	0.4	0.8	1.0
	U15	1.8	1.8	1.4	1.2	1.4	1.4	1.4	1.6	1.6	1.4	1.4	1.2	0.8	1.2	1.0

Table 5. Large rating of each criterion than other criteria.

	$V(S_x >= S_y)$														
y \ x	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
C1		0.98	0.84	0.73	0.78	0.75	0.69	0.88	0.84	0.73	0.70	0.79	0.26	0.66	0.76
C2	1.00		0.85	0.75	0.78	0.76	0.70	0.90	0.85	0.74	0.72	0.80	0.27	0.67	0.78
C3	1.00	1.00		0.91	0.94	0.91	0.85	1.00	1.00	0.89	0.86	0.95	0.43	0.83	0.93
C4	1.00	1.00	1.00		1.00	1.00	0.94	1.00	1.00	0.98	0.94	1.00	0.53	0.92	1.00
C5	1.00	1.00	1.00	0.97		0.97	0.91	1.00	1.00	0.95	0.91	1.00	0.48	0.89	0.99
C6	1.00	1.00	1.00	0.99	1.00		0.94	1.00	1.00	0.98	0.93	1.00	0.51	0.91	1.00
C7	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	0.99	1.00	0.57	0.97	1.00
C8	1.00	1.00	0.96	0.87	0.91	1.00	0.82		0.96	0.86	0.82	0.91	0.41	0.79	0.90
C9	1.00	1.00	0.99	0.89	0.93	0.88	0.84	1.00		0.88	0.85	0.94	0.41	0.82	0.92
C10	1.00	1.00	1.00	1.00	1.00	0.90	0.96	1.00	1.00		0.95	0.95	0.54	0.93	1.00
C11	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	0.59	0.98	1.00
C12	1.00	1.00	1.00	0.95	0.99	1.00	0.90	1.00	1.00	0.94	0.90		0.48	0.88	0.98
C13	1.00	1.00	1.00	1.00	1.00	0.96	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00
C14	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.62		1.00
15	1.00	1.00	1.00	0.97	1.00	1.00	0.92	1.00	1.00	0.95	0.92	1.00	0.50	0.89	
$d'(C_x)$= min	1.00	0.98	0.84	0.73	0.78	0.75	0.69	0.88	0.84	0.73	0.70	0.79	0.26	0.66	0.76

Table 6. Priority weights for criterion.

Criteria	Local weight	Global weight	Ranking
C1	1.000	0.088	1
C2	0.982	0.086	2
C3	0.836	0.073	5
C4	0.729	0.064	11
C5	0.781	0.069	7
C6	0.748	0.066	9
C7	0.687	0.060	13
C8	0.882	0.077	3
C9	0.839	0.074	4
C10	0.729	0.064	10
C11	0.703	0.062	12
C12	0.787	0.069	6
C13	0.262	0.023	15
C14	0.660	0.058	14
C15	0.764	0.067	8

Table 7. Weights between all criteria and alternatives.

Alternatives	Criteria																													
	C1		C2		C3		C4		C5		C6		C7		C8		C9		C10		C11		C12		C13		C14		C15	
	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight	Local Weight	Global Weight
A	1.00	0.220	1.00	0.221	1.00	0.206	1.00	0.215	0.47	0.102	0.53	0.120	1.00	0.203	1.00	0.209	1.00	0.213	1.00	0.212	1.00	0.222	0.66	0.144	0.95	0.165	0.71	0.164	0.68	0.148
B	0.97	0.214	0.89	0.197	0.99	0.204	0.96	0.206	1.00	0.218	0.93	0.212	0.91	0.185	0.94	0.196	0.90	0.192	1.00	0.213	0.97	0.216	0.93	0.201	1.00	0.173	1.00	0.231	1.00	0.216
C	0.88	0.193	0.87	0.191	0.74	0.152	0.75	0.162	0.97	0.212	1.00	0.227	0.90	0.182	0.67	0.140	0.82	0.175	0.94	0.201	0.55	0.123	1.00	0.218	0.90	0.156	0.77	0.177	0.85	0.183
D	0.97	0.212	0.92	0.203	0.98	0.202	0.98	0.211	0.50	0.109	0.45	0.103	0.95	0.193	0.94	0.196	1.00	0.213	0.80	0.170	0.99	0.220	0.60	0.131	1.00	0.173	0.32	0.074	0.37	0.080
E	0.47	0.103	0.63	0.139	0.68	0.141	0.73	0.156	0.84	0.183	0.70	0.159	0.65	0.132	0.65	0.136	0.56	0.119	0.48	0.102	0.65	0.144	0.62	0.136	0.94	0.162	0.73	0.168	0.86	0.185
F	0.26	0.057	0.23	0.050	0.46	0.095	0.23	0.050	0.81	0.176	0.79	0.179	0.51	0.105	0.59	0.123	0.42	0.089	0.48	0.102	0.34	0.075	0.78	0.170	1.00	0.173	0.81	0.186	0.87	0.188

The overall rating of each alternative was calculated by summing the product of the relative priority of each criterion with the relative priority of alternatives considering the corresponding criteria in Table 7.

