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Determination of Optimal Block Size in Angouran Mine Using VIKOR Method

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Abstract

Size optimization of mining blocks is among the most important factors for optimal planning and systematic extraction in a mine. Several technical and economic factors are effective in determining the size of mining blocks. The best size of blocks complies with geostatistical criteria appropriately and reasonably and is relatively favorable compared to other extractive, technical and economic criteria. In this regard, the use of multi-criteria decision-making methods is useful since it enables simultaneous consideration of the impact of several criteria with different relative importance. In this paper, while introducing a comprehensive suite of effective criteria to determine the optimal size of mining blocks using multi-criteria decision-making method of VIKOR, 10-meter blocks were recommended as the best option (most appropriate size) for Angouran mine.

Keywords: Optimal Block Size, Angouran Mine, Block Modeling, Multi-criteria decision-making, VIKOR method

1. Introduction

Today, human ability to extract lower grade minerals has been considerably improved with advances in technology and increase in the value of minerals. In this regard, the use of three-dimensional modeling is inevitable to estimate the exact amount of deposit as well as do detailed planning for mining and ore production. Three-dimensional modeling can be effective in control of mineral mixing in different sectors in addition to consideration of the production plan. Several processes including geological modeling, phasing, design and so forth are involved in the process of three-dimensional modeling. Block modeling, also known as ore body blocking, is one of the most important steps in which the mineral deposit is divided into a series of separate blocks. The size of blocks is the most important parameter influencing the block design and optimal selection of blocks. Estimation variance is an important determinant of block size. Ore grade estimation in smaller blocks is far more difficult than larger blocks, since bases with larger size have lower variability according to the central limit theorem. Moreover, the higher the grade distribution in a deposit, the less accurate the grade estimate in it [1]. In addition, several direct and indirect costs are associated with mining, and some costs such as drilling expenses differ depending on the block size. Therefore, the costs can be reasonably reduced by determining optimal size of the extracted blocks. Optimizing the net present value (NPV) according to geostatistical data and limitations as well as extraction facilities and equipment is an important factor in determining the block size and shape. In addition, extraction parameters including geo-mechanical problems, capacity of mining machinery especially loaders play an important role in determining the block size. Finally, blocking and block modeling determine the deposit and correct advancing direction for mining operations. Given the impact of several measures in determining the size of blocks, it is not possible to determine optimal block size by relying on engineering judgments without a scientific and efficient approach. The use of multi-criteria decision-making methods is very useful as it allows simultaneous consideration of several criteria by taking into account the different relative importance attached to them. In this paper, while introducing a comprehensive set of effective criteria to determine the appropriate block size, the best option (most appropriate size) for Angouran mine was suggested using VIKOR method. Review of research suggests that a number of multi-criteria decision-making methods such as AHP, TOPSIS, ELECTRE have been used alone or in combination with fuzzy logic to solve mining, tunneling and underground space problems, including appropriate extraction method, transportation system, loading-trucking, proper drilling, suitable location, good support system, etc. [2-12]. However, so far no research has been conducted on selecting the appropriate size of mining blocks using VIKOR method.

2. Multi-criteria decision-making methods

These methods are used to select the most suitable choice from among *m* available options. A distinctive feature of these methods is the typical existence of a few countable number of predetermined options. The best option in a multi-attribute model is the one satisfying the most preferred value of each available trait. Modeling is based on formation of contingency table [13]. Linear assignment is an important multi-criteria decision-making method [13]. Similar to other multi-criteria decision-making methods, the performance of options should be first evaluated in terms of criteria. Therefore, the decision matrix is created as follows:

$$X = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \cdots & \cdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$$

where x_{ij} stands for the performance of option i ($i = 1,2,...,m$) in relation to criterion j.

Determining the relative importance of available criteria is an effective step in problem solving process in VIKOR method. For this purpose, we can use methods such as the expert opinion, Shannon entropy and eigenvector [13]. In this study, the eigenvector method was used. VIKOR method of multi-criteria decision-making is described below.

