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Selection of an Appropriate Method to Extract the Dimensional Stones Using FDAHP & TOPSIS Techniques

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ABSTRACT

In this paper, it was aimed to select a suitable method to extract the dimensional stone to increase dimensional stone quarries efficiency. The usual methods including diamond cutting-wire method, blasting method, plug, and feather method, Katrock expanding material and Fract expanding material have compared using TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) method by respecting to the following criteria: grass income, safety, desirability, reduction of environmental impacts, waste and reduction of extracting time. FDAHP (Fuzzy Delphi Analytic Hierarchy Process) approach was used in determining the degree of importance of the criteria by expert decision makers. Also, those criteria performed the same impacts were not considered. Consequently, the diamond wire saw method was suggested as the most appropriate method to extract the dimensional stones. It was concluded that the extraction of dimensional stone using diamond wire saw is the best method based on the mentioned criterion compared to other methods.

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1. Introduction

From the time humankind was thinking about a strong building, quarrying has been started. Hence it could be inferred that the quarry has a history of many thousand years. Iran is a mineral-rich country with high potential in stone quarries. Therefore mining has an important role in the economic growth of the country. Studies show that Iran is the second country of the world for having stone quarries and the first for colorful and variant stones. Recently, some good industrial and laboratory tests in the field of the ability of dimensional stone cutting have been done in the country. Mikaeil et al. developed a statistical model to predict the production rate of diamond wire saws in carbonate rocks cutting [1]. Mikaiel et al. studied the vibration of a circular diamond saw machine during rock sawing by using a fuzzy analytical hierarchy process [2]. Mikaeil et al. developed a new classification system for assessing of carbonate rock sawability [3]. Ataei et al. predicted the production rate of diamond wire saw using statistical analysis [4]. Mikaeil et al. studied the relationship between the production rate of dimensional stone with rock brittleness indexes [5]. Mikaeil et al. investigated the sawability of carbonate rock using fuzzy analytical hierarchy process and technique for order performance by similarity to the ideal solution [6]. Mikaeil et al. estimated the power consumption of circular diamond saw in carbonate rock sawing process by using fuzzy Delphi analytical hierarchy process and technique for order performance by similarity to the ideal solution [7]. Mikaeil et al. studied the relationship between specific ampere draw and rock brittleness indexes in rock sawing process [8]. Ataei et al. studied on ranking the sawability of carbonate rock by using fuzzy analytical hierarchy process approach [9]. Ghaysari et al. predicted the performance of diamond wire saw with respect to texture characteristic of carbonate rock [10]. Mikaeil et al. ranked the sawability of some Iranian famous dimensional stones using fuzzy Delphi and multi-criteria decision-making techniques [11]. Sadegheslam et al. predicted the production rate of diamond wire saw using multiple nonlinear regression analysis and neural network [12]. Mikaeil et al. investigated the relationship between system vibration of cutting machine and rock brittleness indexes during the dimensional stone sawing process [13]. Mikaeil et al. developed a ranking model for ranking the sawability of dimensional stone based on some important mechanical and physical properties [14]. Mikaeil et al. investigated the effect of freezing on strength and durability of dimensional stones using fuzzy clustering technique and statistical analysis [15]. Aryafar and Mikaeil estimated the ampere consumption of dimensional stone sawing machine using the artificial neural networks [16]. Mikaeil et al. predicted the performance of circular saw machine using an imperialist competitive algorithm and fuzzy clustering technique [17]. Mikaeil et al. evaluated the performance of diamond wire saw by using harmony search algorithm [18]. Almasi et al. developed a new rock classification system based on the abrasiveness, hardness, and toughness of rocks and PA to predict the sawability of hard dimensional stone [19]. Almasi et al. investigated the prediction of the dimensional stone cutting rate based on rock properties and device pullback amperage in quarries using M5P model tree [20]. Almasi et al. studied the bead wear in diamond wire sawing based on some important mechanical and physical properties [21]. Akhyani et al. predicted the wear performance of circular diamond saw by combining fuzzy rock engineering system and genetic algorithm in hard rock cutting process [22]. Mikaeil et al. studied on the performance of diamond wire saw by using multivariate regression analysis [23].

