-RESEARCH PAPER-

International Journal of Mining and Geo-Engineering

IJMGE

IJMGE 56-1 (2022) 67-74

DOI: 10.22059/IJMGE.2021.306813.594859

The selection of an appropriate method for Gazik Granite Quarry mine using a hybrid multi-criteria decision-making method

Mohammad Javanshir Giv [a, *], Ahmad Aryafar [a], Mohsen Safari [b]

[a] *Department of Mining, Faculty of Engineering, University of Birjand, Birjand, Iran*

[b] *Department of Mining Engineering, Birjand University of Technology, Birjand, Iran*

Article History:

Received: 23 July 2020.

Revised: 23 July 2021.

Accepted: 21 August 2021.

ABSTRACT

One of the crucial stages in the operation of quarry exploitation is the selection of an appropriate mining method because the lack of attention to this issue may bring about many problems in the process of mining, leading to extra charges incurred to the mine owner or the possible drop in the quality or quantity of the mine product. The adoption of the appropriate method of quarry mining, given the various interacting factors involved, requires a multi-criteria decision-making method. This paper makes use of the hybrid AHP-ELECTRE model to examine the conventional quarry mining methods including Diamond Wire Sawing, Blasting, Feathers, and Wedge as well as the expansive agents such as KATROCK and FRACT.AG in the granite quarry of Gazik located in the South Khorassan Province, taking into consideration various factors such as the gross profit increase, safety, quality, decrease of adverse environmental effects, wastage, and the reduction of mining time. In this model, the weights of the items were applied by the AHP method, and the items were assessed through non-rank comparisons so that, finally, the Diamond Sawing Blasting was chosen as the most appropriate method of Gazik granite quarry mining based on the ELECTRE model. Such studies can aid in managing the mining costs to decrease, which can lead to the profitability of the quarries.

Keywords: *Mining method, Granite quarry, Multi-criteria decision-making, Hybrid AHP-ELECTRE model*

1. Introduction

Selection of the appropriate method for quarry mining is of particular importance because if a suitable mining method is not selected, several difficulties arise in extraction operations, additional costs will be imposed on the project and the quality and quantity of the mineral products may be reduced. Advancement of technology and the use of machinery have abolished primary methods in which human resources somehow played a significant role. Therefore, the adoption of a quarry mining method is considered as a strategic decision in terms of economic, technical, and safety aspects because an appropriate selection will lead to more profitability and vice versa, which can even result in the permanent mine closure. In case an inappropriate method is chosen at the onset, the subsequent modifications will be hard and costly. In this regard, the method of quarry mining should be chosen based on the features of the quarry and its lateral conditions. Given the geometrical and geological complexities of mineral resources, one single mining method cannot be used for all mineral resources, so for a specific reserve, its mining method must be applied. There are several methods used for quarry mining including Feathers and Wedge, Havage, Steel Wire Sawing, Diamond Wire Sawing, Blasting (weak explosives) as well as the expansive agents such as KATROCK and FRACT.AG. Since any of these methods has pros and cons compared to other methods, the adoption of the appropriate method must be done according to the executive conditions, methods specifications, and mineral deposit conditions. Several studies have been conducted on the selection of the mining method by [1-39], but regarding the selection of the quarry mining method, [36, 40-42] have conducted their researches. The above-mentioned studies have all had their defects so that none of them has offered a comprehensive mining method. In order to remove such defects, the hybrid multi-criteria decision-making models can be used to appropriately select a quarry mining method. The current paper utilizes the hybrid AHP-ELECTRE model as the most suitable method of quarry mining in the region of South Khorassan. To this end, some criteria such as gross profit, quality, safety, etc. were considered, and since the ELECTRE method cannot determine the significance of the criteria, and the weights of the criteria would remain unknown, the AHP method was used to determine the weights of the criteria. Next, each item was assessed based on every criterion, which led to the adoption of the best item through the use of the ELECTRE method.

2. Case Study

The Iranian quarries have a wide variety in terms of material and color. One of the most important quarries is granite. The South Khorassan Province, with more than 63 million tons of granite, is considered as one of the poles of these types of quarries in Iran. Given the importance of granite mines in the mineral economy of the South Khorassan Province, as well as the abundance of such mines in the province and the high costs of mining, the adoption of an appropriate mining method at the Gazik granite quarry of the South Khorassan is the objective of the current study. Since there are many problems in the exploitation of this mine, the adoption of an appropriate mining method based on scientific criteria can manage the related costs. Due to this issue, the data on this mine was examined upon being updated through the hybrid AHP-ELECTRE.

3. Hybrid AHP-ELECTRE Multi-Criteria Decision-Making Model

The ELECTRE model is a powerful multi-criteria decision-making

* Corresponding author. *E-mail address:* mjavanshir@birjand.ac.ir (M. Javanshirgiv).

method for selecting the best option out of several ones, but its major defect is that it cannot determine criterion weights. In order to overcome this problem, the hybrid AHP-ELECTRE model can be used, where the criterion weights and the best option are respectively determined through the AHP and ELECTRE methods.

3.1. AHP Method

The Analytical Hierarchy Process (AHP) is an effective multi-criteria decision-making method first posed by Saaty in 1980 [43]. It was designed to assist planners in resolving complex decision-making problems where a large number of planners participate, and several criteria exist in several specific periods [44]. The AHP is an MCDM method that is easy to use and flexible [45]. It allows complex problems with multiple and sometimes conflicting criteria to be addressed. It is suited to some domains and to different problems since it relies on the innate human propensity to conduct comparison [46]. This method, due to its powerful theoretical base, high accuracy, ease of use, reliability, and precise results is considered one of the most prevalent multi-criteria decision-making methods. The AHP method seeks to determine the relative significance of criteria or items based on a binary comparison of the decision-making components while considering the items and criteria. In order to calculate weight in the hierarchy analysis, the elements of each level are compared to the higher ones in a binary manner, followed by the formation of a binary comparison matrix.

