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Use of a mixed integer programming model to achieve an optimum size of blast block in open-pit mining with regard to size of mineable block using fuzzy logic approach

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Abstract

In this paper, we present an integrated model to find the optimum size of blast block that uses (i) a multi-criteria decision-making method to specify the applicable size of the mineable block; (ii) a linear programming method for the selection of the blasted areas to be excavated and in deciding the quantity of ores and wastes to be mined from each one of the selected blocks. These two methods use improved estimates of the orebody characteristics utilizing the blast hole data in addition to the usual borehole statistics to improve the prediction accuracy of the block level ore body characteristics. This work aims to make a mathematical model to figure out the ideal width and length of the blast block in order to curtail drilling and blasting expenses in open-pit mines. As a consequence, the effective blast block size is heeded so as to decrease the expenses of drilling and blasting. Furthermore, a complete set of actual principles is presented to specify the applicable size of the mineable block by means of the multi-criteria decision-making method of fuzzy logic. The aforementioned model is practiced to forecast the block size necessary for the purpose of production planning. Next, a mixed integer programming model is developed to blast planning in order to select the optimal size of the blast block by considering the mineable block. The proposed model is applied in the Chadormalu iron ore mine and the rationality of the model is demonstrated by the outcomes of dissimilar circumstances.

1. Introduction

A precise estimation of the ore/waste block size is necessary for technical and economical designs, and this precision affects the results of the feasibility study, mine planning and scheduling optimization, blast block size, projection of cash flows, and enhancement of the processing plant efficiency. As drilling and blasting operations are regarded as the two significant unit operations, it is essential to scrutinize from planning, design, and within mine exploitation views. In open-pit mines, the above-mentioned operations are considered as the most essential mining processes, holding the fundamental measure of mining outlays. The most inexorable part of mining operations is blasting operation, although the mechanized drilling in surface mining has been extraordinarily advanced.

In every hard rock mine, drilling is counted as one of the important and serious operations, which bestows roughly 15% of the whole mining budget in some mining operations [1]. According to the fact that choosing proper methods of drilling and blasting would considerably diminish outlays and develop productivity while retaining fragmentation and wall control, finding such suitable methods is the procedural parts that have been well-delved [1, 2]. Quite a few elements influence the blasting

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expense of any piece of in-situ rock. It is important to bear in mind that they are not bound to the patterns and blast geometric factors. They take in oversize boulders, labor, toes, and geological nature of the formation, rock type and density, explosives costs, block size, explosives costs, etc. As confirmed in terms of environmental problems and fragmentation, the actual charge of poor blasting can be a number of times the cost of the blast itself. Studies on different operations indicate that a mining process controls mine blasts, mostly fragment rocks, even though there may be ideal fragmentation to develop the efficiency and decrease the charge of the entire downstream events and improve the blast design factors that are able to shrink the drilling and blasting costs of a mine [3]. The main obstacle is to find the optimal dimensions of blast block, although it has been ignored. Nevertheless, the least cost for blast size is not probably the concern of the whole mining system. The objective of the mining operator work should be to accomplish the lowest joined budget of drilling, blasting, loading, hauling, crushing, and grinding. Holistically, a little more money spent on the blast block dimensions' operation can be well-gained later. On the other hand, in mining operations, the design and production program are developed on the basis of a block model.

Shurygin [4] has proposed the optimal effective pattern. In cases where the drilling goal is to evaluate the deposit grade accurately, the objective function is defined as a global kriging variance minimization [5-7]. Qahwash [8] has presented a method for the optimal location of drill holes and their lengths based on the available geophysical data, pointing out the necessity of considering the existing data in locating new drill holes. The researchers have presented the results [9-11] on locating additional drill holes using the semi-manual method for the selection of the drill hole locations. This method is based on dividing the desired area into various blocks, finding the estimation variance for every block, selecting the block with the highest estimation variance as the point for the next drill hole, and calculating the effect of this drill hole on the total estimation variance. Based on the mathematical optimization programming, Chou and Schenk [5] have proposed a model that, unlike the semi-manual algorithm, could find a solution to the problem. Szidarovszky [6] has proposed an algorithm based on the 'branch and bound method for finding the optimal locations of the drill holes with the objective of minimizing the estimation variance while minimizing the number of drill holes. Gershon [12] has proposed a branch and bound search algorithm that could find the locations of exploration drill holes. Hassanipak and Sharafodin [13] have solved the problem of locating the additional drill holes wherein both the effects of the estimation variance on locating the drill holes and the thickness and grade of the ore have been considered. Soltani and Hezarkhani [14] have solved the optimization problem of locating additional drill holes based on the 3D deposit model with the objective of minimizing the estimation variance using the simulated annealing algorithm. Clearly, the location of surplus drilling holes will have a significant impact on the size of the blast block. Several preceding studies have concentrated on drilling and blasting only from the view point of cost decrease by various tools. Afeni and Afum *et al*. have attempted to probe the cost impacts of different drilling utensils and blasting forms by onsite and experimental interpretations in two open-pit mines [15, 16]. Drilling and blasting operations have been technically improved by other researchers. For a bench blasting design, a dynamic model has been analyzed by Sontamino and Drebenstedt [17]. In an open-pit mine, an applied method has been presented by Bowa in order to optimize the blasting design factors including spacing, bench height, drill holes diameter, etc. [18]. In order to decrease the operating outlays over an experimental method, a specific control has been specified by Tosun and Konak for blasting operation [19]. To figure out the extreme surge in mining expenses for which it remains gainful to mine at a smaller block size, Jara *et al*. have conducted a study on the growth in the mining budget providing a zero difference in the net present values between the different block size options [20].

