Selecting Proper Mining Method Using Fuzzy AHP Approach (Case study: Qaleh-Zari Copper Mine of Iran)

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ABSTRACT

Mining method selection is the most important issue through mine planning and design. Therefore, it needs to be chosen appropriately. In this respect, it is crucial to consider the basic parameters such as geological and geotechnical properties of ore deposit, its surrounded strata, economic and technical parameters, and geographical factors; hence, selection of mining method is a multi-criteria decision making problem. A multi-criteria decision making method is used to rank appropriate mining methods based on a set of criteria; nevertheless, this approach has broader applicability. This paper presents a new approach in the selection of an underground mining method based on Fuzzy Analytic Hierarchy Process (Fuzzy AHP) approach for Qaleh-Zari Copper mine of Iran. This method is used to assess the effective criteria and then ranking of the methods through AHP by decision makers. The broad issue includes three possible mining methods and twelve criteria to evaluate them. The suggested method applied to the mine and the most appropriate mining method has been ranked and selected as Shrinkage mining method.

INTRODUCTION

Once an ore body has been probed and outlined and sufficient information has been collected to warrant further analysis, the important process of selecting the most appropriate method or methods of mining can begin. At this stage, the selection is preliminary, serving only as the basis for a project layout and feasibility study (Hartman, 1992). Later it may be found necessary to revised details, but the basic principles for ore extraction should remain a part of the final layout (Hamrin, 1986). Selection of an appropriate mining method is a complex task that requires consideration of many technical, economic, political, social, and historical factors. The appropriate mining method is the method which is 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 which presents the cheapest problem (Nicholas, 1992).

There is no single appropriate mining method for a deposit. Usually, two or more feasible methods are possible (Nicholas, 1981). Each method entails some inherent problems. Consequently, the optimal method is one that offers the least problems (Nicholas, 1981). Each ore body is unique, with its own properties, and engineering judgment has a great effect on the decision in such the versatile job of mining (Hartman, 1992). Therefore, it seems clear that only an experienced engineer, who has improved his experience by working in several mines and gaining skills in different methods, can make a logical decision about mining method selection. Experience and engineering judgment still provide major input into the selection of a mining method but subtle differences in the characteristics of each deposit can be usually perceived 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 considered in the process of mining method selection.

The aim of the present work is to select the proper mining method through a fuzzy AHP solution procedure. With that regard, Qaleh-Zari Copper mine considered as case study. At first, an overview of the selection procedure is cited as well as a brief history of major attempts that have been made for mining method selection. In the following sections, a description of study area is then presented. In next section, the concept of Fuzzy sets and Fuzzy AHP are illustrated. Afterward, the procedure and calculations of mining selection using Fuzzy AHP...
approach is well demonstrated step by step. And finally, a discussion on used method and conclusions of the paper are presented, respectively.

Main aspects influencing on the mining method selection can be categorized as below (Bitarafan and Ataei, 2004):

- 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, grade distribution, quality of resource, etc. The basic components that define the ground conditions include shear strength of rock and discontinuities, natural fractures, orientation of ore body, length, spacing and location of major geologic structures, in situ stress, hydrologic conditions, etc.
- Economic factors such as: capital cost, operating cost, amount of mineable ore, ore grades and mineral contained 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.

There are several methodologies developed to select appropriate mining method for an ore deposit. Bajkonurov (1969), Budko (1971), Imenitov (1970) and Popov (1970) have suggested a procedure for mining method selection that comprises two phases (preliminary mining method selection and the selection of the most suitable mining method from a group of applicable methods). The selection of the most suitable method from a group of applicable methods is made by the techno-economic model procedure. This model is based on the estimation of expected financial effects, which can be acquired by the implementation of each method from a group of applicable methods. The mining method with the best financial effects is selected. Later, Boshkov and Wright (1973), Morrison (1976), Laubscher (1981) and Hartman (1992) have suggested a series of approaches for mining method selection. However, these approaches were inadequate for the development of a methodology that would automatically choose a mining method. The first numerical approach for mining method selection was suggested by Nicholas (1981; 1992). This methodology rates different mining methods based on the rankings of specific input parameters. The mining method with the highest sum result is selected. Nicholas has suggested some modifications that involve the weighting of various categories, such as that of ore geometry, ore zone, hanging wall and footwall. Miller et al. (1995) have developed the UBC methodology. The UBC mining method selection is a modification of the Nicolas methodology that better represents typical Canadian mining design practices. The main weaknesses of these approaches are in the fact that the importance of each selection criteria has not been considered.