2-1- VIKOR method

VIKOR stands for the Serbian phrase *Vlse Kriterijumsk Optimizacija Kompromisno Resenje* meaning "multi-criteria optimization and compromise solution". It is one of the most important multi-criteria decision-making methods developed in 1984 on the basis of consensus with contradictory criteria to choose the preferred option, which is often used to solve discrete problems [14]. This method has been developed for multi-criteria optimization of complex systems. It focuses on categorization and selection from among a set of options, presenting compromise solutions for a problem with conflicting standards, which enables decision makers to achieve a final decision. In this technique, the compromise solution is the closest valid solution to the ideal solution in which *compromise* refers to a mutual agreement [15]. In fact, VIKOR model prioritizes or ranks the options via evaluation of options on the basis of criteria. In this model, there are always several options, which are independently evaluated based on several criteria and the items are eventually ranked by value. The main difference between this model and hierarchical or network decision-making methods is that unlike these methods, there is no pairwise comparison between parameters and options in VIKOR model, and each option will be independently assessed by a criterion. The advantage of VIKOR is that the raw data can be used to evaluate the options as well as expert opinion. This is the main difference between this model and methods such as AHP and ANP. This technique is performed in a few steps as follows [15]:

1. Development of decision matrix

The decision matrix, the scoring matrix of options according to criteria, is firstly formed. The decision matrix is indicated by X and each element of it is represented by x_{ij}.

2. Normalization of data

In this step, the decision matrix is normalized using the following equation:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^{2}}} \tag{1}$$

Xij shows the value of each criterion per option.

3. Weighting the normal matrix

In this step, the elements of normal matrix are multiplied by weight vector of criteria. The elements of this new matrix are indicated by f_{ij} sign.

4. Determining the ideal negative and positive points in normal weight matrix

In this step, the highest and lowest value in each column is determined. In criteria with a positive aspect, the largest number is the one with the highest positive value and the smallest number has the least negative value. This is contrary to the standards with a negative aspect.

$$f_i^* = \max_j f_{ij} \; ; \quad f_i^- = \min_j f_{ij} \tag{2}$$

5. Determining Satisfaction (S) and Rejection (R) indices

Satisfaction index (S) and Rejection index (R) are two basic concepts in VIKOR calculations. The (S) value indicates the relative distance of *i* option from the ideal point and the (R) value represents the maximum rejection of *i* option because of distance from ideal point. In fact, a satisfaction index is obtained for each option per criterion, the sum of which determines the final index of (S_j) option. The highest (S_j) value of each option per criterion is the rejection index of that option (R_j).

$$S_i = \sum_{j=1}^{n} W_j \cdot \frac{f_j^* - f_{ij}}{f_j^* - f_j^-} \tag{3}$$

$$R_i = max\left[w_j . \frac{f_j^* - f_{ij}}{f_j^* - f_j^-}\right] \tag{4}$$

In these equations, f^* represents the highest number of normal weight matrix for each column, f_{ij} the value of desired option for each criterion in normal weight matrix and ^-f the smallest value of normal weight matrix for each column in weighted normalized matrix.

6. Calculation of VIKOR index

In this point, the VIKOR index (Q) is calculated for each option:

$$Q_i = v\left[\frac{S_i - S^*}{S^- - S^*}\right] + (1-v)\left[\frac{R_i - R^*}{R^- - R^*}\right]$$

$$S^* = MinS_i \; ; \; S^- = MaxS_i \tag{5}$$

$$R^* = MinR_i \; ; R^- = MaxR_i$$

v = Constant of 0.5.

S_j = Total value of S for each option. R_j = Total R-value for each option.

S^* and S^- = The highest and lowest value of S index for each option respectively.

R^* and R^- = The highest and lowest value of R index for each option respectively.

7. Ranking of alternatives

In the final step of VIKOR technique, the alternatives are arranged in three groups from small to large based on the values of Q, R and S. The best option is the one with smallest Q, provided that the following two conditions are true:

Condition I: If A_1 and A_2 alternatives hold the first and second rank among *m* alternatives, the following equation should be satisfied:

$$Q(A_2) - Q(A_1) \geq \frac{1}{m-1} \tag{6}$$

Condition II: Option A1 must be recognized as the top rank at least in any of R and S groups. If the first condition is not true, either option will be the best one. If the second condition is not true, A1 and A2 alternatives will be both selected as the best option.