The AHP procedure for accounting relative weights involves three essential steps: defining the effective criteria, establishing a pairwise comparison between the criteria, estimating the relative weights of the criteria. In the first step, according to the problem or objective, the important criteria are defined. Secondly, Through the AHP, experts' judgments are used to measure the relative weights of certain criteria [47]. For this action, initially, a pairwise comparison matrix of criteria (A) is established based upon the judgment of experts using the nine-point scale shown in Table 1. This 1–9 scale measures the intangibles in relative terms.

Table 1. The scale of Relative Importance [48, 49]

Preferences expressed in linguistic variable	Preferences expressed in a numeric variable
Equal importance	1
Moderate importance	3
Strong importance	5
Very strong importance	7
Extreme importance	9
Intermediate values between adjacent scale values	2, 4, 6, 8

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad (1)$$

where a_{ij} denotes the comparative importance of attribute i with respect to attribute j. In the matrix, $a_{ij} = 1$ when i = j and $a_{ij} = \frac{1}{a_{ji}}$

Finally, after the pairwise comparison between the criteria, calculate the relative weights of elements in each pairwise comparison matrix. The relative weights, W, of matrix A are obtained.

$$W = [w_1 \quad w_2 \quad \cdots \quad w_n] \quad (2)$$

where W_i is the relative weight of criteria i.

There are several methods for the calculation of relative weights based on the binary comparison matrix, the most prominent of which are the Least Squares, Logarithmic Least Squares, Eigenvector, and Approximation methods. Of all such methods, the Eigenvector is the most precise, where W_i is so determined that the following relation exists [43]:

$$A.W = \lambda.W \quad (3)$$

The scalar value λ is called the eigenvalue and W is an eigenvector. It follows from this relationship that the determinant of A−λI is zero:

$$det\ (A - \lambda I) = 0, \quad (4)$$

Next, substituting each eigenvalue λ_{max} in the system of equations and solving it, we find the eigenvectors (W) corresponding to the given eigenvalue λ_{max}:

$$(A - \lambda_{\max}.I) \times W = 0, \quad (5)$$

where λ_{max} is the biggest eigenvalue of matrix A and the unit matrix. Premise: For inverse-positive matrices (such as the binary comparison matrix), the Eigenvector can be calculated through the following relation:

$$W = \lim_{k \to \infty} \frac{A^k.e}{e^T.A^K.e}, \quad (6)$$

where; $e^T = [1 \quad 1 \quad \ldots \quad 1]$.

3.2. ELECTRE Method

The ELECTRE (Elimination Et Choice in Translating to Reality) approach was first introduced by Benayoun, Roy, and Sussman in 1968 [50]. The method was later developed by Bernard Roy [51, 52]. It is a multi-criteria decision-making procedure that can be applied when a set of alternatives must be ranked according to a set of criteria reflecting the decision maker's preferences. The relationships between the alternatives and the criteria are described using the attributes referred to the aspects of the alternatives that are relevant according to the established criteria [53, 54]. That is, this method is based on the study of outranking relations, exploiting notions of concordance [51, 55-56]. These outranking relations are built in such a way that it is possible to compare alternatives [57]. All the stages of the ELECTRE technique are based on a harmonious as well as a non-harmonious collection, due to which it is referred to as *coordination analysis*.

The steps for implementing the ELECTRE method are described below [58-63]:

Step 1: Define the decision matrix.

Perform the ranking of the alternatives based on the aggregation of the decision-makers [64].

The decision matrix of each alternative for each attribute, X, is given in Eq. (7):

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}, \quad (7)$$

where x_{ij} is the performance value of i^{th} alternative (i=1, 2, ..., m) on j^{th} criterion (j=1, 2, ..., n), m is the number of alternatives compared and n is the number of the criteria.

Step 2: Normalize the decision matrix.

In this step, the values X_{ij} of the decision matrix must be normalized to a scale comparable to r_{ij} so that the elements become unit-free. The process is to transform different scales and units among various criteria into common measurable units to allow comparisons across the criteria. Several normalization techniques have been proposed by past researchers to transform the different units into dimensionless values. In this research, the norm technique (Eq. 9) is used for computing element r_{ij} of the normalized decision matrix, which is given as the normalized decision matrix (R).

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \cdots & \cdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}, \quad (8)$$

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (9)$$

Step 3: Establish the criteria weighted matrix.

It cannot be assumed that each evaluation criterion is of equal importance because the evaluation criteria have various meanings.

Therefore, the weight of the criteria must be calculated. The weight value indicates the relative importance of each criterion, given as W:

$$W = \begin{bmatrix} w_1 & & 0 \\ \vdots & w_2 \cdots & \cdots \\ 0 & \cdots & w_n \end{bmatrix}, \quad (10)$$

where; w_j represents the importance weight of criterion C_j.

Step 4: Compute the normalized weighted decision matrix.

By determination of the weight of each criterion, the weighted normalized decision matrix (V) can be obtained as follows:

$$V = R \times W = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \cdots & \cdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix}, \quad (11)$$

where; $\tilde{v}_{ij} = \tilde{r}_{ij} . \tilde{w}_j$

Step 5: Determine the concordance and discordance sets

By comparison of all source pairs in each criterion, concordance and discordance sets are generated.