For a successful mining method selection, some alternative methods are primarily chosen in accordance with existing technical and economic condition. Afterward, the proper mining method 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 method selection problems in the literature, make the evaluations using the same evaluation scale and preference functions on the criteria basis. 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. The main reasoning for using fuzzy AHP has 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. Ataei et al. (2008) have used the AHP approach for mining method selection. Bitarafan and Ataei (2004) have used different fuzzy methods as an innovative tool for criteria aggregation in mining decision problems. Also, Alpay and Yavuz (2009) have suggested a combination of AHP and fuzzy logic methods for underground mining method selection. Bogdanovic et al. (2012) have applied integrated AHP and PROMETHEE method as a mining method selection tool.

As mentioned before, the main objective of this paper is to select the proper mining method for Qaleh-Zari Copper mine of Iran through fuzzy AHP approach. In the next sections, method selection procedure for the mine is presented.

**MATERIALS AND METHODS**

*Description of study area:*
Qaleh-Zari Copper mine, the only underground vein-type deposit copper mine in Iran, located in central part of Iran near the city of Birjand in southern Khurasan province and lied in 180 Km far from South-western of Birjand township and north-eastern margin of Lut desert. Its longitude, latitude and altitude are 58° 57', 48° 31' and 1539 m, respectively. The Copper ore grade varies from 0.5% to 8% accompanied by little amount of Gold and Silver. The average grade of raw material has been evaluated as 3.8%. After processing, the concentrate is transported to south port to be exported. It is cited that the amounts of Silver and Gold in each ton of concentrate have been estimated about 500 to 600 grams and 10 to 15 grams, respectively. The volcanism of Eocene is formed host rock of the mineral veins. There are some natural discontinuities assisting to separation of ore deposit from its host rock. The major mineral components of this ore body consist of Chalcopyrite, Pyrite, Hematite, Galena and Sphalerite. Total ore deposit has been determined as 10 million tons (Jahanshahi, 2004). Geomechanical parameters and geometry of Qaleh-Zari Copper deposit are listed in Table 1.

| Table 1: Geomechanical parameters and geometry of Qaleh-Zari copper deposit |
|-------------------------------|-----------------|---------------|---------------|
| Parameter | Unit | Value | Value | Value |
| UCS (MPa) | >250 in ore | 100-250 in hangingwall | 100-250 in footwall |
| RQD (%) | 90 - 100 | 75 - 90 | 75 - 90 |
| RMR | 90 | 74 | 74 |
| Thickness (m) | 1 - 3 | 80 | Vein-type |
| Dip (Deg.) | 80 | |
| Shape | |
| Grade (%) | 1 - 4 | |
| Depth (m) | 240 | |
| Ore deposit (million t.) | 10 | |

*Uniaxial Compressive Strength
**Rock Quality Designation
***Rock Mass Rating

Fuzzy sets:
Zadeh (1965) presented the fuzzy set theory for the first time to handle the unclarity of human's decision making. A set of fuzzy objects is a series with continuum grades of membership. This set is described through a function of membership attributed to each object with membership grade between 0 and 1 (Zadeh, 1965). Expanded form of a crisp set is considered as a fuzzy set. In crisp sets, full membership or non-membership of objects are only take into account, whereas fuzzy sets considered partial memberships. This means that an element can partially be a member of a fuzzy set (Erçin and Karakasoglu, 2006; 2008). Fuzzy approaches are influential tools for encountering uncertain issues in decision-making when complete or exact data is not available (Chien-chang, 2011). Such methods are more remarkable when applied to complex phenomena which can't easily be depicted by conventional mathematical methods, particularly in the case of finding an appropriate solution (Bojadziev and Bojadziev, 1998). Currently, compared to classic theories, fuzzy methods are extensively used in various areas due to its capability to reflect real world (Erçin and Tütüncü, 2007). Results achieved from modeling using fuzzy sets demonstrated that such methods can be considered as an effective way for formulating decision making issues where the information available is intellectual and misty (Zimmermann, 1992).

A. Linguistic Variable:
A linguistic variable is considered as a variable whose value is a word or a sentence in natural language (Zadeh, 1975). For instance and better understanding, age is a linguistic variable so that can be described in fuzzy forms such as young, not young, very young, not very young, etc. instead of the numbers (Bellman and Zadeh, 1977; Erçin, 2011). While it is too difficult to state an event or circumstance conditions in conventional quantitive terms, linguistic variables are significantly able to represent the occurrence characteristics. Linguistic approach is successfully utilized in various fields such as artificial intelligence, economics, multi criteria decision making, etc. (Zadeh, 1975; Erçin, 2011).

