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Development of a new system for improving blastabality by using the Fuzzy Delphi AHP method

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ABSTRACT

Blastability is one of the most important and effective parameters in open pit mining, which is closely related to rock mass, environmental conditions, and explosion systems. To investigate blastability, many classification systems have been proposed so far, each of which has expressed some of the parameters affecting the blasting according to environmental conditions and based on empirical judgments. Therefore, the factors affecting blastability can be identified and determined according to theories and environmental conditions. Due to the necessity and presentation of a classification system to investigate the blastability of the Sangan iron ore mines project, by studying and examining each of these factors, in this paper, this classification system was presented and introduced. For this purpose, according to the response received from a questionnaire sent to experts around the world and using the fuzzy Delphi Hierarchical Analysis (FDAHP) method, the weighting of each of the factors affecting the proposed classification system was performed and finally, a new classification system was introduced to optimize blastability classification.

Keywords: *Blastability, Rock mass system, FDAHP, Sangan iron ore mines*

1. Introduction

Blasting is one of the main mining operations, so this operation requires full knowledge of all effective parameters for optimal design. Unstable ground conditions or poor design can lead to adverse consequences such as flyrock, ground vibration, backbreak, noise generation, dust generation, and large blocks that need to be broken again[1 and 2]. Despite the development of various methods for determining blastability, so far not much effort has been made to develop quantitative and systematic parameters affecting this capability of the rock. Studies in this field, which have sometimes led to the presentation of relationships, are not able to express the fire feature of rock mass and a comprehensive relationship or classification system to predict this rock mass capability has not been presented yet [2]. Efforts to do so have not been widely used in blasting operations. Because in order to make these classification systems operational, it is necessary to study a number of rock mass characteristics that require a lot of time to estimate. While in the mining industry, time and speed of production are very important and this design requires a rock mass classification system that can quickly describe the characteristics of the rock mass in relation to its blasting. On the other hand, it has the ability to establish a relationship with design parameters and explosives.

The importance of having such a rock mass classification system is its applicability in mining projects to design the optimal blast design to achieve the desired size distribution of blast particles with the least explosive consumption[3]. In case of achieving such a classification of rock mass, in addition to reducing the cost of production of desired mineral materials, the cost of loading, transportation, crushing, and processing of the mineral can be greatly reduced, and as a result, the economic potential of the mine increased sharply. Blastability is a very important feature in blast design in mines and construction activities that are closely related to rock mass system, explosion system, and explosion environmental conditions and the result is crushing rock mass to dimensions and distribution of required granulation (See Figure 1). Because the properties affecting the explosiveness and the result of the blast are many, researchers in their research, depending on the weight of the impact, have examined some of them and have inferred their effect through relationships[2 - 4].

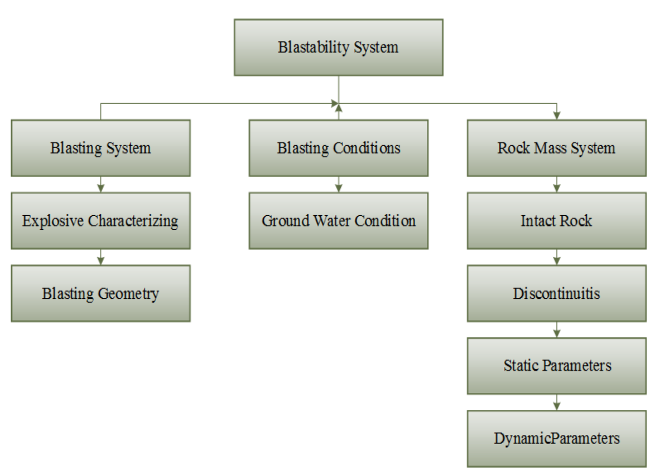

Figure 1. Determine importance factor for blastability.

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According to the research conducted in the field of blastability, the purpose of this paper is to introduce and present a new classification system to optimize the blastability in the Sangan iron ore mines. To implement these factors, with the case study that was done, the factors are presented in two categories of positive and negative according to Table 1. Also, the two parameters of slope and orientation difference are presented as negative factors and were determined by studying geotechnical logs and surface measurements. Finally, according to the response received from experts, a new classification system was presented using the FDAHP method.

Table1: Importance Parameter for determine new classification.