There are few studies in the field of selection of dimensional stone extraction methods. There are various methods for extraction of dimension stones, but the most common technique in the vast majority of Iran`s quarries are plug and feather, diamond wire saw, blasting (low density) and expanding chemicals (FRACT and Katrock). All methods have advantages and disadvantages compared with each other, so without a multi-criteria method investigation, it could not be decided which of the methods is more effective. In order to choose the appropriate method, a set of factors including gross profit, desirability, safety, etc., should be considered. In this article, after introducing each method and consideration of effective factors, the best extraction method due to the Technique for Order of Preference by Similarity to Ideal Solution Method (TOPSIS) is proposed.

2. Ordinary methods in quarrying

There are different methods in order to extract a dimensional stone cube. However, the most common methods in the vast majority of Iran`s quarries are plug and feather, diamond wire saw, blasting and expanding chemicals (FRACT and Katrock). Plug and feather is the oldest method of extraction. In this method, some holes are dug on a line which is supposed to be cut. The diameter, depth and the amount of holes, depends on the stones' type. The block is cut more easily if the distance between holes is decreased and the depth is increased. After boring holes, metal plugs and a metal feathers are put into the hole, and then the feather is hit by a sledgehammer until the cube is cut due to the expansion of fractures. In the blasting method, at first, some horizontal and vertical holes are bored and then blasting process is used to cut the block. The main difference between explosive methods used in quarry and mining is that in the quarry, the cube must crack and loosen in the desired direction and not to destroy other blocks. One of the methods that are getting increasingly popular in Iran is expanding powder. This material is used instead of blasting in quarries with a great increase of usage day after day. The mechanism of this method is more similar to the plug and feather method rather than the explosive material method such as gunpowder, dynamite, and ANFO. In order to use the materials, parallel holes must be bored, and then a mixture of this powder and water should be applied to the holes. After a while due to hydration and watering, the slurry will expand, and this expansion will cause detaching of the cube. In 1978 the first diamond wire saw machine was applied in Carrara Mine. Until now the method advanced rapidly both in equipment and wires. In this method, the diamond wire saw is looped around the cutting part and is cooled by water during the process. By applying the diamond wire saw through perpendicular holes, a loop is shaped. During the cutting process, the machine gets far from working face and by moving on rails while the wire is in tension.

3. Effective factors in quarrying method selection

Factors including gross profit, desirability, safety, time, environmental parameters and waste affect choosing quarry method. These factors could be divided into quantitative and qualitative groups. Some of these factors have negative effects on choosing a method, and some have positive. For example, the environmental effect is a negative and safety is a positive factor in choosing a method. Table 1 shows the quantitative and qualitative factors due to their negative and positive effects.

Table 1
Effective factors in quarrying method selection due to their roles.

parameters	Environmental parameters	Goodness	Safety	Waste	Time	Gross Profit
Parameter specifications	Qualitative	Qualitative	Qualitative	Qualitative	Quantitative	Quantitative
	Negative	Positive	Positive	negative	negative	Positive

Consider a block with a meter in its dimensions and 3 degrees of freedom. To extract this block with each method such as a diamond wire saw, plug and feather, blasting and expanding chemicals FRACT and Katrock, extraction cost and income due to block`s price is shown in the table below. The costs in table 2 are according to costs in some working mines in Iran [24,25].

Table 2
Gross Profit of different quarrying methods due to selling a cubed meter of dimension rock.