The concordance set (S_{ke}) of A_k and A_e (k,e= 1, 2, ..., m, k#e) is composed of all the criteria for which A_k is preferred to A_e. The discordance set (I_{ke}) is the complementary set of S_{ke}.

$$S_{ke} = \left\{ j \middle| v_{kj} \geq v_{ej} \right\} \quad (12)$$

$$I_{ke} = \left\{ j \middle| v_{kj} \prec v_{ej} \right\} \quad (13)$$

Step 6: Calculate the concordance matrix:

The relative value of the concordance sets is measured by means of the concordance index. The concordance index is equal to the sum of the weights associated with those criteria and relations which are contained in the concordance sets. Therefore, the concordance index C_{ke} between the pair of alternatives k and e is defined as:

$$c_{ke} = \frac{\sum_{j \in S_{ke}} W_j}{\sum_{j=1} W_j}, \quad (14)$$

where$\sum_{j=1} W_j = 1$; therefore, C_{ke} concordance matrix elements are calculated using the formula:

$$c_{ke} = \sum_{j \in S_{ke}} W_j \quad (15)$$

The concordance index lies between 0 and 1($0 \leq C_{ke} \leq 1$).

The concordance matrix is calculated as below:

$$C = \begin{bmatrix} - & c_{12} & \cdots & c_{1m} \\ c_{21} & - & \cdots & c_{2m} \\ \vdots & \vdots & - & \vdots \\ c_{m1} & \cdots & c_{m(m-1)} & - \end{bmatrix} \quad (16)$$

Step 7: Calculate the discordance matrix.

The discordance index (d_{ke}) is the relation of the largest difference overall discordant criteria to the largest difference over all the criteria between the two alternatives and is calculated using the formula:

$$d_{ke} = \frac{\max_{j \in I_{ke}} \left| v_{kj} - v_{ej} \right|}{\max_{j \in J} \left| v_{kj} - v_{ej} \right|} \text{ and } (0 \leq d_{ke} \leq 1) \quad (17)$$

The discordance matrix is calculated as below:

$$D = \begin{bmatrix} - & d_{12} & \cdots & d_{1m} \\ d_{21} & - & \cdots & d_{2m} \\ \vdots & \vdots & - & \vdots \\ d_{m1} & \cdots & d_{m(m-1)} & - \end{bmatrix} \quad (18)$$

It is to be noted that the data available in the agreement matrix has a marked difference from the data in the opposed matrix so that they are complements. The weight differences are obtained by the agreement matrix while the differences among the specified amounts are obtained through the opposed matrix.

Step 8: Determine the concordance dominance matrix:

This matrix can be calculated with the aid of a threshold value for the concordance index. A_k will only have a chance of dominating A_e, if its corresponding concordance index C_{ke} exceeds at least a certain threshold value $\bar{c}$ i.e., $C_{ke} \geq \bar{c}$, and

$$\bar{c} = \sum_{\substack{k=1 \\ k \neq e}}^{m} \sum_{\substack{e=1 \\ e \neq k}}^{m} \frac{c_{ke}}{m(m-1)} \quad (19)$$

In the sixth step, the way of calculating the agreement index of C_{ke} was expressed. Now, a specified amount will be determined for the agreement index known as the agreement boundary and will be shown by *c*. If C_{ke}> c, the preference of *k* option over *e* is acceptable; otherwise, there is no such a preference over *e* by *k*.

On the basis of the threshold value, a Boolean matrix F can be constructed, the elements of which are defined as:

$$f_{ke} = \begin{cases} 1 & c_{ke} \geq \bar{c} \\ 0 & c_{ke} < \bar{c} \end{cases} \quad (20)$$

Then, each element of 1 on the matrix F represents the dominance of one alternative with respect to another one.

Step 9: Determine the discordance dominance matrix.

This matrix is constructed in a way analogous to the *F* matrix on the basis of a threshold value $\bar{d}$ to the discordance indices.

$$\bar{d} = \sum_{\substack{k=1 \\ k \neq e}}^{m} \sum_{\substack{e=1 \\ e \neq k}}^{m} \frac{d_{ke}}{m(m-1)} \quad (21)$$

As mentioned in the seventh step, the less the disagreement index (C_{ke}), the better; because the amount of disagreement implies the preference of *k* over *e*. If d_{ke}> d, then the amount of disagreement has been much and it cannot be ignored. So, the elements of g_{ke} of the discordance dominance matrix G are calculated as:

$$g_{ke} = \begin{cases} 0 & d_{ke} > \bar{d} \\ 1 & d_{ke} \leq \bar{d} \end{cases} \quad (22)$$

Also, the unit elements in the *G* matrix represent the dominance relationships between any two alternatives.

Step 10: Determine the aggregate dominance matrix.

This step is to calculate the intersection of the concordance dominance matrix F and discordance dominance matrix G. The resulting matrix, called the aggregate dominance matrix H, is defined by means of its typical elements h_{ke} as:

$$h_{ke} = f_{ke} . g_{ke} \quad (23)$$

Step 11: Determine the best alternative

The aggregate dominance matrix *H* gives the partial-preference ordering of the alternatives. If h_{ke}= 1, then A_k is preferred to A_e for both the concordance and discordance criteria (i.e. the preference exceeds the agreement boundary while the disagreement and loss are less than the disagreement boundary), but A_k still has the chance of being dominated by the other alternatives. So, there should be an option that is more probable to dominate than to be dominated, which can lead to the ranking of the options.

4. Introduction to Quarry Mining Methods

There are several methods used for quarry mining including Feathers and Wedge, Blasting, expansive chemical agents, Diamond Wire Sawing, Steel Wire Sawing, Havage, Flame-Jet drilling, etc. In the current study, the methods of Feathers and Wedge, Diamond Wire Sawing, Blasting, and expansive agents (KATROCK and FRACT) have been assessed. Below, you can see a summary of each method.