Parameters	Description	Abbreviation	Unit	Effects
P1	Uniaxial Compressive Strength	UCS	MPa	Positive
P2	Uniaxial Tensile Strength	UTS	MPa	Positive
P3	Elasticity of Modulus	E	MPa	Positive
P4	Density	DEN	t/m^3	Positive
P5	Rock Quality Designation	RQD	%	Positive
P6	Spacing of Discontinuity	SD	Meter	Positive
P7	Ground Water Condition	GW	Quality	Positive
P8	Orientation	Ori	angle	Negative
P9	Dip	Dip	angle	Negative

2. Lu and Latham Classification System

Lu and Latham proposed a new classification system to improve blastability [1]. This model has been developed based on comprehensive information on the properties of intact rock and discontinuities. They classified rock masses into five classes based on their explosiveness: very comfortable, comfortable, medium, hard, and very hard. The method used in his studies was the Rock Engineering System (RES) method by using the interaction matrix.

Rock engineering system is a method that includes the ability to study the complex process of Rock mass properties. This method was developed in 1992 by Hudson. In general, in this system, the characteristics and behavior of a bivariate system are estimated and finally, this binary system decides the total rock mass conditions. In the Rock engineering system, the identification of critical parameters, effective paths, return loops, and evaluation of appropriate selection methods are performed using the interaction matrix. The interaction matrix is the main element of the rock engineering system, which is used to list the effective parameters in a project related to rock engineering and to display the interaction between them. In Lu and Latham's system, for assessment blastability index by using the interaction matrix, all the factors affecting the system must first be arranged along the main diameter of the matrix, which is called dimensional sentences.

In this classification, 12 factors are considered the main factors in the blasting classification system. These 12 factors are the dimensional sentences of the interaction matrix. The matrix is coded using theoretical results and experiments or objective measurements or both. However, according to these 12 factors, there are one or two measurable parameters that can be used to show the effect of factors in a study area. These factors act as dimensional sentences in the interaction matrix. Relevant factors and parameters are P_1: rock mass compressive strength, P_2: rock mass tensile strength, P_3: rock density, P_4: elasticity, P_5: longitudinal wave velocity, P_6: rock hardness, P_7: Poisson ratio, P_8: fracture toughness, P_9: block size, P_{10}: rock mass brittleness, P_{11}: longitudinal field velocity ratio to laboratory velocity, P_{12}: discontinuity plate strength[1]. Quantifying and determining the value of the directional effect, the amount of water available and some other factors are also very important that need further research. Lu and Latham then determined the importance of the parameters by using the matrix in action and calculating the effect and effectiveness. Numerous factors affect explosiveness. But only the factors that play a major role in influencing the explosive system are of practical importance. According to the CE diagram according to Figure 2 and the sequential histogram obtained in Figure 3, the factors that have the largest share in the system, i.e., more than 70% of the total have been allocated as factors used in evaluating the capability. Rock mass explosions are selected. Thus, this method obtains the ability to explode rock mass based on the following formula:

$$BD = \sum_{j=1}^{n} W_j \times R_j \tag{1}$$

In the above relation, BD is called the crush resistance of the rock and the determining factor of explosiveness. R_j is the value of factor j obtained from the study area. W_j value coefficient obtained for the factor j. Thus, the value of BD will be between 0 and 1, and the higher the BD, the more the rock will have an explosion resistance.

P1	0.65	0.7	0.85	0.65	0.55	0.4	0.75	0.5	0.55	0.3	0.4
0.75	**P2**	0.4	0.45	0.65	0.5	0.4	0.65	0.6	0.45	0.5	0.5
0.9	0.75	**P3**	0.8	0.7	0.8	0.45	0.5	0.25	0.25	0.2	0.2
0.8	0.5	0.7	**P4**	0.6	0.6	0.55	0.25	0.25	0.3	0.45	0.15
0.45	0.65	0.7	0.45	**P5**	0.5	0.25	0.45	0.45	0.4	0.25	0.45
0.7	0.5	0.75	0.4	0.5	**P6**	0.25	0.45	0.35	0.35	0.45	0.4
0.4	0.2	0.4	0.65	0.25	0.45	**P7**	0.5	0.2	0.25	0.25	0.15
0.5	0.7	0.2	0.2	0.15	0.5	0.35	**P8**	0.4	0.25	0.2	0.3
0.25	0.3	0.25	0.5	0.35	0.25	0.3	0.4	**P9**	0.8	0.65	0.45
0.65	0.6	0.3	0.35	0.25	0.35	0.4	0.55	0.65	**P10**	0.8	0.2
0.45	0.45	0.2	0.6	0.6	0.45	0.2	0.15	0.5	0.55	**P11**	0.25
0.25	0.65	0.1	0.3	0.45	0.25	0.15	0.5	0.55	0.25	0.3	**P12**

Figure 2: Interaction Matrix for blastability index.