Cost (Toman per a cubed meter)	Plug and feather	Diamond cutting wire	Blasting	Expanding Materials	
				Fract	Katrock
Drilling cost	5000	3000	5000	35000	5000
Used material cost	10000	-	40000	21500	12000
Cutting Cost	-	30000	-	-	-
Machines Cost	800	400	800	500	800
Excess Waste transportation cost	1800	-	3600	1500	1800
Cost Total	17600	33400	49400	27000	19600
Sales Price	340000	360000	240000	360000	360000
Gross Profit	322400	333000	190600	333000	340400

Again consider a block with a meter in its dimensions and 3 degrees of freedom. In the methods include drilling parallel holes, as an average spacing, there is a hole in every 10 cm, and hence in each non-free dimension of the block, there are ten holes that considering 10 m depth of each hole, about 30 m overall drillings are needed. Assume each meter takes 5 min, the total drilling time is 150 min. Usually, it takes 30 min to fill the holes with expanding chemicals and the operation time for Katrock is about 16 hours and for FRACT is 10 hours. Finally, the approximate time to produce a cube with one m^3 volume for two methods is about 19 and 13 hours, respectively. In diamond wire saw method, boring three holes every 1 meter takes 15 min and consuming time to apply wire is 30 min. According to the average time of cutting of a cube with one m^3 volume, the total time to quarry a block is 4 hours. Of course, it should be mentioned that time-consuming to produce the block in each method differs from mine to mine due to geo-mechanical properties of the rock. In plug and feather and explosive methods, like the same as in parallel holes method, 30 holes in 3 non-free dimensions of the rock must be bored which due to the time needed for boring each hole, 150 min is needed totally for extraction. Also, 3 hours needed for breaking the block, therefore 5.5 hours needed for extraction of a cube with one m^3 volume. For filling the holes with explosives, each hole would take 5 min which in total comes to 2.5 hours for 30 holes. Therefore 5 hours needed to excavate a cube with one m^3 volume using the blasting method. Table 3 shows the time consumption of each method.

Table 3
Necessary time for quarrying using different methods.

Time(Hours)	Plug and feather	Diamond cutting wire	Blasting	Expanding materials	
				Fract	Katrock
	5.5	4	5	13	19

If the mineral resources are regarded as national wealth, therefore wasting of them during extraction should be considered as quarry method disadvantages, then the number of wastes could be considered as an important factor in choosing a method. Fissures created by explosive and plug and feather methods during extraction is considered as one of the ways which lead to producing waste when causing the dimension stone to break during the cutting process. Due to quarry mechanism, waste producing in diamond wire saw and expanding chemicals methods is less than other traditional methods. This is a qualitative factor according to the quality of production. The results of waste produced in each method are given in table 4.

Table 4
Qualitative comparison of the produced waste form of a cubic meter quarrying for different methods.

Waste	Plug and feather	Diamond Cutting Wire	Blasting	Expanding Materials	
				Fract	Katrock
	High	Seldom	High	Low	Middle

Lung diseases and eyesore are a frequent health problem among workers which work with expanding powders. Although there is no evidence to prove the relationship between these health problems and expanding powders, use of low quality and harmful ingredients in expanding powder produce which leads to low production price could be a possible effective factor. Also, the possibility of producing harmful gas when using these nonstandard powders could not be neglected. Because of the low quality of some of these materials, during usage especially in hot weather, they expand immediately after using and act like blasting. The blasting method has the least score in this case due to the production of hazardous gases and uncontrolled rock fracturing. Safety of each method is shown in table 5.

Table 5
Qualitative comparison of the safety of different methods.

Safety	Plug and feather	Diamond Cutting Wire	Blasting	Expanding materials	
				Fract	Katrock
	High	High	Low	Middle	Low

Diamond wire saw`s cubs have a major difference in quality compared with other methods produced cubs. This methods cube quality leads to a reduction of transportation costs, increasing production efficiency, facility in movement and improvement of working face. Because blocks extracted by a diamond wire saw do not need pre-cutting, therefore the final cost reduces in this method. In other words, the more quality of extracted blocks leads to more profit in markets. The quality of extracted blocks in the blasting method, plug and feather and expanding chemicals, and diamond wire saw are weak, intermediate and high respectively. Table 6 shows the cubs quality of each method.

Table 6
Qualitative comparison of different Quarrying Method Goodness.

Goodness	Plug and feather	Diamond Cutting Wire	Blasting	Expanding materials	
				Fract	Katrock
	Low	Very high	Low	high	Low

Generally, mining activities will affect at least one of the environment components like water, soil, and weather. According to environmental problems which each method produce, qualitative scores are given for each method that is shown in Table 7.