4.1. Feathers and Wedge

The Feathers and Wedge method is an old method for extracting stone blocks. First, a series of holes are drilled along the intended line of fracture. The diameter, depth, and a number of these holes depend on the quality of the stone. The closer the holes are to each other and the deeper they are, the easier the separation would be. After drilling the holes, two metal blades and one hard metal wedge are placed in each hole. This way, the wedge is first put into the position using a light hammer. Next, with a 10-kg mallet, the wedge is hit on until the stone cracks, which leads to obtaining a stone block upon the expansion of the fractures.

4.2. Diamond Wire Sawing

The first unit of Diamond Wire Sawing was established in the Carrara mine. Then on, the method has undergone quick advancement regarding the equipment and parts of the wire. In this method, first, three holes, perpendicular to one another (one vertical and two horizontal ones), are made using a Russell machine or Wagon Drill. Then, in order to cut the bottom, from inside the two horizontal holes, a diamond wire attached to a wheel passes, which moves non-stop on the stone towards a definite direction and is cooled down by water during the operation, making a groove in the stone. This way, the stone is cut. After cutting the bottom, the side and back parts are cut similarly, and the stone is removed off the work bed. During the cutting operation, the machine moves away from the work bed as it goes on the track, keeping the wire pulled.

4.3. Blasting Method

In the method of extracting blocks using blasting, horizontal and vertical holes are first drilled. Then, using special explosives and a detonating fuse, the blasting is done and the block is separated from the mass of stone. The main difference between blasting in quarries and usual blasting lies in the fact that in the former, the fracture must be made in a specific direction without damaging the neighboring stones.

4.4. Expansive Chemical Agents

One conventional mining method in Iran is the use of various types of expansive agents. These materials are increasingly used in quarries instead of inflammable substances. The explosive power of these materials is not equal to that of black powder, dynamite, and ANFO. They function like Feathers and Wedge. To use the materials, some parallel holes must be drilled in the stone. Then, the intended material is mixed with water to form grout. The obtained grout is poured into the holes, which expands several times its size due to the hydration effect, leading to the final crack of the stone and the separation of the block.

5. Effective Criteria in Selecting Granite Quarry Mining

Some factors such as gross profit, quality, safety, time, environmental effects, and wastage are important and must be considered in the quarry mining methods, which can be classified into qualitative and quantitative groups. Some of these criteria have positive and some others have negative effects on the selection of the mining method. For example, the environmental factor could have negative impacts and the safety factor could have positive impacts on the selection. The qualitative and quantitative status of the factors, along with their positive or negative effects, is shown in Table 2. Below, each method is explained with regard to the criteria.

Table 2. Effective Criteria for quarry mining method selection

Criterion	Gross profit	Time	Waste rock production	Safety	Stone quality	Environmental Problems
Category	Quantitative	Quantitative	Qualitative	Qualitative	Qualitative	Qualitative
Type of criteria	Positive	Negative	Negative	Positive	Positive	Negative

- Gross Profit (cost-income)

Given one block with three free surfaces, for any of the methods of Diamond Wire Sawing, Feathers and Wedge, Blasting, KATROCK, and FRACT expansive agents, the extraction cost and the income from selling the stone blocks are as shown in the following table. The costs have been calculated in Table 3 according to the average costs obtained from some active mines in Iran.

Table 3. The gross profit from each method is based on the income from selling one cubic meter of stone block

Cost (Rial*/m³)	Expansive agent		Blasting	Diamond wire sawing	Feathers and wedge
	KATROCK	FRACT			
Drilling Cost	60000	420000	60000	36000	60000
Cost of consumables	144000	258000	480000	0	120000
Cutting cost	0	0	0	360000	0
The cost of machinery	9600	6000	9600	4800	9600
Waste handling cost	21600	18000	43200	0	21600
Total cost	235200	702000	592800	400800	211200
Price	4320000	4320000	2880000	4320000	4080000
Gross profit	4084800	3618000	2287200	3919200	3868800

*1$=150000Rials

- Time

If one block is considered with the freedom degree of 3 with the same dimensions, given the fact that in the parallel-holes method, on average, in every 10 centimeters, one hole is drilled, in each of the non-free dimensions of the block, 10 one-meter holes, a total of 30 meters of drilling will be required. Should the drilling time of each meter by five meters, the total drilling time will be 150 minutes. The time required for filling the holes with expansive agents is usually 30 minutes and the waiting time for KATROCK and FRACT expansive agents to function is respectively 16 and 10 hours. So, the total time required for producing one cubic meter of block in the two methods will be 19 and 13 hours. In the Wire Sawing method, drilling 3 conductor one-meter holes will take 15 minutes and the time required for the passage of the wire will be 30 minutes. Given the average cutting speed of one square meter per hour, the total time of the block extraction in this method will be 4 hours. Yet, it should be mentioned that the production time in these three methods is not exactly in the aforementioned ratio, and may vary due to the aeromechanics features of stone in various mines. In the Feathers and Wedge and Blasting methods, 30 holes must be drilled in three non-free dimensions of the stone, which, given the time required for drilling every meter, will take 150 minutes to complete the drilling operation. Moreover, given the fact that a total of 3 hours is required for cracking the stone, the extraction of one cubic meter needs 5.5 hours in this method. Also, given the time required for filling each hole with explosives is 5 minutes, 2.5 hours is required for filling 30 holes. Therefore, in the Blasting method, 5 hours is required to extract a cubic meter of a block. The time required for extracting one cubic meter of stone in different methods is shown in Table 4.

- Waste Rock Production

In case mineral reserves are considered as a national capital so that waste rocks of mining are looked at as a waste of capital, the waste rocks become prominent factors to be considered for the selection of a mining method. One type of such waste rocks produced in the quarry mining is the joints at Blasting and Feathers and Wedge methods which damage the rock at the time of cutting. Given the mechanism of mining in the Diamond Wire Sawing and Expansive Agents, the waste rocks produced in these methods are less than that produced in traditional methods. Considering the quality of production, this criterion can be considered as a qualitative one. The results obtained from the qualitative comparison of the amount of waste rock produced from one meter of rock in various methods are shown in Table 4.