3. Fuzzy Delphi Analytical Hierarchical Process

The Delphi method is the result of studies conducted by Rand in the 1950s to create a way to reach a consensus among group experts. This method replaces the traditional research approach using statistical methods. Delphi is a way of structuring a group communication process in such a way that the process allows group members to challenge the problem. Allowing this structured relationship requires the need for feedback on the role of individuals, and the evaluation of group judgments allows for correcting views [5]. Therefore, the purpose of this method is to reach the most secure group agreement of experts on a specific topic, which is done by using questionnaires and consulting experts many times according to their feedback. The traditional Delphi method always involves the low convergence of expert opinions, high implementation costs, and the possibility of deleting some of the opinions of individuals. For this purpose, in order to improve the traditional Delphi method, the concept of integrating the traditional Delphi method with fuzzy theory was proposed. The fuzzy Delphi method proposed by Kauffman and Gupta in 1988 is a generalization of the traditional Delphi method in management science. In the Delphi method, predictions presented by experts are expressed in the form of definite numbers, while the use of definite numbers for long-term predictions is usually erroneous.

Experts, on the other hand, use their mental abilities and competencies to predict, and this shows that the uncertainty caused by the situation is a possibility, not a possibility, so the possibility of uncertainty is compatible with fuzzy sets, and therefore It is better to use long-term predictions and real-world decisions using fuzzy sets and fuzzy numbers. The characteristics of both traditional and fuzzy Delphi methods are shown in Table 2. Different types of fuzzy numbers such as triangular or trapezoidal numbers can be used to obtain expert opinions. Thus, in the first stage, the necessary information is received from the experts in the form of a questionnaire that has already been prepared and analyzed.

Table 2: Comparison of traditional Delphi method with fuzzy Delphi method.

Criteria	Traditional Delphi Method	Fuzzy Delphi Method
Stages	After several stages of consideration, experts reach a consensus on an issue	With one review step, all theories are covered
Flexibility	Experts change their minds to get the average opinion of others. Otherwise, they may be deleted.	The opinions of all experts are respected and different degrees of membership are considered for all possible consensus.
Cost	It requires a lot of time and money and the ambiguity of the process cannot be removed	No need to spend a lot of time and the ambiguity of the process will be removed.

In the fuzzy Delphi method, experts usually present their ideas in the form of minimum value, maximum value, and maximum value in the form of fuzzy numbers. Then the average of the experts' opinions (numbers provided) and the amount of disagreement of each expert is calculated from the average. Then in the next step, this information is sent to the experts to obtain new opinions, then each expert based on the information from the previous stage of the theory Offers a new one or modifies its previous comment. This process continues until the average of the fuzzy numbers becomes stable enough.

FDAHP, which is a combination of two methods of hierarchical analysis and the fuzzy Delphi method, shows that the use of fuzzy numbers consistent with the fuzzy Delphi method and its application in the hierarchical analysis method can lead to better results in the final weighting of each to be decided from the parameters. The steps are as follows:

3.1. Expert Analysis

As mentioned in the previous paragraphs, in this step, a form according to Table 3 should be prepared and sent to the experts.in this step, first, the different experts in Case parameters affecting a phenomenon or decision qualitatively apply their theories as little as possible.