B. Description of Fuzzy Number:
A fuzzy number \( \tilde{M} \) is a convex normalized fuzzy set \( \tilde{M} \) of the real line \( \mathbb{R} \) such that (Zimmermann, 1992; Erçin, 2011; Torlak et al., 2011):
- It exists such that one \( x_0 \in \mathbb{R} \) with \( \mu_{\tilde{M}}(x_0) = 1 \) (\( x_0 \) is called mean value of \( \tilde{M} \))
- \( \mu_{\tilde{M}}(x) \) is piecewise continuous.

There is the possibility to use various fuzzy numbers but Triangular Fuzzy Numbers (TFNs) have been extensively used due to their easy applications in fuzzy point of view. In current work, Triangular Fuzzy Numbers applied to the fuzzy AHP method. A triangular fuzzy number \( \tilde{M} \) is shown in Fig. 1 (Deng, 1999). As
seen, there are three values in TFN as l, m and u. The parameter l is the smallest possible value, parameter m is the most likely value and parameter u is the largest possible value. If we consider two positive triangular fuzzy numbers as \((l_1, m_1, u_1)\) and \((l_2, m_2, u_2)\) then we have (Eqs. 1-4):

\[
(l_1, m_1, u_1) + (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2)
\]

\[
(l_1, m_1, u_1) \cdot (l_2, m_2, u_2) = (l_1 \cdot l_2, m_1 \cdot m_2, u_1 \cdot u_2)
\]

\[
(l_1, m_1, u_1)^{-1} \approx \left( \frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1} \right)
\]

\[
(l_1, m_1, u_1) \cdot k = (l_1 k, m_1 k, u_1 k)
\]

Where \(K\) is a positive real number.

The distance between two triangular fuzzy numbers can be calculated by vertex method as below (Eq. 5) (Chen, 2000):

\[
d_e(\hat{m}, \hat{n}) = \sqrt{1/3[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]}
\]

**Fig. 1:** Triangular fuzzy number (Deng, 1999)

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**C. A Brief Overview of Fuzzy Analytic Hierarchy Process (Fuzzy AHP):**

Saaty (1980) invented Analytic Hierarchy Process (AHP) as a powerful and fruitful approach for decision making problem. From that time up to now, AHP method entrenched itself into wide range of multiple criteria decision-making problems (Vaida and Kumar, 2006). Despite extensive use of conventional AHP, there are some deficiencies to apply expert’s opinion in this process (Kahraman et al., 2003). It is particularly appear when traditional AHP cannot reflect the intrinsic uncertainty and exact pair-wise comparisons. It is because of utilizing an exact value to reflect expert’s idea (Deng, 1999; Wang and Chen, 2007; Naghadehi et al., 2009). In order to achieve more accurate results in judgments, fuzzy analytical hierarchy process was proposed and used to solve the hierarchical problems (Kahraman et al., 2003). Van Laarhoven and Pedrycz (1983) applied fuzzy AHP method through their studies by triangular fuzzy numbers illustrated in Fig. 1. Buckley (1985) used trapezoidal fuzzy numbers through his work. Chang (1996) utilized fuzzy AHP through application of triangular fuzzy numbers and extent analysis method for pair-wise comparison (Ertugrul and Karakasoglu, 2006; 2008).

In current research work, the extent fuzzy AHP is utilized. In this context, assume \(X = \{x_1, x_2, x_3, \ldots, x_n\}\) as an object set, and cosider \(G = \{g_1, g_2, g_3, \ldots, g_n\}\) as a goal set. Afterwards, each object is taken and extent analysis for each goal is performed, respectively. Therefore, m extent analysis values for each object can be acquired. The procedure of the method can be explained using the following signs as below (Ertugrul and Karakasoglu, 2008; Chang, 1996; Momeni, 2009):

\[
M_{g_i}^1, M_{g_i}^2, \ldots, M_{g_i}^n, \quad i = 1, 2, 3, \ldots, n
\]

Where \(M_{g_i}^j (j = 1, 2, 3, \ldots, m)\) are TFNs.