Table 7
Environmental Parameters Qualitative Comparison of different Quarrying Method

Safety	Plug and feather	Diamond Cutting Wire	Blasting	Expanding materials	
				Fract	Katrock
	High	High	Low	Middle	Low

4. Selection a suitable extraction method using FDAHP & TOPSIS techniques

The TOPSIS method was first presented by Yoon and Hwang [26,27]. Recently for multiple-criteria decisions, this method along with other methods such as AHP, FAHP, genetic algorithm and so on or alone have been used [27–37]. In this method, alternatives are categorized by their similarity to the ideal solution. Therefore, when an alternative is more similar to the ideal solution, has a higher rank. To define this method, two concepts of “ideal solution” and “similarity to ideal solution” has been used. The ideal solution is the solution that is the best in every aspect which generally doesn’t exist, and we try to get near to it. In order to determine the similarity of a method to ideal and negative ideal solution, its distance from ideal and negative ideal solution is measured, and alternatives are analyzed and categorized by relative distance from negative ideal solution to the sum of the distance from ideal and negative ideal solutions. If in a multiple-criteria decisions problem, consisting of m alternatives and n criteria, in order to choose the best alternative using similarity to ideal solution method, steps are as following [28].

According to the number of cases and criteria and analyzing of all cases for different criteria, a decision matrix is constructed as Equation 1.

$$D=\begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \cdots & \cdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \tag{1}$$

Where X_{ij} is the operator of i alternative (i=1, 2, ..., m) to j criteria (j=1, 2 …, n).

According to existing methods for quarry of dimensional stones in Iran, five methods including plug and feather, diamond wire saw, expanding chemicals FRACT and Kat-rock and blasting as alternatives and factors including production cost, desirability, safety, time, ease of extraction, waste and environmental effects as problem criteria have been investigated. Qualitative and quantitative values for each factor and method (decision matrix) are shown in Table 8.

Table 8
Decision matrix.

Criteria	waste	Environmental effects	Time	Safety	Goodness	Gross Profit
Expanding Material (Katrock)	Average	High	19	Low	Low	340400
Expanding Material (Fract)	Low	Average	13	Average	High	333000
Blasting	High	High	5	Low	Low	190600
Diamond Cutting Wire	Very Low	Low	4	High	Very High	333000
Plug and feather	High	Very Low	5.5	High	Low	322400

Because considered criteria (production cost, desirability, safety, time, ease of extraction, waste and environmental effects) have quantitative and qualitative values, hence before making decision matrix, it is necessary to convert qualitative values in to quantitative (Table 8). To do so, table 9 can be used so that for qualitative values of very little to very much, equivalent quantitative values of 1 to 9 could be replaced. Table 10 shows the revised decision matrix (according to quantitative values).

Table 9
Quantitating of qualitative parameters.

Qualitative Parameters	Very High	high	Average	Low	Very Low
Equivalent quantitative Value	9	7	5	3	1

Table 10
Decision Matrix due to their quantitative value.

Criteria	Waste	Environmental effects	Time	Safety	Goodness	Gross Profit
Expanding Material (Katrock)	5	7	19	3	3	340400
Expanding Material (Fract)	3	5	13	5	7	333000
Blasting	7	7	5	3	3	190600
Diamond Cutting Wire	1	3	4	7	9	333000
Plug and feather	7	1	5.5	7	3	322400

In the next step, various criteria with different dimensions are changed to dimensionless criteria and matrix R define as Equation 2.

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \cdots & \cdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \quad (2)$$

There are different methods to dimensionless, but for similarity to ideal solution method, the Equation 3 is used:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (3)$$

To normalize the decision matrix, Equation 3 could be used. The normalized matrix is shown in table 11.

Table 11
Normalized Decision Matrix.