3.2. Calculate fuzzy numbers

The calculation of fuzzy numbers according to the various theories obtained from the survey of experts is directly considered. Fuzzy numbers in this step can be calculated based on various membership functions such as the triangular method or the trapezoidal state. Due to the high application and ease of calculating the triangular method, the calculation of triangular fuzzy numbers is shown in accordance with Figure 4. In this case, a fuzzy number is represented by the following relations:

$$a_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij}) \quad (2)$$

$$\alpha_{ij} = Min(\beta_{ijk}), k = 1, \dots, n \quad (3)$$

$$\delta_{ij} = \left(\prod_{k=1}^{n} \beta_{ijk}\right), k = 1, \dots, n \quad (4)$$

$$a_{ij} = Max(\beta_{ijk}), k = 1, \dots, n \quad (5)$$

3.3. Fuzzy inverse matrix formation

In this step, according to the fuzzy numbers obtained in the previous step, the pairwise comparison matrix between different parameters is formed as follows:

$$\tilde{A} = [\widetilde{\alpha_{ij}}] \quad \widetilde{\alpha_{ij}} \times \widetilde{\alpha_{ij}} \approx 1 \quad \forall i = 1,2, \dots, n \quad (6)$$

Or:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (\alpha_{12}, \delta_{12}, \gamma_{12}) & (\alpha_{13}, \delta_{13}, \gamma_{13}) \\ (1/\gamma_{12}, 1/\delta_{12}, 1/\alpha_{12}) & (1,1,1) & \alpha_{23}, \delta_{23}, \gamma_{23} \\ (1/\gamma_{13}, 1/\delta_{13}, 1/\alpha_{13}) & (1/\gamma_{23}, 1/\delta_{23}, 1/\alpha_{23}) & (1,1,1) \end{bmatrix} \quad (7)$$

Table3: Sample of questionnaire sent to expert in around the word .

	Importance of Each Parameters				
Parameters	Very Weak (1)	Weak (3)	Moderate (5)	Strong (7)	Very Strong (9)
UCS			×		
UTS		×			
E		×			
DEN		×			
RQD			×		
SD			×		
GW	×				
OD			×		
DIP			×		

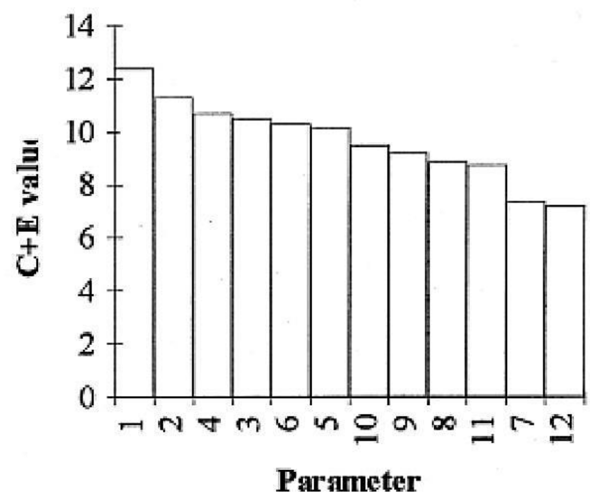

Figure 3: Weighting histogram for blastability parameters.

3.4. Calculate the relative fuzzy weight of the parameters

The relative fuzzy weights of the parameters are obtained from the following equations:

$$\tilde{Z}_i = [\widetilde{\alpha_{ij}} \otimes \dots \otimes \widetilde{\alpha_{in}}]^{1/n} \quad (8)$$

$$\widetilde{W}_i = \tilde{Z}_i \otimes [\tilde{Z}_i \oplus \dots \oplus \tilde{Z}_i]^{-1} \quad (9)$$

In the above equations: $\widetilde{\alpha_1} \otimes \widetilde{\alpha_2} = (\alpha_1 \times \alpha_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2)$, the $\otimes$ symbol is the multiplication of fuzzy numbers, the symbol $\oplus$ represents the sum of fuzzy numbers, and the symbol $\widetilde{W}_i$ the symbol is a line vector that represents the fuzzy weight of the *ith* parameter.

3.5. Defuzzification Parameters

To defuzzification the weight of the parameters in the previous step, using the geometric mean of the fuzzy components is calculated as follows:

$$W_i = (\prod_{j=1}^{3} w_{ij})^{1/3} \quad (10)$$

4. Sangan Iron Ore Mine Project

Sangan iron ore mine project is located in the province of Khorasan Razavi in north-eastern Iran, approximately 30 km from the Afghanistan border (see Figure 5). Three principal zones of mineralization have been identified within the Sangan deposit and are referred to as Anomaly A, Anomaly B, and Anomaly C. This report covers work compiled on Anomalies B and C North only. The area is fairly typical of the range and basin landscape (Figure 6) [6 and 7]. Broad, low-angle plains are punctuated by short (in length) chains of mountains. Elevations in the Sangan Iron Deposit area range from about 1,800 m to the north of Anomaly B to 1,200 m at the mine office.