3. Angouran lead - zinc mine

Angouran lead and zinc deposit is located 311 km west to Zanjan in Sanandaj-Sirjan zone (Figure 1a). The nearest town to the mine is Dandi and Ghalejough is the nearest village to it. Total deposit of the ore contains 19.3 million metric tons of mixed sulfide-nonsulfide ores, including 14.6 million tons of non-sulfide ore with 22% zinc and 4.6% lead grade. It includes a total of 4.7 million tons of sulfide ore with 27.7% zinc and 2.4% lead grade as well as 110 grams per ton of silver. Some of the geological specifications of the area are represented in Figure 1b. [16 - 17]. Schema of Angouran mine is shown in Figure 2.

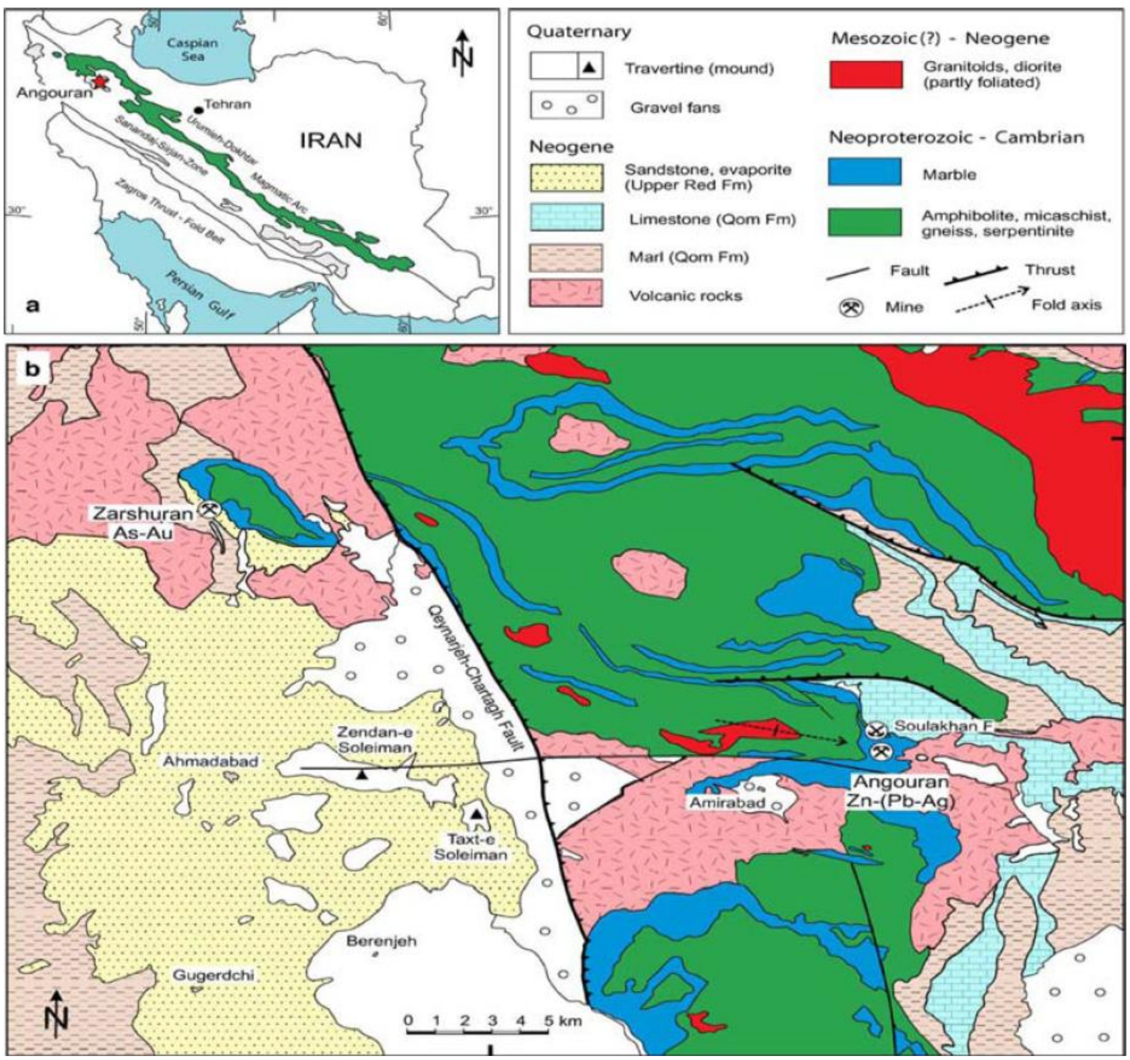

Figure 1: Geography of Angouran mine (a) and regional geological map of the area (b) [17]