Criteria	waste	Environmental effects	Time	Safety	Goodness	Gross Profit
Expanding Material (Katrock)	0.434	0.607	0.775	0.253	0.239	0.492
Expanding Material (Fract)	0.260	0.434	0.530	0.421	0.559	0.482
Blasting	0.607	0.607	0.204	0.253	0.239	0.276
Diamond Cutting Wire	0.087	0.260	0.163	0.589	0.718	0.482
Plug and feather	0.606977	0.087	0.224303	0.589506	0.239	0.466356

In this stage according to importance factor of different criteria in the decision, we have a matrix as Equation 4.

$$W = \begin{bmatrix} w_1 & & 0 \\ \vdots & w_2 \cdots & \cdots \\ 0 & \cdots & w_n \end{bmatrix} \quad (4)$$

It is clear that W is a diametric matrix which elements on the diameter are non-zero and equal to related importance vector factor.

The most important part of the decision-making process in order to perform comprehensive analysis and classification of a problem with a number of criteria is to distinguish each criteria’s weight and their effect on that problem. Because executive decisions always made on some multi and relational criteria, each criterion`s effect lead to some difficulties in making a decision. Therefore, defining the weight of each criterion is always the most important step. Two of the most recent methods for weighting effective criteria in a making decision problem are simple weighting method and hierarchy analyzes method. Existing methods are depended on personal experience and observation. Therefore, the possibility of making mistakes and choosing the wrong answer is high. To overcome this problem and use a vast opinion and experience of other researchers, new method like Delphi Fuzzy Hierarchy Analyze Method is introduced. This method is applicably, and effectiveness rather than to the classic methods increase by using others. In this research using this method, we tried to analyze and investigate the weight of criteria for choosing optimum dimension stone quarry method, according to the researcher's comments. In order to use other`s opinions for weighting criteria, a survey was conducted with university professors and investors around the country. Table 12 shows the survey. In this survey, we ask professionals to score each factor`s effectiveness, based on their personal views (Table 13).

Table 12
A Sample of sent Polls forms to experts.

Importance of parameters ➔ **Quarrying method selection criteria**	Very Important	important	Average Importance	Less Importance	Insignificant
Gross Profit	×				
Time			×		
Waste				×	
Safety				×	
Goodness		×			
Environmental Parameters				×	

Table 13
Numerical rate allocation of paired comparison [38].

Relative comparison of criteria	Numerical rates
Absolute importance	9
Very strong importance	7
Strong importance	5
Weak importance	3
Same importance	1
Preferences of intervals	2, 4, 6, 8

According to the survey, the corresponding comparison even matrix based on each professional`s point of view is made. Table 14 shows some of these matrixes.

Table14
Paired comparison matrix.

Criteria	Waste	Environmental Parameters	Time	Safety	Goodness	Gross Profit
Gross Profit	5	5	3	5	2	1
Goodness	3	3	2	3	1	1.2
Safety	1	1	1.2	1	1.3	1.5
Time	2	2	1	2	1.2	1.3
Environmental Parameters	1	1	1.2	1	1.3	1.5
Waste	1	1	1.2	1	1.3	1.5

After doing the survey and forming comparison even matrix, the results were used to form a fuzzy comparison even matrix. To form this matrix, fuzzy Delphi-analytical hierarchy process method (FDAHP), triangular membership function and therefore fuzzy triangular numbers have been used. Calculations are consisted of:

To calculate fuzzy numbers ($\tilde{a}_{ij}$), opinions from the survey have been used directly. In this research fuzzy numbers are calculated based on the triangular membership function (Figure 1). Based on Figure 1, in fuzzy Delphi method, a fuzzy number is calculated by equations 5 to 8 [39].