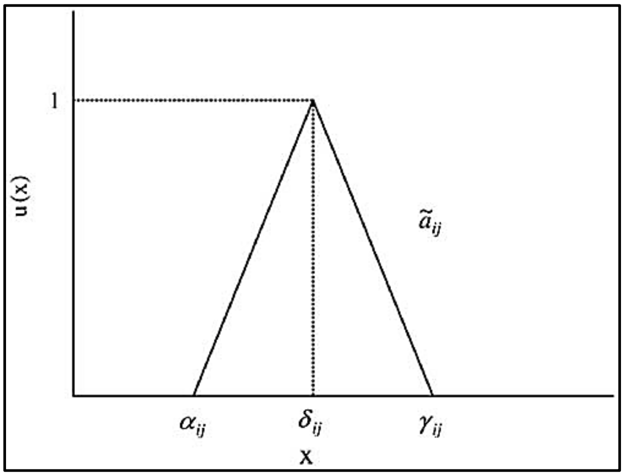

Figure 4 Triangular membership functions in the fuzzy Delphi method.

Figure 5: Location Map of Sangan Project.

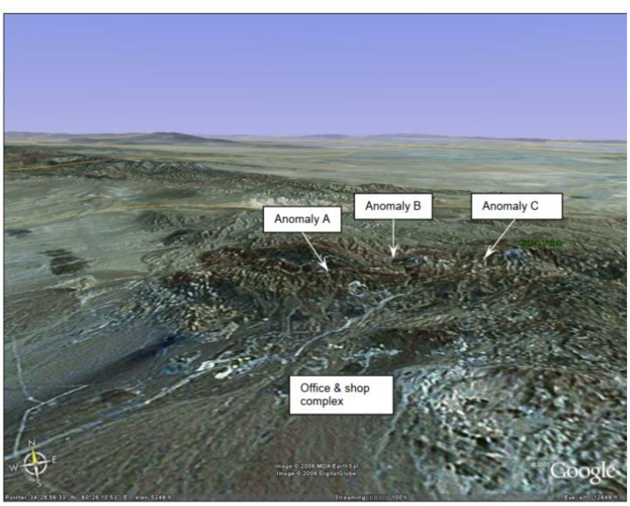

Figure 6 Google Earth Satellite view of Sangan project area looking northeast.

The studies include 20 sections of surface surveys and the study of 3 geotechnical boreholes in B mine[8], the results of which are shown in Table 4.

Preliminary study of geology and lithology

- Estimation of rock strength (by point load test and uniaxial compressive strength obtained by examining the results of drilling cores).
- Measurement of rock quality index that has been done directly by geotechnical boreholes and surface measurement
- Investigating the distance between discontinuities and groundwater conditions

The range of results from geotechnical surveys is shown in Table 5.

5. Discussion

In this section, in order to develop the new blastability classification system in B mine of Sangan, initially, related withdrawals were made from different sites. In the next step, according to the questionnaire shown in Table 3, the parameters affecting the blasting in accordance with the Lu and Latham classification were examined according to the conditions of the mines themselves.

According to Table 6, it is observed that groundwater conditions have a significant impact on blastability, and on the other hand, because this parameter is a qualitative criterion, using the Likert scale, we first turn it into a quantitative parameter. Parameters such as slope and directional difference of discontinuities are also examined separately.

After determining the problem criteria and scoring according to the conditions of the study project, in the next step using the FDAHP method and after receiving the questionnaires, the score was assigned to the parameters received from the experts. After receiving the mentioned forms, the results of which are presented in Figure 7, in the next step, the pairwise comparison matrix corresponding to each of the parameters, which according to different experts is formed separately for each expert, is presented in Table 7.