$\boldsymbol{W_A}$ =(0.220×0.088)+(0.221×0.086)+(0.206×0.073)+(0.215×0.064)+(0.102×0.069)+(0.120×0.066)+(0.203×0.060)+(0.209×0.077)+(0.213×0.074)+(0.212×0.064)+(0.222×0.062)+(0.144×0.069)+(0.165×0.023)+(0.164×0.058)+(0.148×0.067)= 0.187

$\boldsymbol{W_B}$ =(0.214×0.088)+(0.197×0.086)+(0.204×0.073)+(0.206×0.064)+(0.218×0.069)+(0.212×0.066)+(0.185×0.060)+(0.196×0.077)+(0.192×0.074)+(0.213×0.064)+(0.216×0.062)+(0.201×0.069)+(0.173×0.023)+(0.231×0.058)+(0.216×0.067)= 0.206

$\boldsymbol{W_C}$ =(0.193×0.088)+(0.191×0.086)+(0.152×0.073)+(0.162×0.064)+(0.212×0.069)+(0.227×0.066)+(0.182×0.060)+(0.140×0.077)+(0.175×0.074)+(0.201×0.064)+(0.123×0.062)+(0.218×0.069)+(0.156×0.023)+(0.177×0.058)+(0.183×0.067)= 0.181

$\boldsymbol{W_D}$ =(0.212×0.088)+(0.203×0.086)+(0.202×0.073)+(0.211×0.064)+(0.109×0.069)+(0.103×0.066)+(0.193×0.060)+(0.196×0.077)+(0.213×0.074)+(0.

170×0.064)+(0.220×0.062)+(0.131×0.069)+(0.173×0.023)+(0.074×0.058)+(0.080×0.067)= 0.168

$\boldsymbol{W_E}$ =(0.103×0.088)+(0.139×0.086)+(0.141×0.073)+(0.156×0.064)+(0.183×0.069)+(0.159×0.066)+(0.132×0.060)+(0.136×0.077)+(0.119×0.074)+(0.102×0.064)+(0.144×0.062)+(0.136×0.069)+(0.162×0.023)+(0.168×0.058)+(0.185×0.067)= 0.142

$\boldsymbol{W_F}$ =(0.0.57×0.088)+(0.050×0.086)+(0.095×0.073)+(0.050×0.064)+(0.176×0.069)+(0.179×0.066)+(0.193×0.060)+(0.123×0.077)+(0.089×0.074)+(0.102×0.064)+(0.075×0.062)+(0.170×0.069)+(0.173×0.023)+(0.186×0.058)+(0.188×0.067)= 0.116

According to the above-mentioned calculations, the alternative weights and their rankings were shown in Table 8.

Table 8. Alternative weights.

Alternatives	Alternatives weight	Ranking
A	0.187	2
B	0.206	**1**
C	0.181	3
D	0.168	4
E	0.142	5
F	0.116	6

Considering the overall results in Table 8, alternative “B” must be selected as the most suitable extraction equipment system to meet the Hamkar coal mine requirements since the priority value for this alternative (0.461) is the highest compared to the others. The second high score belongs to alternative “C”.

Comparing e alternatives B and C, it is obvious that the only difference between them is the support system type. It seems that according to the Hamkar coal mine conditions, shearer on floor can be used by both the wooden and hydraulic prop support systems.

5. Conclusions

Selection of a suitable extraction equipment for a mechanized longwall mining in steeply inclined coal seams involves considering several criteria such as the geometric properties of coal seam, hydraulic and geological conditions, geomechanical properties of coal and country rocks, dilution, equipment salvage, and operation costs. Such a decision process can be evaluated in a more scientific way using the FAHP method. Therefore, application of the FAHP method was introduced in this paper for selecting an extraction equipment for the Hamkar Coal mine. In the proposed FAHP model, fifteen criteria and 6 longwall extraction equipment systems were considered for an inclined coal seam.