Figure 2: Schema of Angouran mine

3-1- Determination of the proper shape and size of blocks

According to statistical analysis, variography and review of variograms' zone impact obtained from grade file showing the same values in different directions, cube shape of equal x, y and z dimensions was recognized as the appropriate shape for the blocks. The use of cubic form led to equal variance of estimation error in three dimensions and a good correspondence with variography studies [18]. Geostatistical and extraction data are used to determine the block size. Based on geostatistical parameters, the suitable size of blocks is half of the distance between exploratory networks. Since the distance of exploratory profiles in Angouran mine is approximately 50 meters, the maximum block size of mine should be selected 25 m. The block size must be chosen consistent with production design features and should account for production plan. Given the capacity of machinery in this mine, the minimum size of extractable and loadable block equals 2.5 meters. By determining the minimum and maximum size of the extracted block, the question of most suitable size in 2.5-25 meters is raised. Furthermore, according to design of extraction steps in the mine, block size must be an integer multiple of the step height. Therefore, the proposed size of blocks in this mine was 2.5, 5, 7.5, 10-25 meters, and the most appropriate dimension should be selected from among blocks of these sizes. Initial investigation of selected sizes showed that choosing sizes over 15 meters is highly different from the size of available mining steps and can severely affect the mining plan. Accordingly, the review range of block size was limited to 2.5-15 m range [18].

3-2- The effective criteria in optimizing the block size

For size optimization of mining blocks, first the block model of deposit was constructed using 2.5, 5, 7.5, 10, 12.5 and 15 m blocks by Macromine modeling program. Using kriging method and based on variogram parameters, the grade of various deposit blocks was then determined. Kriging is a geostatistical method based on weighted moving average and is the best unbiased linear estimator. This estimator guarantees the unbiased feature while ensuring the minimum variance [1]. Then, using Macromine software, three statistical parameters of standard deviation, mean and fit of estimated data with normal distribution using t estimator were calculated for each of the dimensions and statistical analysis results are presented below. As mentioned, in addition to the geostatistical parameters, the extraction parameters are important in choosing the optimum block size. In this study, six additional criteria including safety, environmental impact, productivity, capacity of machinery, capital costs and operating costs have been considered. Table 1 shows the characteristics of nine most effective factors used in this study determining the size of blocks. C_1 to C_3 criteria are quantitative criteria and various numerical values, some calculations and Macromine software have been used for their estimation. Other criteria are qualitative and expert opinion has been used to determine their values for different options (different block sizes). In criteria with positive impact, the higher the value of these criteria for an option, the higher preference of that option. In criteria with a negative impact, the increasing value of these criteria for an option reduces the preference of that option for selection.

Table 1: Effective criteria in determining the appropriate size of blocks

criterion	t estimator	Standard deviation (%)	Mean (%)	Safety	Environmental impact	Productivity	Production capacity of machinery	Capital costs	Operational costs
sign	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
Aspect	Positive	Negative	Positive	Negative	Negative	Positive	Negative	Positive	negative

3-3- Determining the proper block size using VIKOR method

At this stage, according to the proposed dimensions for block size, six sizes including 2.5 m (A1), 5 m (A2), 7.5 m (A3), 10 m (A4), 12.5 m (A5) and 15 m (A6) were selected as six options (alternatives) based on nine effective criteria, including C_1 to C_9 and the decision matrix was formed to choose the proper size for mineral block in Angouran mine. This hierarchical structure of this problem is shown in Figure 3.