- Safety

Many of the people who have used chemical expansive agents have suffered from pulmonary and eye discomfort. Although the direct effect of using such agents on the aforementioned discomforts has not been confirmed yet, the low quality of production and use of harmful materials for the sake of the low cost of production can cause these illnesses. Moreover, the possibility of producing toxic gases at the time of using the non-standard chemicals cannot be ignored. Due to the low quality of some of these materials, in warm weather and especially at the holes drilled in the stones which have long been exposed to sunlight, these chemicals are quickly enlarged, functioning almost as explosives do, which leads to throwing the stones. The Blasting method also has the least advantage because of toxic gas emissions resulting from the explosives decomposition and stone-throwing. The results of studying safety issues for each of the methods are presented in Table 4.

- Stone Blocks Quality

The product obtained from the Diamond Wire Sawing is so different from that of traditional methods that the transportation cost decreases, the production efficiency increases in stone factories, and the transportation and work bed are facilitated. Given the fact that the extracted block from the Diamond Wire Sawing method does not require an initial cutting, the final production cost decreases in this method. In other words, it could be stated that the higher the quality of the extracted block, the more its sale price will be. The extracted block in the Blasting method is of the least quality while the quality of the obtained block through expansive chemicals and the Feathers and Wedge method is in the middle of those of Diamond Wire Sawing and Blasting methods. The results of the examination of the quality in each method are presented in Table 4.

- Environmental Problems

Generally speaking, any mineral operation impacts at least one of the environmental elements such as water, soil, and weather. Given the environmental problems which are incurred by quarry mining methods, the points were allocated to any of the methods as shown in Table 4.

Table 4. Decision matrix

Alternative		Gross profit (+)	Stone quality (+)	Safety (+)	Time (-)	Environmental Problems (-)	Waste rock production (-)
Expansive agent	KATROCK	4084800	Low	Low	19	High	Medium
	FRACT	3618000	High	Medium	13	Medium	Low
Blasting		2287200	Low	Low	5	High	High
diamond wire sawing		3919200	Very High	High	4	Low	Very Low
Feathers and wedge		3868800	Low	High	5.5	Very Low	High

6. The Selection of the Quarry Mining Method Using the Hybrid AHP-ELECTRE Model

First, develop a hierarchy by the three major levels of the goal, the objectives, and the alternatives. The hierarchy for the selection of the quarry mining method selection is illustrated in Figure 1. Then, the decision-making matrix showing the options in terms of various factors must be formed. To this end, given the available quarry mining methods, five options of Feathers and Wedge, Diamond Wire Sawing, FRACT, and KATROCK expansive agents, as well as Blasting, were assessed in terms of six factors, i.e. the gross profit, quality, safety, time, waste rock amount and environmental effects for which the results are shown in Table 4.

In the next step, the qualitative criteria must be turned into quantitative ones. So, quality, safety, environmental effects, and waste rocks expressed qualitatively must be turned into quantitative amounts based on Table 5. The results of this are presented as the modified decision matrix in Table 6. Then, the matrix must become dimensionless using Eq. (10), being turned into numbers between zero and one. The normalized decision matrix (dimensionless) is presented in Table 7.

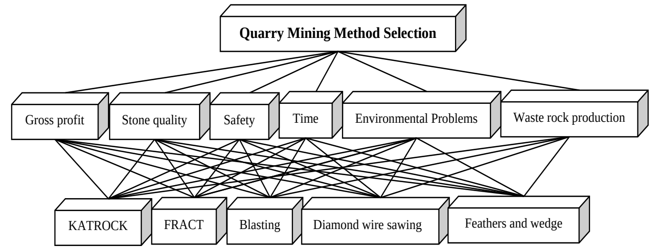

Figure 1. The hierarchical structure of the quarry mining method selection

Table 5. Linguistic variables for the ratings

Linguistic variables	Numeric variable	
	Positive criteria (+)	Negative criteria (-)
Very Low	1	9
Low	3	7
Medium	5	5
High	7	3
Very High	9	1

Table 6. Decision matrix expressed in numeric variable

Alternative		Gross profit (+)	Stone quality (+)	Safety (+)	Time (-)	Environmental Problems (-)	Waste rock production (-)
Expansive agent	KATROCK	4084800	3	3	19	3	5
	FRACT	3618000	7	5	13	5	7
Blasting		2287200	3	3	5	3	3
diamond wire sawing		3919200	9	7	4	7	9
Feathers and wedge		3868800	3	7	5.5	9	3

Table 7. Normalized decision matrix

Alternative		Gross profit (+)	Stone quality (+)	Safety (+)	Time (-)	Environmental Problems (-)	Waste rock production (-)
Expansive agent	KATROCK	0.49	0.24	0.25	0.77	0.22	0.38
	FRACT	0.48	0.56	0.42	0.53	0.38	0.53
Blasting		0.28	0.24	0.25	0.20	0.23	0.23
diamond wire sawing		0.48	0.72	0.59	0.16	0.53	0.68
Feathers and wedge		0.47	0.24	0.59	0.22	0.68	0.23

In the next step, given the fact that the ELECTRE method is not able to determine the weight or significance of the criteria, the AHP method is used to determine the significant coefficients of the criteria. To this end, the criteria are compared in pairs, and upon their comparison, the numerical points (paired comparison matrix) will be allocated based on the lingual variables presented in Table 1, the results of which by the paired comparison matrix are as shown in Table 8.