$$a_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij}) \tag{5}$$

$$\alpha_{ij} = Min(\beta_{ijk}), k = 1,...,n \tag{6}$$

$$\delta_{ij} = \left(\prod_{k=1}^{n} \beta_{ijk}\right)^{1/n}, k = 1,...,n \tag{7}$$

$$\gamma_{ij} = Max(\beta_{ijk}), k = 1,...,n \tag{8}$$

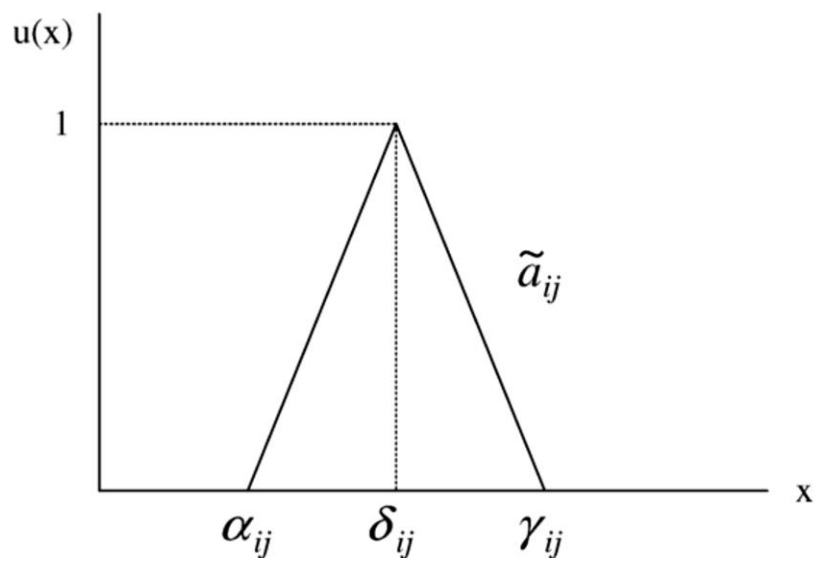

Fig 1. Triangle Membership function in Fuzzy – Delphi Method [19].

In above relations γij and αij are upper and lower limit of referees' ideas, respectively. Also, it is the relative importance of i parameter to j in the opinion of k professional.

In this stage, using fuzzy numbers and Equation 9, fuzzy comparison even matrix is formed [39].

$$\tilde{A} = [\tilde{a}_{ij}], \tilde{a}_{ij} \times \tilde{a}_{ij} \approx 1, \forall i, j = 1,2,...,n \tag{9}$$

Alternatively, in the form of:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (\alpha_{12},\delta_{12},\gamma_{12}) & (\alpha_{13},\delta_{13},\gamma_{13}) \\ (1/\gamma_{12}, 1/\delta_{12}, 1/\alpha_{12}) & (1,1,1) & (\alpha_{23},\delta_{23},\gamma_{23}) \\ (1/\gamma_{13}, 1/\delta_{13}, 1/\alpha_{13}) & (1/\gamma_{23}, 1/\delta_{23}, 1/\alpha_{23}) & (1,1,1) \end{bmatrix} \quad (10)$$

The fuzzy comparison even matrix for this problem is shown in table 15. In this matrix, Ci is as each criterion which is compared with each other according to corresponding fuzzy numbers.

Table 15
Paired Fuzzy Comparison Matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	(1, 1, 1)	(1, 3.11, 5)	(1, 2.27, 5)	(2, 3.29, 5)	(0.5, 1.08, 2)	(2.4, 15, 9)
C_2	(0.2, 0.32, 1)	(1, 1, 1)	(0.33, 0.69, 2)	(0.33, 1.13, 3)	(0.2, 0.36, 0.5)	(0.33, 1.69, 7)
C_3	(0.2, 0.44, 1)	(0.5, 1.44, 3)	(1, 1, 1)	(1, 1.6, 3)	(0.2, 0.49, 1)	(0.5, 1.87, 7)
C_4	(0.2, 0.3, 0.5)	(0.33, 0.89, 3)	(0.33, 0.62, 1)	(1, 1, 1)	(0.2, 0.33, 1)	(0.33, 1.28, 3)
C_5	(0.5, 0.93, 2)	(2, 2.8, 5)	(1, 2.01, 5)	(1, 3.01, 5)	(1, 1, 1)	(1, 3.79, 9)
C_6	(0.11, 0.24, 0.5)	(0.14, 0.59, 3)	(0.14, 0.53, 2)	(0.33, 0.78, 3)	(0.11, 0.26, 1)	(1, 1, 1)