The second step is to find the weight of the parameters using the AHP method

At this stage, considering that the survey forms have been received, all the results are used to form the main pairwise comparison matrix and the desired parameters. In the formation of the mentioned matrix, as mentioned in section 3, using the triangular membership function and as a result, triangular fuzzy numbers according to Figure 4 and relations 2 to 5 were used. In the next step, using equation 8, the fuzzy numbers are calculated for different parameters, the result of which is shown in Table 8. Finally, according to equations 9 and 10, the fuzzy weight of each parameter is calculated, respectively, and the results of calculating the non-fuzzy weight are shown in Table 9. The Delphi fuzzy weight bar graph showing the parameter's affecting explosiveness is also shown in Figure 8 As can be seen, the uniaxial compressive strength parameter, modulus of elasticity, and uniaxial tensile strength have the greatest impact on the explosiveness and the discontinuity distance parameter has the least impact on the rock mass explosive capability.

After determining the final weight of each of the parameters affecting the explosiveness of the rock mass, in this step, according to the proposed formula 1, the new classification system is scored, and the set of scores for this classification is 100. Table 10 shows the positive parameters of the proposed classification system and Table 11 shows the negative parameter of the proposed classification system. Table 12 also shows the groundwater rating, which is a negative indicator based on the rating of the rock mass rating system. Finally, the final rating of the classification system, which shows the rock mass blasting capability, is shown in Table 13.

Table4: Geotechnical Borehole characterization of Anomaly B.

Location	No	Section	Dip (degree)	Azimuth	Depth (m)
North	169	20	60	180	320
South	166	18	70	180	240
Eastern	168	12	70	120	380

Table 5: Rock quality evaluation by using geotechnical investigation.

		Borehole 166		Borehole 168		Borehole 169	
	Parameters	Ave. Value	Rating	Ave. Value	Rating	Ave. Value	Rating
	UCS (MPa)	80.18	7	77.21	7	84.48	7
	RQD (%)	44.17	8	53.15	13	66.77	13
Discontinuity Condition	Spacing (cm)	62	8	53	5	62	8
	Rough	Slightly rough	8	Slightly rough	8	Slightly rough	8
	Opening	Open	7	Open	7	Complete open	0
	Durability	No	5	No	5	No	5
	Weathered	very weathered	0	slightly weathered	5	slightly weathered	5
	Ground water	Saturated	0	dry	10	Saturated	0
	RMR Rating	Medium	53	Best	63	Medium	56

Table 6: Convert qualitative to quantitative ground water criteria using Likert scale.

	Very Best	Best	Moderate	Weak	Very Weak
GW	Dry	Moisture	Wet	Drop	Flow
Rating	9	7	5	3	1

Table 7: FDAHP Method pairwise comparison matrix.

	UCS			UTS			E			DEN		
UCS	1.000	1.000	1.000	0.778	1.114	1.667	0.778	1.207	1.667	1.000	1.533	2.333
UTS	0.600	0.992	1.286	1.000	1.000	1.000	0.778	1.144	1.800	0.778	1.474	1.800
E	0.600	0.886	1.286	0.556	0.937	1.286	1.000	1.000	1.000	1.000	1.311	1.800
DEN	0.429	0.695	1.000	0.556	0.759	1.286	0.556	0.812	1.000	1.000	1.000	1.000
RQD	0.556	0.926	1.286	0.556	1.049	1.800	0.556	1.133	1.800	0.556	1.504	3.000
SD	0.333	0.794	1.286	0.333	0.927	1.800	0.333	1.022	1.800	0.333	1.333	3.000
GW	0.200	0.517	1.000	0.333	0.564	1.400	0.333	0.608	1.400	0.333	0.867	2.333
OD	0.143	0.868	1.286	0.111	1.022	1.800	0.200	1.037	1.800	0.200	1.407	3.000
DIP	0.429	0.735	1.000	0.333	0.871	1.667	0.556	0.915	1.667	0.556	1.193	2.333