Table 8. Pairwise comparison matrix for quarry mining methods criteria

	Gross profit	Stone quality	Safety	Time	Environmental Problems	Waste rock production
Gross profit	1	3	7	5	9	3
Stone quality	1/3	1	5	3	7	2
Safety	1/7	1/5	1	1/2	2	1/3
Time	1/5	1/3	2	1	3	1/2
Environmental Problems	1/9	1/7	1/2	1/3	1	1/5
Waste rock production	1/3	1/2	3	2	5	1

After the formation of the paired comparison matrix, the relative weights of the criteria are calculated through the eigenvector method entitled the criterion weight matrix (W) as follows:

$$W=\begin{bmatrix} 0.44 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.24 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.05 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.09 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.03 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.15 \end{bmatrix}$$

Upon the determination of the criterion weight matrix, the normalized weighted decision matrix is obtained via Eq. (11) (Table 9).

Table 9. The normalized weighted decision matrix

Alternative		Gross profit (+)	Stone quality (+)	Safety (+)	Time (-)	Environmental Problems (-)	Waste rock production (-)
Expansive agent	KATROCK	0.217	0.058	0.013	0.070	0.007	0.057
	FRACT	0.211	0.134	0.021	0.048	0.011	0.080
Blasting		0.121	0.058	0.013	0.018	0.007	0.034
diamond wire sawing		0.212	0.172	0.029	0.015	0.016	0.103
Feathers and wedge		0.205	0.058	0.029	0.020	0.020	0.034

In order to specify the best option through the ELECTRE method, the set of concordance and discordance criteria are formed based on Eqs. (12) and (13). Then, using Relations 14 and 17, the concordance and discordance matrices (C and D matrices) are respectively determined. After that, using Eqs. (19) and (20), the concordance dominance matrix (F), and using Eqs. (21) and (22), the discordance dominance matrix (G) is determined, finally leading to the determination of the ultimate aggregate dominance matrix (H) based on Relation 23.

$$C=\begin{vmatrix} - & 0.62 & 0.76 & 0.62 & 0.71 \\ 0.38 & - & 0.73 & 0.62 & 0.71 \\ 0.56 & 0.27 & - & 0.18 & 0.51 \\ 0.38 & 0.82 & 0.82 & - & 0.85 \\ 0.53 & 0.29 & 0.88 & 0.20 & - \end{vmatrix}$$

$$D=\begin{vmatrix} - & 1 & 0.54 & 1 & 1 \\ 0.30 & - & 0.50 & 1 & 0.60 \\ 1 & 1 & - & 1 & 1 \\ 0.40 & 0.60 & 0.60 & - & 0.60 \\ 0.28 & 1 & 0.16 & 1 & - \end{vmatrix}$$

$$F=\begin{vmatrix} - & 1 & 1 & 1 & 1 \\ 0 & - & 1 & 1 & 1 \\ 0 & 0 & - & 0 & 0 \\ 0 & 1 & 1 & - & 1 \\ 0 & 0 & 1 & 0 & - \end{vmatrix}$$

$$G=\begin{vmatrix} - & 0 & 1 & 0 & 0 \\ 1 & - & 1 & 0 & 1 \\ 0 & 0 & - & 0 & 0 \\ 1 & 1 & 1 & - & 1 \\ 1 & 0 & 1 & 0 & - \end{vmatrix}$$

$$H=\begin{vmatrix} - & 0 & 1 & 0 & 0 \\ 0 & - & 1 & 0 & 1 \\ 0 & 0 & - & 0 & 0 \\ 0 & 1 & 1 & - & 1 \\ 0 & 0 & 1 & 0 & - \end{vmatrix}$$

In the end, Table 10 is obtained given the number of the dominated and non-dominated criteria determined by the ultimate aggregate dominance matrix. The criterion which is more dominated than peripheral is considered as preferred, and the rankings of them are shown in Table 10.

As shown in the prioritization of the options, the Diamond Wire Sawing is an appropriate method for Gazik granite quarry mine through the hybrid AHP-ELECTRE model.

Table 10. Selection of the best alternative

Alternative	Number of the dominated	Number of the non-dominated	Difference	Ranking
Expansive agent (KATROCK)	1	3	-2	Rank 3
Expansive agent (FRACT)	2	2	0	Rank 2
Blasting	0	4	-4	Rank 4
Diamond wire sawing	3	1	2	Rank 1
Feathers and wedge	1	3	-2	Rank 3

7. Conclusion

The selection of an appropriate quarry mining method is of prominent significance. In this regard, considering the complexities existing in the geometric and geological features of mineral resources, one mining method cannot be prescribed for all types of mineral resources. So, given such complexities, any resource demands its appropriate mining method. This is not an exception for quarries too so that the selection of an appropriate quarry mining method can increase the efficiency and national gross production. There are numerous methods for quarry mining, but since each method has its own pros and cons, finding the ideal method requires a close examination of the involved factors. Although many quarry mining methods have been introduced, most of them have defects, lacking a comprehensive model of mining. Of such defects, the lack of involving important criteria in the selection of quarry mining methods, the lack of considering all the available methods, and the significant coefficients of the criteria could be named. Therefore, to overcome the defects, hybrid multi-criteria decision-making can be used to select the appropriate quarry mining method. This paper made use of the hybrid AHP-ELECTRE model in order to select the quarry mining method, which led to the selection of the Diamond Wire Sawing is the best option. The results reveal that mining using the Diamond Wire Sawing, contrary to miners' belief (of its having costs of personnel, used energy, and materials) is the optimum method.

REFERENCES

[1] Boshkov, S. H., & Wright, F. D. (1973). Basic and parametric criteria in the selection, design and development of underground mining systems. SME mining engineering handbook, 1, 12-2.

[2] Morrison, R. G. K. (1976). A philosophy of ground control: a bridge between theory and practice. Department of Mining and Metallurgical Engineering, McGill University.

[3] Laubscher, D. H. (1977). Geomechanics classification of jointed rock masses-mining applications. Trans. Instn. Min. Metall, 86, A1-8.