Among the 6 extraction equipment system alternatives considered, alternative "B" (coal cut using shearer on the floor, support using hydraulic props, and conveying coal by gravity force) was the most suitable extraction equipment system when the alternatives were evaluated according to the considered criteria. Moreover, the results obtained for the FAHP analysis in ranking the effective criteria (Table 6) shows that dip of coal seam (C1) and seam thickness (C2) have the most influence on the selection of an extraction equipment in mechanized coal mines. Dip of the Hamkar coal seam is 45 to 60 degrees. This amount affects a fully-mechanized system adversely. As it is not possible to keep shearer-loaders and shield type roof support stable under these conditions, it is essential for more attention to be paid to the ability of the extraction equipment in these parameters during the design process. In the future studies, the proposed method can be applied for selection of the methods in other sectors.

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References

[1]. Deepak, D. (1986). Longwall face support design-a micro-computer model. Journal of Mines, Metals & Fuels.

[2]. Ataei, M., Khalokakaei, R. and Hossieni, M. (2009). Determination of coal mine mechanization using fuzzy logic. Mining Science and Technology (China). 19 (2): 149-154.

[3]. Dongsheng, Z. , Xianchen, Z. and Xuefeng, Y. (2005). Center Fuzzy evaluation on geological conditions of coal seam in china. National Natural Science Foundation of China (NSFC). 1: 1-7.

[4]. Guo, W. and Xin, J. (1990). Fuzzy evaluation of powered support suitability to coal seams. International Journal of Mining and Geological Engineering. 8 (2): 163-177.

[5]. Goshtasbi, K., Oraee, K. and Khakpour-Yeganeh, F. (2006). Shield support selection based on geometric characteristics of coal seam. Journal of Mining Science. 42 (2): 151-156.

[6]. Tu, H., Tu, S., Yuan, Y., Wang, F. and Bai, Q. (2015). Present situation of fully mechanized mining technology for steeply inclined coal seams in China. Arabian Journal of Geosciences. 8 (7): 4485-4494.

[7]. Walsh, J.J. and Watterson, J. (1990). New methods of fault projection for coalmine planning. In Proceedings of the Yorkshire Geological and Polytechnic Society. Geological Society of London. 48 (2): 209-219.

[8]. Peng. S.S. (2006). Longwall Mining. Richmond: West Virginia University, Morgantown.

[9]. Özfırat, M.K. (2012). A fuzzy method for selecting underground coal mining method considering mechanization criteria. Journal of Mining Science. 48 (3): 533-544.

[10]. Bitarafan, M. (2004). Mining method selection by multiple criteria decision making tools. Journal of the Southern African Institute of Mining and Metallurgy. 104 (9): 493-498.

[11]. Basçetin, A. (2004). Technical note: an application of the analytic hierarchy process in equipment selection at Orhaneli open pit coal mine. Mining Technology. 113 (3): 192-199.

[12]. Acaroglu, S. (2006). Analytical hierarchy process for selection of roadheaders. Journal of the Southern African Institute of Mining and Metallurgy. 106 (8): 569-575.

[13]. Ataei, M., Jamshidi, M., Sereshki, F. and Jalali, S.M.E. (2008). Mining method selection by AHP approach. Journal of the Southern African Institute of Mining and Metallurgy. 108 (12): 741-749.

[14]. Alpay, S. and Yavuz, M. (2009). Underground mining method selection by decision making tools. Tunnelling and Underground Space Technology. 24 (2): 173-184.

[15]. Zare Naghadehi, M., Mikaeil, R. and Ataei, M. (2009). The application of fuzzy analytic hierarchy process (FAHP) approach to selection of optimum underground mining method for Jajarm Bauxite Mine, Iran. Expert Systems with Applications. 36 (4): 8218-8226.

[16]. Ertuğrul, İ. and Karakaşoğlu, N. (2009). Performance evaluation of Turkish cement firms with fuzzy analytic hierarchy process and TOPSIS methods. Expert Systems with Applications. 36 (1): 702-715.

[17]. Sun, C.C. (2010). A performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods. Expert systems with applications. 37 (12): 7745-7754.

[18]. Rafiee, R., Ataei, M. and Jalali, S.M.E. (2013). The optimum support selection by using fuzzy analytical hierarchy process method for Beheshtabad water transporting tunnel in Naien. Iranian Journal of Fuzzy Systems. 10 (6): 39-51.

[19]. Myszkowski, M. and Paschedag, U. (2008). Longwall mining in seams of medium thickness-comparison between shearer and plow. In 21st Word Mining Congress. Kraków.

[20]. Anon. (2005). Basic Design of Hamkar Coal Mine Project. Report-Mining. IMPASCO Company.

[21]. Ishizaka, A. and Labib, A. (2011). Review of the main developments in the analytic hierarchy process. Expert systems with applications. 38 (11): 14336-14345.