RQD			SD			GW			OD			DIP		
0.778	1.163	1.800	0.778	1.363	3.000	1.000	2.511	5.000	0.778	2.011	7.000	1.000	1.489	2.333
0.556	1.154	1.800	0.556	1.310	2.333	0.714	2.308	3.000	0.556	2.288	9.000	0.600	1.552	3.000
0.556	1.040	1.800	0.556	1.240	3.000	0.714	2.086	3.000	0.556	1.621	5.000	0.600	1.330	1.800
0.333	0.860	1.800	0.333	1.060	3.000	0.429	1.794	3.000	0.333	1.441	5.000	0.429	1.083	1.800
1.000	1.000	1.000	1.000	1.111	1.667	1.286	2.225	5.000	0.714	1.619	5.000	1.000	1.292	1.667
0.429	0.838	1.000	1.000	1.000	1.000	0.600	1.981	5.000	0.429	1.476	5.000	0.600	1.092	1.667
0.200	0.553	0.778	0.200	0.620	1.000	1.000	1.000	1.000	0.200	0.925	3.000	0.200	0.733	1.000
0.200	0.933	1.400	0.200	1.089	2.333	0.333	2.114	5.000	1.000	1.000	1.000	0.333	1.137	1.400
0.600	0.801	1.000	0.600	0.912	1.667	1.000	1.889	5.000	0.714	1.153	3.000	1.000	1.000	1.000

Table 8: Fuzzy Weight Calculates

	$\tilde{Z}$			$\tilde{Z}_i$		
P1	0.28	24.58	2858.33	0.87	1.43	2.42
P2	0.03	20.73	1417.18	0.67	1.40	2.24
P3	0.02	6.31	433.83	0.66	1.23	1.96
P4	0.00	1.09	187.46	0.46	1.01	1.79
P5	0.09	8.56	867.86	0.76	1.27	2.12
P6	0.00	2.68	520.71	0.45	1.12	2.00
P7	0.00	0.04	10.67	0.28	0.69	1.30
P8	0.00	3.16	285.77	0.24	1.14	1.87
P9	0.01	1.11	162.04	0.61	1.01	1.76
				5.01	**10.29**	**17.47**

Table 9: Defuzzification Weight Calculates..

	$\tilde{W}_i$			W
P1	0.050	0.139	0.483	0.151
P2	0.038	0.119	0.392	0.122
P3	0.038	0.136	0.447	0.134
P4	0.026	0.098	0.357	0.098
P5	0.014	0.110	0.374	0.084
P6	0.035	0.098	0.351	0.107
P7	0.026	0.108	0.400	0.105
P8	0.016	0.067	0.260	0.066
P9	0.044	0.123	0.423	0.133
SUM				1

Table 10: Proposed classification to investigate blastability improved in Sangan project (positive parameters).

	Very Easy	Easy	Moderate	Difficult	Very difficult
Parameters	**1**	**2**	**3**	**4**	**5**
UCS	<25	25-60	60-100	100-180	>180
E	<25	25-50	50-100	100-150	>150
UTS	<1.5	1.5-2.5	2.5-3	3.0-4.0	4
DEN	<2	2-2.4	2.4-2.75	2.75-3	>3
RQD	<40	40-60	60-75	75-90	>90
SD	<0.1	0.1-0.5	0.5-1.5	1.5-2.5	2.5-3

Table 11: Proposed classification to investigate blastability improved in Sangan project (Negative parameters)

.	Very difficult	Difficult	Moderate	Easy	Very Easy
DIP	0-15	15-35	35-55	55-75	75-90
Rating	0	-4	-8	-12	-15
	Very Easy	Easy	Moderate	Difficult	Very Difficult
OD	0-30	30-60	60-90	90-120	>120
Rating	-15	-12	-9	-6	-3

Table 12: Ground water condition rating to investigate a new classification.

	Very Difficult	Difficult	Moderate	Easy	Very Easy
GW	dry	damp	wet	dripping	flowing
RMR Rating	15	10	7	4	0

Table 13: Proposed Classification Rating in Sangan Project.

	Very Easy	Easy	Moderate	Difficult	Very difficult
Blastability Class	1	2	3	4	5
BD	<0.25	0.25-0.50	0.50-0.70	0.70-0.85	>0.85

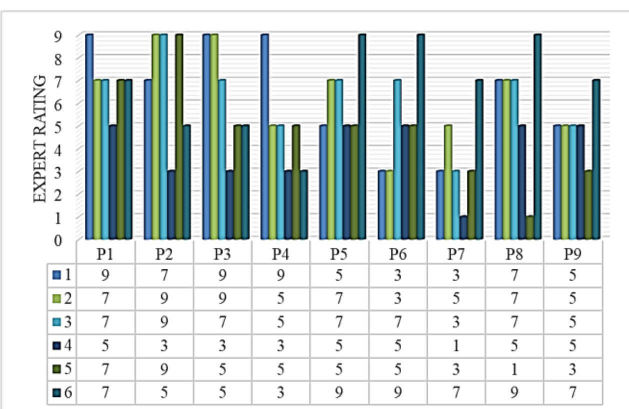

Figure 7 General results of surveys and scores assigned to each parameter by experts.