[4] Laubscher, D. H. (1981). Selection of mass underground mining methods. Design and operation of caving and sublevel stoping mines, 23-38.

[5] Nicholas, D. E. (1981). Method selection-a numerical approach. Design and operation of caving and sublevel stoping mines, 39-53.

[6] Tymshore, I. (1981). Computer evaluation of mining projects. Mining Journal, 2(111).

[7] Hamrin, H. (1982). Choosing an underground mining method. Underground mining methods handbook, 88-112.

[8] Brady, B. H. G., & Brown, E. T. (1985). Rock Mechanics for Underground Mining. George Allen & Unwin–London.

[9] Yun, Q. X., & Huang, G. Q. (1987). A fuzzy set approach to the selection of mining method. Mining Science and Technology, 6(1), 9-16.

[10] Laubscher, D. M., & Page, C. H. (1990). The design of rock support in high stress or weak rock environments. Proc. 92nd Can. Inst. Min. Metall. AGM.

[11] Hartman, H. L. (1992). SME Mining Engineering Handbook (Volume 2, Chapter 23.4). Selection Procedure, New York, AIME, 2090-2106.

[12] Nicholas, D. E. (1992). Selection method. SME Mining Engineering Handbook, 2090-2106.

[13] Adler, L., & Thompson, S. D. (2011). Mining methods classification system. SME Mining engineering handbook, 349-355.

[14] Kahriman, A., Ceylanoğlu, A., Demirci, A., Arpaz, E., & Görgülü, K. (1994). Selection of optimum underground mining method for Kayseri Pinarbasi-Pulpinar chromite ore. Bulletin of Chamber of Mining Engineers of Turke, 25(4), 27-41.

[15] Demirci, A., Ceylanoglu, A., & Kahriman, A. (1995). Determined of Optimum Underground Mining Method at Aegean Metal Eskisehir Chrome Enterprise and Projected Studies, Final Report. Cumhuriyet University, Sivas, Turkey.

[16] Miller-Tait, L., Pakalnis, R., & Poulin, R. (1995). University of British Columbia. Vancouver, BC, Canada: UBC mining method selection, Mine Planning and Equipment Selection.

[17] Clayton, C., Pakalnis, R. & Meech, J. (2002). A knowledge-based system for selecting a mining method, IPPM Conference, Canada, 161-178.

[18] Guray, C., Celebi, N. E., Atalay, V., & Pasamehmetoglu, A. G. (2003). Ore-age: a hybrid system for assisting and teaching mining method selection. Expert Systems with Applications, 24(3), 261-271.

[19] Bitarafan, M. R., & Ataei, 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.

[20] Shahriar, K., Shariati, V., & Namin, F. S. (2007, January). Geomechanical characteristics study of deposit in underground mining method selection process. In 11th ISRM Congress. International Society for Rock Mechanics and Rock Engineering.

[21] Yavuz, M., & Alpay, S. (2008). Underground mining technique selection by multicriterion optimization methods. Journal of Mining Science, 44(4), 391-401.

[22] Samimi Namin, F., Shahriar, K., Ataee-Pour, M., & Dehghani, H. (2008). A new model for mining method selection of mineral deposit based on fuzzy decision making. Journal of the Southern African Institute of Mining and Metallurgy, 108(7), 385-395.

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

[24] Naghadehi, M. Z., Mikaeil, R., & 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.

[25] Bakhtavar, E., Shahriar, K., & Oraee, K. (2009). Mining method selection and optimization of transition from open pit to underground in combined mining. Journal of Archives of Mining Sciences, 54(3), 481-493.

[26] Azadeh, A., Osanloo, M., & Ataei, M. (2010). A new approach to mining method selection based on modifying the Nicholas technique. Applied Soft Computing, 10(4), 1040-1061.

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

[28] Bogdanovic, D., Nikolic, D., & Ilic, I. (2012). Mining method selection by integrated AHP and PROMETHEE method. Anais da Academia Brasileira de Ciências, 84(1), 219-233.

[29] Ataei, M., Shahsavany, H., & Mikaeil, R. (2013). Monte Carlo Analytic Hierarchy Process (MAHP) approach to selection of optimum mining method. International Journal of Mining Science and Technology, 23(4), 573-578.

[30] Peskens, T. W. (2013). Underground mining method selection and preliminary techno-economic mine design for the Wombat orebody, Kylylahti deposit, Finland (Doctoral dissertation, Delft University of Technology).

[31] Shariati, S., Yazdani-Chamzini, A., & Pourghaffari Bashari, B. (2013). Mining method selection by using an integrated model. International Research Journal of Applied and Basic Sciences, 6(2), 199-214.

[32] Rahimi Ghazikalayeh, A., Ebrahimabadi, A., & Alavi, I. (2014). Selecting Proper Mining Method Using Fuzzy AHP Approach (Case study: Qaleh-Zari Copper Mine of Iran). Journal of Applied Science and Agriculture, 9(1), 1-10.

[33] Ozfirat, P. M., Ozfirat, M. K., Malli, T., & Kahraman, B. (2015). Integration of fuzzy analytic hierarchy process and multi-objective fuzzy goal programming for selection problems: An application on roadheader selection. Journal of Intelligent & Fuzzy Systems, 29(1), 53-62.

[34] Karimnia, H., & Bagloo, H. (2015). Optimum mining method selection using fuzzy analytical hierarchy process–Qapiliq salt mine, Iran. International Journal of Mining Science and Technology, 25(2), 225-230.

[35] Njamba, N. M., & Mutambo, V. (2016). Design an Appropriate Mining Method for Extraction of Ore between 330ml and 400ml at Baluba East Upper T-Block. International Journal of Mining Engineering and Mineral Processing, 5(1), 16-23.