Now each criterion`s fuzzy weight could be calculated, using equations 11 and 12 [39].

$$\tilde{Z}i = \left[\tilde{a}_{ij} \otimes \ldots \otimes \tilde{a}_{in}\right]^{1/n} \quad (11)$$

$$\tilde{W}i = \tilde{Z}i \otimes (\tilde{Z}i \oplus \ldots \oplus \tilde{Z}n) \quad (12)$$

In equations 11 and 12, $\otimes$ and $\oplus$ are signs for fuzzy numbers` multiplication and summation respectively. Finally, which is a row vector defines the fuzzy weight of i parameter.

$$\tilde{Z}_1 = \left[\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \ldots \tilde{a}_{112}\right]^{1/12} = [1.12, 2.17, 3.62]$$

$$\tilde{Z}_2 = \left[\tilde{a}_{21} \otimes \tilde{a}_{22} \otimes \ldots \tilde{a}_{212}\right]^{1/12} = [0.34, 0.73, 1.66]$$

$$\tilde{Z}_3 = \left[\tilde{a}_{31} \otimes \tilde{a}_{32} \otimes \ldots \tilde{a}_{312}\right]^{1/12} = [0.46, 0.99, 1.99]$$

$$\tilde{Z}_4 = \left[\tilde{a}_{41} \otimes \tilde{a}_{42} \otimes \ldots \tilde{a}_{412}\right]^{1/12} = [0.34, 0.64, 1.29]$$

$$\tilde{Z}_5 = \left[\tilde{a}_{51} \otimes \tilde{a}_{52} \otimes \ldots \tilde{a}_{512}\right]^{1/12} = [1, 1.98, 1.62]$$

$$\tilde{Z}_6 = \left[\tilde{a}_{61} \otimes \tilde{a}_{62} \otimes \ldots \tilde{a}_{612}\right]^{1/12} = [0.21, 0.5, 1.44]$$

$$\sum \tilde{Z}_i = [3.47, 7.1, 13.62]$$

$$\tilde{W}_1 = \tilde{Z}_1 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [3.89, 15.2, 49.3]$$

$$\tilde{W}_2 = \tilde{Z}_2 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [1.17, 5.12, 22.62]$$

$$\tilde{W}_3 = \tilde{Z}_3 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}\ )^{-1} = [1.61, 6.95, 27.17]$$

$$\tilde{W}_4 = \tilde{Z}_4 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [1.17, 4.51, 17.5]$$

$$\tilde{W}_5 = \tilde{Z}_5 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [3.47, 13.86, 49.3]$$

$$\tilde{W}_6 = \tilde{Z}_6 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.73, 3.51, 19.64]$$

After finding each parameter`s fuzzy weight, all the numbers change to unfuzzy numbers, using Equation 13 [39].

$$\widetilde{W}i = (\prod_{i=1}^{3} \omega_j)^{1/3} \tag{13}$$

$$W_1 = (\prod_{i=1}^{3} \omega_j)^{1/3} = 14.29 \tag{14}$$

So, each parameter`s weight is calculated by fuzzy Delphi-analytical hierarchy process, and the relevant value of each is shown in Table 16.

Table 16
Final weights of Parameters obtained using AHP method.

Parameters		Final Weight
C_1	Gross Profit	0.3
C_2	Time	0.11
C_3	Waste	0.14
C_4	Safety	0.09
C_5	Goodness	0.28
C_6	Environmental Parameters	0.08

The calculated eigenvector for total criteria after calculated by fuzzy Delphi-analytical hierarchy process is as followed:

W= [0.3, 0.11, 0.14, 0.09, 0.28, 0.08]

The weighted decision matrix is equal to dimensionless decision matrix times to weighted criteria matrix (Equation 15).

$$V = R \times W = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \cdots & \cdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix} \tag{15}$$