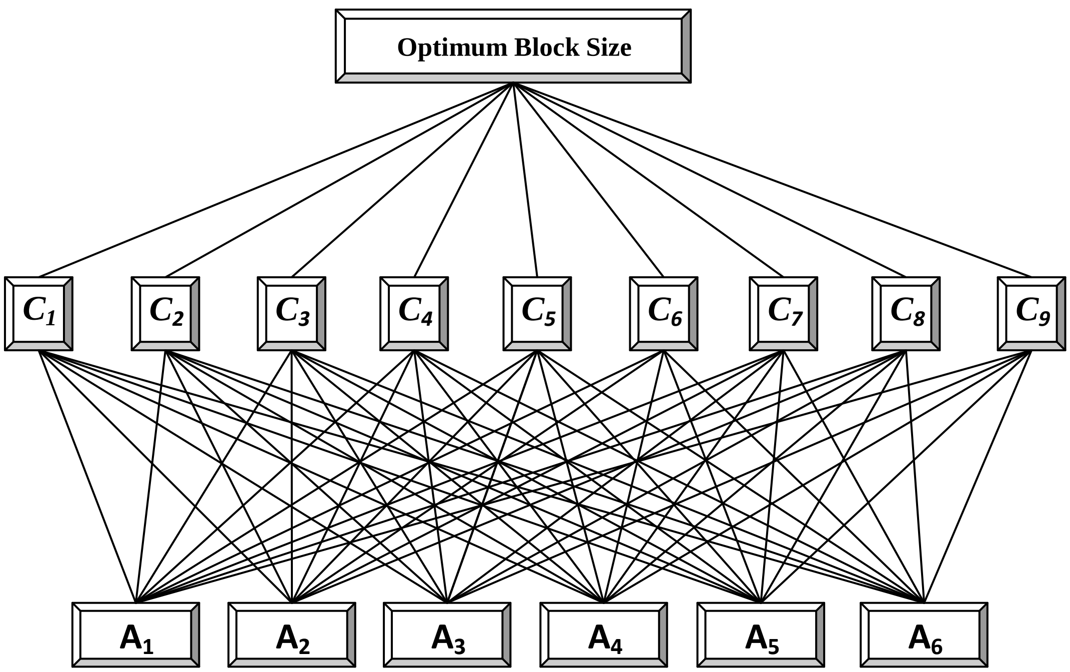

Figure 3: Hierarchical structure of selection of proper block size

As noted above, C_1, C_2 and C_3 are quantitative criteria and their values for various options have been determined on the basis of detailed calculations. Other criteria are qualitative and expert opinion has been used to determine their values for different options. Rating and scoring in relation to the value of each of the qualitative criteria (C_4 to C_9) for each of the options was performed based on the sevenfold range according to Table 2. Thus, the decision matrix was determined according to Table 3.

Table 2: Scoring range for qualitative criteria [19]

Expression variable	Very low	low	Low intermediate	intermediate	High intermediate	high	Very high	Intermediate states
Numerical value	0	1	3	5	7	9	10	2, 4, 6 & 8

Table 3: Decision Matrix

Alternatives (Dimension of block)	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
2.5*2.5*2.5 (A1)	22.97	7.78	22.06	9	1	1	1	1	7
5*5*5 (A2)	22.67	7.67	21.84	7	1	3	3	3	5
7.5*7.5*7.5 (A3)	23.1	7.69	22.27	5	3	5	5	5	3
10*10*10 (A4)	22.72	7.71	21.09	3	5	7	9	5	3
12.5*12.5*12.5 (A5)	23.08	7.65	22.3	1	7	9	3	7	5
15*15*15 (A6)	23.11	7.69	22.27	1	7	9	1	9	5

Eigenvector technique was used to determine the relative importance of criteria [19]. For the purpose, paired comparison matrix of criteria (Table 5) was formed through survey of expert opinion on the relative importance of criteria in accordance with whole time (Table 4). In the end, while calculating the geometric mean of data in each row, the geometric mean obtained in each row was divided by sum of geometric mean elements to normalize the data (i.e. making the sum of weights equal to 1). In this way, the final normalized weight of each criterion (also known as eigenvector) was obtained. The results are shown in Table (6).