[36] Dehghani, H., Siami, A. and Haghi, P., A new model for mining method selection based on grey and TODIM methods, J. Min. & Environment, 2017, vol. 8, no. 1, pp. 49-60.

[37] Javanshirgiv, M., & Safari, M. (2017). The selection of an underground mining method using the Fuzzy TOPSIS method: a case study in the Kamar Mahdi II fluorine mine. Mining Science, 24, 161-181.

[38] Balusa, B. C., & Singam, J. (2018). Underground mining method selection using WPM and PROMETHEE. Journal of the Institution of Engineers (India): Series D, 99(1), 165-171.

[39] Kabwe, E. (2017). Optimal mining method selection for Nchanga's Upper Orebody using analytic hierarchy process and Yager's method. Mining Technology, 126(3), 151-162.

[40] Aryafar, A., Mikaeil, R., & Ataei, M. (2010). Selection of an appropriate method to extract the structural stones using TOPSIS multi-criteria method. Journal of Applied Geology, 6(3).

[41] Javanshirgiv, M., Moghadder, M. T., & Safari, M. (2017). The

selection of appropriate mining method for the Deh Gheybi Granite Quarry Mine using the FTOPSIS method. International Journal of Mining and Mineral Engineering, 8(2), 113-130.

[42] Esmailzadeh, A., Mikaeil, R., Sadegheslam, G., Aryafar, A., Hosseinzadeh Gharehgheshlagh, H. (2018). Selection of an Appropriate Method to Extract the Dimensional Stones Using FDAHP & TOPSIS Techniques. Journal of Soft Computing in Civil Engineering, 2(1), 101-116.

[43] Saaty, T.L. (1980). The analytic hierarchy process: planning, priority setting and resource allocation, McGraw-Hill, New York.

[44] Akcan, S., and Güldeş, M. (2019). Integrated multicriteria decision-making methods to solve supplier selection problem: a case study in a hospital. Journal of healthcare engineering, 2019, 1-10

[45] Despodov, Z., Mitić, S., & Peltečki, D. (2011). Application of the AHP method for selection of a transportation system in mine planning. Podzemni radovi, (19), 93-99.

[46] Emrouznejad, A., & Marra, M. (2017). The state of the art development of AHP (1979–2017): a literature review with a social network analysis. International Journal of Production Research, 55(22), 6653-6675.

[47] Karahalios, H., Yang, Z. L., Williams, V., & Wang, J. (2011). A proposed System of Hierarchical Scorecards to assess the implementation of maritime regulations. Safety Science, 49(3), 450-462.

[48] Lee, A. H., Chen, W. C., & Chang, C. J. (2008). A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan. Expert systems with applications, 34(1), 96-107.

[49] Safari, M., Ataei, M., Khalokakaie, R., & KARAMOZIAN, M. (2010). Mineral processing plant location using the analytic hierarchy process—a case study: the Sangan iron ore mine (phase 1). Mining Science and Technology (China), 20(5), 691-695.

[50] Banayoun, R., Roy, B., & Sussman, N. (1966). Manual de Reference du Programme Electre, Note de Synthese et Formation 25. Direction Scientifique SEMA.

[51] Roy, B. (1968). Classement et choix en présence de points de vue multiples. Revue française d'informatique et de recherche opérationnelle, 2(8), 57-75.

[52] Wang, X., & Triantaphyllou, E. (2008). Ranking irregularities when evaluating alternatives by using some ELECTRE methods. Omega, 36(1), 45-63.

[53] Aiello, G. I. U. S. E. P. P. E., Enea, M., & Galante, G. (2006). A multi-objective approach to facility layout problem by genetic search algorithm and Electre method. Robotics and Computer-Integrated Manufacturing, 22(5-6), 447-455.

[54] Wu, Z., & Abdul-Nour, G. (2020). Comparison of Multi-Criteria Group Decision-Making Methods for Urban Sewer Network Plan Selection. CivilEng, 1(1), 26-48.

[55] Vincke, P. (1992). Multicriteria decision-aid. John Wiley & Sons. New York.

[56] Belton, V., & Stewart, T. (2002). Multiple criteria decision analysis: an integrated approach. Springer Science & Business Media.

[57] de Almeida, A. T. (2007). Multicriteria decision model for outsourcing contracts selection based on utility function and ELECTRE method. Computers & operations research, 34(12), 3569-3574.

[58] Naumann, F. (2003). Quality-driven query answering for integrated information systems (Vol. 2261). Springer.

[59] Cho, K. T. (2003). Multicriteria decision methods: an attempt to evaluate and unify. Mathematical and computer modelling, 37(9-10), 1099-1119.

[60] Chatterjee, P., Athawale, V. M., & Chakraborty, S. (2009). Selection of materials using compromise ranking and outranking methods. Materials & Design, 30(10), 4043-4053.

[61] Wu, M. C., & Chen, T. Y. (2009, August). The ELECTRE multicriteria analysis approach based on intuitionistic fuzzy sets. In 2009 IEEE International Conference on Fuzzy Systems (pp. 1383-1388). IEEE.

[62] Hartati, S., Wardoyo, R., Harjoko, A., Palembang-prabumulih, J., & Ilir, O. (2011). Electre methods in solving group decision support system bioinformatics on gene mutation detection simulation.

[63] Chatterjee, P., Mondal, S., & Chakraborty, S. (2014). A comprehensive solution to automated inspection device selection problems using Electre methods. International Journal of Technology, 2, 193-208.

[64] Fitriadi, R. (2006). Pendekatan Compromise Programming dengan memperhitungkan Faktor lingkungan (Studi Kasus Industri Otomotif PT. XX" Jawa Tengah)", Jurnal Ilmiah Teknik Industri, 5(2), 72-81.