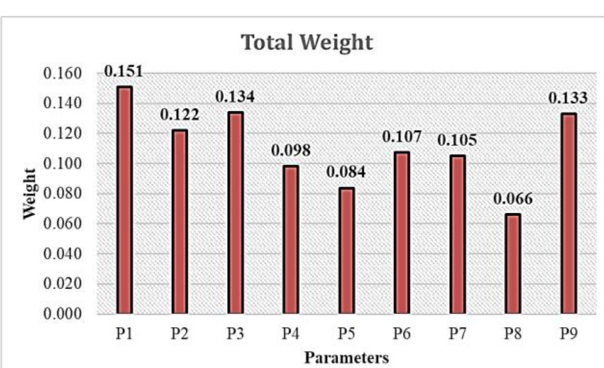

Figure 8 Final Weight of FDAHP Method.

6. Conclusions

Considering that blasting ability is one of the most important influencing parameters in open pit mining projects, therefore the purpose of this article is to present a new classification system in order to optimize blasting ability in Sangan iron ore mining projects. In order to review and present the desired classification system, according to the investigations that were carried out, important and influential factors on the explosiveness were identified, and to weight and influence each of these factors on the new classification system, according to the questionnaire that was prepared, Expert have been sent. After receiving the questionnaire, the weighting of each of the desired parameters and the effect of each on the new classification system was checked using the hierarchical Delphi fuzzy analysis method. To provide a new classification system, surface evaluations were performed according to surface geotechnical studies, and in the next step, geotechnical logs were checked, and in this case, two parameters of slope and directional difference, which have a negative effect on the classification system, were measured and obtained. Also, the condition of underground water which affects the blasting process in Sangan iron ore mines was taken into consideration and included in the new classification system. In order to reduce costs and increase the efficiency of the blasting, the use of a new classification system in the Sangan iron ore mining project can be very effective

REFERENCES

[1] J.-P. Latham and P. Lu, "Development of an assessment system for the blastability of rock masses," *Int. J. Rock Mech. Min. Sci.*, vol. 36, no. 1, pp. 41–55, 1999.

[2] J. P. Latham, J. Van Meulen, and S. Dupray, "Prediction of

fragmentation and yield curves with reference to armourstone production," *Eng. Geol.*, vol. 87, no. 1–2, pp. 60–74, 2006, doi: 10.1016/j.enggeo.2006.05.005.

[3] J. P. Latham, J. Van Meulen, and S. Dupray, "Prediction of in-situ block size distributions with reference to armourstone for breakwaters," *Eng. Geol.*, vol. 86, no. 1, pp. 18–36, 2006, doi: 10.1016/j.enggeo.2006.04.001.

[4] Y. Azimi, M. Osanloo, M. Aakbarpour-Shirazi, and A. Aghajani Bazzazi, "Prediction of the blastability designation of rock masses using fuzzy sets," *Int. J. Rock Mech. Min. Sci.*, vol. 47, no. 7, pp. 1126–1140, 2010, doi: 10.1016/j.ijrmms.2010.06.016.

[5] S. H. Hosseini, M. Ataei, and M. Osanloo, "A new classification system for evaluating rock penetrability," *Int. J. Rock Mech. Min. Sci.*, vol. 46, no. 8, pp. 1329–1340, 2009, doi: 10.1016/j.ijrmms.2009.07.002.

[6] G. Report and M. Update, "Sangan Project Geology Report & Model Update," no. April 2008.

[7] H. Nikafshan Rad, Z. Jalali, and H. Jalalifar, "Prediction of rock mass rating system based on continuous functions using Chaos-ANFIS model," *Int. J. Rock Mech. Min. Sci.*, vol. 73, pp. 1–9, 2015, doi: 10.1016/j.ijrmms.2014.10.004.

[8] Z. Jalali, "Development of slope mass rating system using K-means and fuzzy c-means clustering algorithms," *Int. J. Min. Sci. Technol.*, vol. 26, no. 6, pp. 959–966, 2016, doi: 10.1016/j.ijmst.2016.09.004.