[22]. Yu, M.C., Keng, I. and Chen, H.X. (2015). Measuring service quality via a fuzzy analytical approach. International Journal of Fuzzy Systems. 17 (2): 292-302.

[23]. Wang, T.C. and Chen, Y.H. (2007). Applying consistent fuzzy preference relations to partnership selection. Omega. 35 (4): 384-388.

[24]. Najafi, M., Ramezanzadeh, A. and Dezvareh, G.A. (2017). Determination of suitable method for solution mining brine recycling using fuzzy analytical hierarchy method. Desalination and Water Treatment Journal. doi: 10.5004/dwt.2017.20162.

[25]. Kahraman, C., Cebeci, U. and Ulukan, Z. (2003). Multi-criteria supplier selection using fuzzy AHP. Logistics information management. 16 (6): 382-394.

[26]. Boender, C.G.E., De Graan, J.G. and Lootsma, F.A. (1989). Multi-criteria decision analysis with fuzzy pairwise comparisons. Fuzzy sets and Systems. 29 (2): 133-143.

[27]. Csutora, R. and Buckley, J.J. (2001). Fuzzy hierarchical analysis: the Lambda-Max method. Fuzzy sets and Systems. 120 (2): 181-195.

[28]. Van Laarhoven, P.J.M. and Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. Fuzzy sets and Systems. 11(1-3). 229-241.

[29]. Chang, D.Y. (1996). Applications of the extent analysis method on fuzzy AHP. European journal of operational research. 95 (3): 649-655.

[30]. Saaty, T.L. (1980). The analytic hierarchy process. Mc Graw Hill. NY.

[31]. Chen, C.T., Lin, C.T. and Huang, S.F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. International journal of production economics. 102 (2): 289-301.

انتخاب تجهیزات مناسب برای استخراج لایه‌های شیب‌دار زغال‌سنگ به روش جبهه‌کار بلند مکانیزه با استفاده از فرآیند تحلیل سلسله مراتبی فازی، مطالعه موردی: معدن زغال‌سنگ همکار

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چکیده:

روش استخراج جبهه کار بلند یکی از پرکاربردترین روش‌های استخراج لایه‌های با شیب کم تا زیاد است. انتخاب تجهیزات استخراجی مناسب نقش بسیار مهمی در ایمنی، تولید و بررسی فنی و اقتصادی معدن دارد. پارامترهای زیادی بر انتخاب تجهیزات برای استخراج لایه‌های زغال‌سنگ شیب‌دار به روش جبهه‌کار بلند مکانیزه اثرگذار است. مهم‌ترین پارامترهای اثرگذار شامل خصوصیات هندسی لایه زغال‌سنگ (شیب، ضخامت و یکنواختی)، شرایط زمین‌شناسی و هیدرولوژیکی (گسل‌ها، شکستگی‌ها، درزه‌ها و آب زیرزمینی) و خصوصیات ژئومکانیکی لایه زغال‌سنگ و سنگ دربرگیرنده است. استخراج لایه‌های شیب‌دار با شیب بیشتر از ۴۰ درجه متفاوت از لایه‌های کم شیب است و نیازمند تجهیزات ویژه‌ای می‌باشند. از این رو تأثیر پارامترهای اثرگذار باید به طور همزمان در انتخاب تجهیزات استخراجی لایه‌های شیب‌دار در نظر گرفته شود. در این تحقیق از روش تحلیل سلسله مراتبی فازی برای انتخاب تجهیزات استخراجی معدن زغال‌سنگ همکار استفاده شده است. برای این منظور ۱۵ معیار شامل شیب لایه زغال‌سنگ، ضخامت لایه، یکنواختی، گسترش لایه، گسل‌ها، شکستگی‌ها و درزه‌ها، آب زیرزمینی، مقاومت کمربالا و کمرپایین، مقاومت زغال‌سنگ، تنش برجا، تجهیزات جانبی، ترقیق، انعطاف‌پذیری تجهیزات و هزینه‌های عملیاتی در نظر گرفته شده است. با در نظر گرفتن شش روش استخراجی تجهیزات جبهه‌کار بلند، نتایج تحقیق با کاربرد روش تحلیل سلسله مراتبی فازی نشان داده است که استفاده از شیرر روی کف برای برش زغال‌سنگ، نگهداری کارگاه توسط پایه‌های هیدرولیکی و حمل زغال‌سنگ به بیرون کارگاه تحت نیروی ثقل مناسب‌ترین گزینه است.

کلمات کلیدی: لایه‌های شیب‌دار زغال‌سنگ، فرآیند تحلیل سلسله مراتبی فازی، تجهیزات استخراجی.