Table 4: Nine-quantity whole time spectrum for paired comparison of criteria [20]

Expression variable	Very low importance	Low importance	Intermediate importance	High importance	Very high importance	Importance intermediate between the states
Numerical value	1	3	5	7	9	2, 4, 6 & 8

Table 5: Paired comparison matrix of criteria

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
C1	1.00	0.50	1.00	0.25	3.00	0.50	0.20	0.50	0.33
C2	2.00	1.00	3.00	0.50	2.00	0.33	0.20	0.14	0.11
C3	1.00	0.33	1.00	0.20	2.00	0.33	0.33	0.20	0.14
C4	4.00	2.00	5.00	1.00	2.00	0.50	0.33	0.20	0.14
C5	0.33	0.50	0.50	0.50	1.00	0.33	1.00	0.20	0.50
C6	2.00	3.00	3.00	2.00	3.00	1.00	0.50	0.33	0.20
C7	5.00	5.00	3.00	3.00	1.00	2.00	1.00	0.50	0.33
C8	2.00	7.00	5.00	5.00	5.00	3.00	2.00	1.00	0.33
C9	3.00	9.00	7.00	7.00	2.00	5.00	3.00	3.00	1.00

Table 6: Final weight of criteria

Criteria	Final weight	Criteria	Final weight
C_1	0.04803	C_6	0.09732
C_2	0.04795	C_7	0.13637
C_3	0.03545	C_8	0.20901
C_4	0.07565	C_9	0.30963
C_5	0.04059		

After determining the decision matrix and relative importance of the criteria, other steps of VIKOR method to choose the optimum size of blocks are described below. Based on Equation 1, first the normal decision matrix was defined (Table 7) and then the weighted normal matrix was obtained by multiplying the normal matrix elements by relative importance of the criteria. Results are listed in Table 8.

Table 7: Normal matrix

0.4087	0.4126	0.4098	0.6152	0.0864	0.0921	0.0891	0.0725	0.6444
0.4034	0.4067	0.4057	0.4785	0.0864	0.2762	0.2673	0.2176	0.4603
0.4111	0.4078	0.4137	0.3418	0.2592	0.4603	0.4454	0.3627	0.2762
0.4043	0.4089	0.3918	0.4785	0.4319	0.6444	0.8018	0.3627	0.2762
0.4107	0.4057	0.4143	0.2051	0.6047	0.4603	0.2673	0.5078	0.4603
0.4112	0.4078	0.4137	0.0684	0.6047	0.2762	0.0891	0.6529	0.0921

Table 8: Normal weighted matrix

0.0198	0.0145	0.0465	0.0035	0.0090	0.0121	0.0152	0.1995
0.0195	0.0144	0.0362	0.0035	0.0269	0.0364	0.0455	0.1425
0.0196	0.0147	0.0259	0.0105	0.0448	0.0607	0.0758	0.0855
0.0196	0.0139	0.0362	0.0175	0.0627	0.1093	0.0758	0.0855
0.0195	0.0147	0.0155	0.0245	0.0448	0.0364	0.1061	0.1425
0.0196	0.0147	0.0052	0.0245	0.0269	0.0121	0.1365	0.0285

In the end, while determining the positive and negative ideal points in normal weight matrix (Table 9) and using equations 3 and 4 of satisfaction index, the rejection and VIKOR indexes are calculated (Table 10).

Table 9: Determining the ideal negative and positive points

f^*	0.4112	0.4057	0.4143	0.6152	0.0864	0.6444	0.8018	0.0725	0.0921
f^-	0.4034	0.4126	0.3918	0.0684	0.6047	0.0921	0.0891	0.6529	0.6444

Table 10: Satisfaction, rejection and VIKOR indexes for alternatives

alternatives	S_i	R_i	Q_i
A1	0.3764	0.1045	0.9391
A2	0.5136	0.2064	0.4203
A3	0.5985	0.2064	0.1916
A4	0.6136	0.3096	0.0000
A5	0.3538	0.1045	1.0000
A6	0.5421	0.209	0.3397

Finally, the options were arranged based on the values of Q, R, S in three groups from small to large. The best option is that having the smallest Q, so the fourth option (10×10×10 meters) was recommended as optimal size for mineral blocks in Angouran mine.

Conclusion

Several factors affect the size choice of mineral blocks. Without using a scientific and efficient approach, appropriate block size cannot be determined based on mere engineering judgment. In addition to good compliance with geostatistical and spatial distribution principles of data, optimal block size should have relative desirability relative to other extraction, technical and economic criteria. The use of multi-criteria decision-making techniques is very helpful as it enables consideration of simultaneous impact of different criteria by taking into account their different relative importance. In this paper, we introduced a comprehensive set of effective criteria to determine the appropriate size of block using the multi-criteria decision-making method of VIKOR, which indicated 10 m block as the nest option (most appropriate size) for Angouran mine.