The weighted decision matrix is equal to dimensionless decision matrix multiplied by weighted criteria matrix:

$$V = \begin{vmatrix} 0.147 & 0.084 & 0.061 & 0.024 & 0.067 & 0.047 \\ 0.147 & 0.057 & 0.037 & 0.04 & 0.156 & 0.033 \\ 0.083 & 0.022 & 0.086 & 0.024 & 0.067 & 0.047 \\ 0.134 & 0.018 & 0.012 & 0.056 & 0.201 & 0.02 \\ 0.14 & 0.024 & 0.086 & 0.056 & 0.067 & 0.007 \end{vmatrix}$$

A+ shows the ideal solution and A- the negative ideal solution, then:

$A^+ = \{v_1^+, v_2^+ \ldots, v_i^+ \ldots, v_n^+\}$

$A^- = \{v_1^-, v_2^- \ldots, v_i^- \ldots, v_n^-\}$

Where vi+ is the best value of i values and vi- is the worst value of i criteria from all alternatives respectively. Alternatives in A+ and A- are better and worse alternatives respectively. Ideal solution (A^+) and negative ideal solution (A^-) are equal to:

$$A_j^+ = (0.148, 0.018, 0.012, 0.056, 0.201, 0.007)$$
$$A_j^- = (0.083, 0.084, 0.086, 0.024, 0.067, 0.047)$$

For each case, distance from the ideal limit and negative ideal limit are calculated from Equations 16 and 17.

$$S_j^+ = \sqrt{\sum_{i=1}^{n} (V_{ij} - V_j)^2} \tag{16}$$

$$S_j^- = \sqrt{\sum_{i=1}^{n} (V_{ij} - V_j)^2} \tag{17}$$

Where in these equations i index is the related criteria, and the j is the related alternative.

Finally, the similarity index is calculated from Equation 18.

$$C_j^+ = \frac{S_j^-}{S_j^+ + S_j^-} \tag{18}$$

The similarity index value varies from zero to 1, and whenever an alternative is closest to ideal, the similarity index value is near to 1. It is obvious that if $A_j = A^+$ then, $S_j^+ = 0$. Therefore, alternative e ranking is based upon similarity index value. So, the alternative which has the highest similarity index value, has the first ranking and the one with the lowest similarity index value has the last ranking [40].

For each method, distance from ideal and negative ideal solution and similarity index are calculated and shown in Table 17. As seen, a ranking of priority methods is as: diamond wire saw, expanding chemicals FRACT, plug, and feather, Katrock, and blasting.

Table 17

Separation from ideal and negative ideal solution and similarities index.

Options	Similarity Index	Separation from Ideal Solution	Separation from negative Ideal Solution
Expanding Material (Katrock)	0.296	0.165	0.069
Expanding Material (Fract)	0.633	0.072	0.124
Blasting	0.262	0.174	0.062
Diamond Cutting Wire	0.93	0.014	0.182
Plug and feather	0.388	0.153	0.097

5. Conclusion

The different methods have been developed and applied to extract the dimensional stones. As time goes by and improvement of technology, the primary methods that the human force played a significant role, might be abandoned. Thus, selection of the proper method among of all existing methods is a multi-criteria decision problem. Nevertheless, at first, the available criterions should be determined as well as considering their views; the appropriate method can be selected. Methods including Plug and feather, diamond wire saw, blasting (low density) and expanding chemicals (FRACT and Katrock) are the most common methods in the majority of Iran`s quarries. All methods have advantages and disadvantages compared with each other, so without a precise investigation of effective factors and criteria, finding the ideal method is impossible. In this article the common dimension stone excavation methods including wedge and blades, diamond wire saw, explosives and expansive chemicals (FRACT and Katrock) in respect to different criteria such as production cost, desirability, safety, time, ease of extraction, waste and environmental effects have been compared. After that the most convenient method for extraction of dimension stones (closest method to ideal method) was chosen, using fuzzy- Delphi analytical hierarchy process method (FDAHP) and the technique for an order of preference by similarity to ideal solution method (TOPSIS). The results showed that the extraction of dimensional stones is suitable by using diamond wire saw method. According to the results, this method has a high safety, very high goodness, high gross profit, very low waste, low environmental effects and medium time for extraction.

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