The stages used in extent analysis process can be presented as following (Chang, 1996):

**Step 1:** Definition of the value of fuzzy synthetic extent with respect to the object, as below (Eq. 6):

\[
S_i = \sum_{j=1}^{n} M_{g_i}^j \odot \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{g_i}^j \right]^{-1}
\]
To obtain $\sum_{j=1}^{n} M_{gi}^j$ (Fuzzy Summation of Row), the fuzzy addition operation of m extent analysis values for a particular matrix is performed such as (Eq. 7):

$$\sum_{j=1}^{n} M_{gi}^j = \left( \sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_j \right)$$  \hspace{1cm} (7)

And to obtain $\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, the fuzzy addition operation of $M_{gi}^j$ ($j=1, 2, ..., m$) values is performed such as (Eq. 8): (Summation of Column)

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left( \sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right)$$  \hspace{1cm} (8)

And the inverse of the vector above is calculated, as follow (Eq. 9):

$$\left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left( 1/\sum_{i=1}^{n} u_i, 1/\sum_{i=1}^{n} m_i, 1/\sum_{i=1}^{n} l_i \right)$$  \hspace{1cm} (9)

Step 2: Consider $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ as two triangular fuzzy numbers; hence, the degree of possibility of $M_2 \geq M_1 = (l_1, m_1, u_1)$ is defined as (Eqs. 10-12):

$$V(M_2 \geq M_1) = \sup_{y \in \mathbb{R}} \left[ \min \left( u_{M_1(x)}, u_{M_2(y)} \right) \right]$$  \hspace{1cm} (10)

or: $V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = u_{M_2(d)}$  \hspace{1cm} (11)

$$\left( M_2 \geq M_1 \right) = \begin{cases} 1 & \text{IF } m_2 \geq m_1 \\ 0 & \text{IF } l_1 \geq u_2 \\ l_1 - u_2 / (m_2 - u_2) - (m_1 - l_1) & \text{OTHERWISE} \end{cases}$$  \hspace{1cm} (12)

That: $V(M_2 \geq M_1) = \text{Bigness degree}$, $M_1$= First S, $M_1$= secondary $S$.

Fig. 2 demonstrates Eq. (11) where $d$ is the ordinate of the highest intersection point $D$ between $\mu_{M_1}$ and $\mu_{M_2}$ to compare $M_1$ and $M_2$, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$ (Duru et al., 2011).

**Fig. 2:** The intersection between $M_1$ and $M_2$ (Buckley, 1985)

Step 3: The degree of possibility for a convex fuzzy number to be greater than k convex fuzzy $M_i$ ($i=1, 2, k$) numbers can be defined by (Eq. 13):

$$V(M \geq M_1, M_2, ..., M_k) = V(M \geq M_1) \text{ and } (M \geq M_2) \text{ and ... and } (M \geq M_k) = \min (M \geq M_i)$$  \hspace{1cm} (13)

For $k = 1, 2, ..., n$; $k \neq i$.

Then the weight vector is given by (Eq. 14):
Where \( A_i (i = 1, 2, ..., n) \) is the \( n \) number of elements (Duru et al., 2011).

Step 4: The normalized weight vectors are obtained through normalization process, as below (Eq. 15):

\[
W = (d(A_1), d(A_2), ..., d(A_n))^T
\]

Where \( W' \) is a non-fuzzy number.

Step 5: Determination of alternatives of final weight, as below (Eq. 16):

\[
A_2 = (A_1 \to C_1 \times C_1 \to GOAL) + (A_1 \to C_2 \times C_2 \to GOAL) + ... + (A_1 \to C_n \times C_n \to GOAL)
\]

Where \( n \) is the number of criteria.

**Application of fuzzy AHP approach for selecting proper mining method in Qaleh-Zari copper mine:**

The selection process of mining method gets started by gathering and evaluating given ore deposit data. The selection criteria include deposit thickness (C1), deposit dip (C2), deposit shape (C3), RSS of ore (C4), RSS of hangingwall (C5), RSS of footwall (C6), RMR of ore (C7), RMR of hangingwall (C8), RMR of footwall (C9), depth (C10), ore grade (C11) and ore uniformity (C12). 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 mining alternatives selected based on experts’ opinions. Ranking of considered mining methods for Qaleh-Zari Copper mine is finally carried out utilizing AHP method.

Here, it should be stated that according to ore deposit properties (particularly thickness, dip and shape) and possibly conventional mining methods for Qaleh-Zari deposit, there are only 3 appropriate mining alternatives for the mine including Shrinkage (SH), Sub-level Stoping (SLS), and Cut & Fill (CF) mining methods. The algorithm of FAHP approach is considered as steps presented and observed in the following sections (Alavi et al., 2011).

**A. Making Hierarchical Structure of the Problem:**

The criteria and mining alternatives can be ruled as a hierarchical structure of the problem, shown in Fig. 3.

![Fig. 2: Hierarchical structure of problem](image-url)
B. 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. Fuzzy numbers defined as very low [0, 1, 3], low [1,3,5], medium [3,5,7], high [5,7,9], very high [7,9,10] that is shown in Table 2.