References

1. Haldar S. K., *Mineral Exploration: Principles and Applications*. Elsevier Science Publishing Co Inc, United States (2013).
2. Oraee K., Hosseini N., Gholinejad M., *A New Approach for Determination of Tunnel Supporting System Using Analytical Hierarchy Process (AHP)*. Proceeding of 2009 Coal Operators' Conference, The AusIMM Illawarra Branch. University of Wollongong. (2009) 78- 89.
3. Aghajani A., Osanloo M., *Application of AHP-TOPSIS Method for Loading-Haulage Equipment Selection in Open pit Mines*. XXVII international Mining Convention, Mexico (2007).
4. Bascetin A., *An application of the analytic hierarchy process in equipment selection at Orhaneli open pit coal mine*. Mining Technology (Trans. Inst. Min. Metall. A). 113 (2004) A192-A199.
5. Samanta B., Sarkar B., Murherjee S. K., *Selection of opencast mining equipment by a multi-criteria decision-making process*. Mining Technology (Trans. Inst. Min. Metall. A), 111 (2002) 136–142.
6. Zare Naghadehi M., Mikaeil R., Ataei M., *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, (2008) doi:10.1016/j.eswa.2008.10.006
7. Karadogan A., Bascetin A., Kahriman A., Gorgun S., *A new approach in selection of underground mining method*. In: Proceedings of the International Conference – Modern Management of Mine Producing, Geology and Environment Protection, (2001) 171– 183.
8. Ataei M., *Multi criteria selection for alumina–cement plant location in East-Azerbaijan province of Iran*. The Journal of the South African Institute of Mining and Metallurgy, 105 (7) (2005) 507–514.
9. Bitarafan M. R., Ataei M., *Mining method selection by multiple criteria decision making tools*. The Journal of the South African Institute of Mining and Metallurgy. 104 (9) (2004) 493–498.
10. Kazakidis V. N., Mayer Z., Scoble M. J., *Decision making using the analytic hierarchy process in mining engineering*. *Mining Technology (Trans. Inst. Min. Metall. A)*, 113 (1) (2004) 30–42.
11. Bottero M., Peila D., *The use of the Analytic Hierarchy Process for the comparison between micro tunneling and trench excavation*. Tunneling and Underground Space Technology, 20 (6) (2005) 501–513.
12. Alpay S., Yavuz M., *Underground mining method selection by decision making tools*. *Tunneling and Underground Space Technology*, 24 (2) (2009) 173–184.
13. Saaty T. L., Vargas L. G., *Decision making with the analytic network process: economic, political, social and technological applications with benefits, opportunities, costs and risks*, New York: Springer (2006).
14. Chu M. T., Shyu J., Tzeng G. H., Khosla R., *Comparison among three analytical methods for knowledge communities group-decision analysis*. Expert Systems with Applications, 33(4) (2007) 1011–1024.
15. Opricovic S., Tzeng G. H., *Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS*. European Journal of Operational Research, 156(2) (2004) 445–455.
16. Earth mine Corporate consulting., *Report of plan of ANGOURAN mine*. (2013).
17. Boni M., Gilg H. A., Balassone G., Schneider J., Allen C. R., Moore F., *Hypogene Zn carbonate ores in the Angouran deposit. NW Iran*. Miner Deposit, 42(8) (2007) 799-820.
18. Khereshki M. H.; Sharif J., *Determination of optimum block size of Angouran Zinc-Lead Mine with geostatistic and extraction data by AHP-TOPSIS*. Fifth Conference on Mining Engineering, 22-24 October, Mosalla Imam Khomeini, Tehran, (2014) in Persian.
19. Mahdavi I., Mahdavi-Amiri N., Heidarzade A., Nourifar R., *Designing a model of fuzzy TOPSIS in multiple criteria decision making*. Applied Mathematics and Computation, 206(2) (2008) 607–617.
20. Aczel J., Saaty T. L., *Procedures for synthesizing ratio judgments*, Journal of Mathematical Psychology, 27 (1983) 93-102.

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