Table 2: Preference values for the questionnaires

<table>
<thead>
<tr>
<th>Quality Judge</th>
<th>Fuzzy Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>0,1,3</td>
</tr>
<tr>
<td>low</td>
<td>1,3,5</td>
</tr>
<tr>
<td>Average</td>
<td>3,5,7</td>
</tr>
<tr>
<td>High</td>
<td>5,7,9</td>
</tr>
<tr>
<td>Extreme</td>
<td>7,9,10</td>
</tr>
</tbody>
</table>

Then, a comprehensive pair-wise comparison matrix is built. One of these pair-wise comparisons with respect to C10 (depth criterion) is shown below in Table 3 as an example.

Table 3: The alternatives fuzzy dual comparison matrix toward together, with respect to C10

<table>
<thead>
<tr>
<th>C10</th>
<th>CLS</th>
<th>SH</th>
<th>CF</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS</td>
<td>0.142,1,153.9</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>SH</td>
<td>0.142,1,153.9</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>CF</td>
<td>1.1</td>
<td>0.111,0.886,7</td>
<td>0.111,0.886,7</td>
</tr>
</tbody>
</table>

C. 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 depth criterion (C10), for example, are calculated like in Eq. (6): $S_1= 0.058, 0.348, 1.998, S_2=0.058, 0.348, 1.998, S_3=0.033, 0.304, 2.724$.

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

Table 4: The degree of possibility in Table 3

| $V(s_1\geq s_2)=1.000$ | $V(s_1\geq s_3)=1.000$ | $V(s_2\geq s_1)=1.000$ | $V(s_2\geq s_3)=1.000$ | $V(s_3\geq s_1)=0.984$ | $V(s_3\geq s_2)=0.984$ |

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

Table 5: Un-normalized weight and normalized weight respect to depth criterion

<table>
<thead>
<tr>
<th>$d_i'(A_j)$</th>
<th>$\hat{w}_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>normalized</td>
</tr>
<tr>
<td>1.000</td>
<td>0.335</td>
</tr>
<tr>
<td>1.000</td>
<td>0.335</td>
</tr>
<tr>
<td>0.984</td>
<td>0.334</td>
</tr>
</tbody>
</table>

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

D. Determination of Alternatives Final Weight (Selection of Mining Method):

In the last part, final weights of alternatives are determined by conflation of scores. By using of Eq. (16), alternative SH (Shrinkage mining method) which has the highest priority weight is selected as an appropriate mining method for Qaleh-Zari Copper mine. The ranking order of the alternatives with fuzzy AHP method is $SH> SLS> CF$ that are shown in Fig. 4.
Verification of the model:

As cited before, there are a number of methods developed to select suitable mining methods for an ore deposit based on physical characteristics of the deposit such as shape, thickness, plunge, depth, grade distribution, and geomechanical properties of the rock. From these methods and as part of study, Nicholas and UBC methods – due to their popularity and reliability - were chosen to verify the achieved results from FAHP approach. In this respect, the process of selecting appropriate mining method was carried out for Qaleh-Zari Copper mine using Nicholas and UBC methods. The results are shown in Tables 6-7.

Table 6: Results of mining method selection using Nicholas method for the mine

<table>
<thead>
<tr>
<th>Mining Method</th>
<th>Calculated Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS</td>
<td>41</td>
</tr>
<tr>
<td>SH</td>
<td>34</td>
</tr>
<tr>
<td>CF</td>
<td>33</td>
</tr>
</tbody>
</table>

Table 7: Results of mining method selection using UBC method for the mine

<table>
<thead>
<tr>
<th>Mining Method</th>
<th>Calculated Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLS</td>
<td>29</td>
</tr>
<tr>
<td>SH</td>
<td>38</td>
</tr>
<tr>
<td>CF</td>
<td>32</td>
</tr>
</tbody>
</table>

As seen in the above tables, the results are a bit different from obtained FAHP analysis. However, UBC method suggests Shrinkage mining method as the most adequate mining method for Qaleh-Zari mine; the same result has achieved using FAHP approach.

Conclusions:

The Selection of optimum mining method is one of crucial issues in mine planning and plays a major role in mining projects from both technical and economic point of view. Hence, the convenient mining method for each mine should appropriately be chosen from among relevant mining 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 geographical factors should be taken into account. The aim of this research work is to select proper mining method for Qaleh-Zari Copper 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 mining methods 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’ pair-wise 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 optimum mining method for Qaleh-Zari Copper mine found as Shrinkage mining method and the ranking order of the alternatives is Shrinkage (SH), Sub-level stopping (SLS) and Cut and Fill (CF) mining methods, respectively.

REFERENCES