The blast block dimensions select an essential factor of the model since this brings about mining dilution and selectivity influences the operation and mining outlays. The current study aimed to put a figure on the effect of the blast block size on the mining selectivity and its influence over the projects of the last economic outcomes (expenses, income, and reduced cash currents). Based on the review of the literature, no serious study has been thoroughly conducted on this issue yet. Thus in this paper, the objective is to find the optimal blast block dimensions by correct choosing the ore/waste block size. The proposed model estimates the size of a mineable block based on the multi-criteria decision-making theory and using the effective parameters. Then estimating the dimensions of the blast block was obtained using mixed integer programming (MIP) and integration of the

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decision-making theory in the mentioned model. This paper is organized as what follows. Section 2 describes the effective parameters in the extraction block selection. The decision-making theory for matrix correlation is shown in Section 3. In Section 4, the necessity of determining the optimal size of the blast block has been explained. In Section 5, problem modeling is performed based on MIP with available constraints. The framework of the proposed hybrid model is presented in Section 6. The proposed model is implemented on the Chadormalu Iron Ore mine and its results can be seen in Section 7. Finally, the conclusions are made in the last section.

2. Elements influencing optimal mineable block size

Finding the mineable block size depends on three main factors including the mining equipment, deposit geology that results in the mining exploitation method, and site factors. Regarding the mentioned issues, the selective mineable blocks should have the ability to predict the amounts of ore, waste or their mixture, which are to be used for production drilling. Figure 1 illustrates the factor affecting the choice of an ideal mineable block.

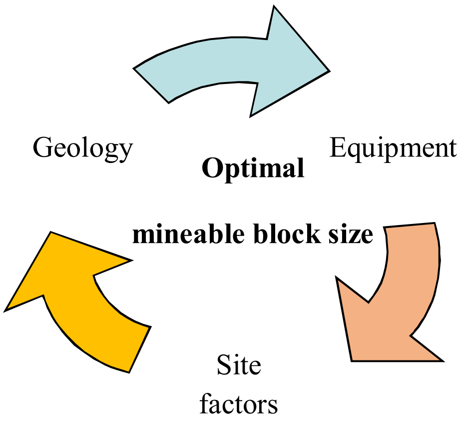

Figure 1. Loop-like relationship between effective parameters in choosing the optimal mineable block size.

Each aspect of the main factors includes the following parts:

- Geology: Rock density (RD), strike and dip value (SV), joint structure and frequency (JF), grade (G), dilution (D), water status in the block (W).
- Equipment: Feed thrust (FT), impact frequency (IFR), piston strike (PS), impact pressure (IP), rotation rate (RR), type of drill rig (DR), type of bit (B).
- Site factors: Dimensions of the face (DF), hole diameter ratio/spacing and burden (SB), length of hole (LH), inclination of hole (IH), number of rows (NR), wet or dry holes (WD), drilling sequence (DS).

3. Multi-criteria decision-making method

When the number of benchmarks rises in multi-criteria decision-making methods, it is difficult to enforce a paired comparison process. This subject becomes critical when the number of decisions and variables surges. Furthermore, the involvement of the decision team or the attitude of experts deeply affect the fallouts. This research wok introduces a mathematical model initially presented by Folchi [21]. Additionally, this model is practiced to evaluate the environmental influences of an open-pit mine in Italy. In consequence, a correlation matrix (holding impacting factors (IFs) and decision components (DCs)) is practiced. Some authors have already applied this approach [22, 23] to evaluate mines from an environmental view point. Nevertheless, the aim of this work was to employ the model for the first time in the field of mineable block dimensions and to determine its ability. The fuzzy logic will modify the model [24] to define some scenarios and values so as to improve the consistent precision. The factors influencing the size of blocks are considered as the input data of the model. The analysis of different literature defines the fuzzy scenarios of each factor. To determine the influence of IFs on each DC (Eq. 1), the values for IFs are multiplied by the correlation matrix. Considering the general influences, the AS index is attained due to Eq. 2-4.

$$[E]_{1\times m} = [F]_{1\times n} \cdot [C]_{n\times m} \qquad (1)$$

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$$AS_{Geo} = \sum_{j=1}^{m} E_j \tag{2}$$

$$AS_{Equ} = \sum_{j=1}^{m} E_j \tag{3}$$

$$AS_{SF} = \sum_{j=1}^{m} E_j \tag{4}$$

where E is a (1 × m) matrix in which each element signifies the amount of the general effect on every decision component, F represents a (1 × n) matrix in which features symbolize values of the influencing elements, and C is an (n × m) correlation matrix. The factors n and m are the numbers of IFs and decision components, individually; and AS_{Geo}, AS_{Equ}, and AS_{SF} are the block score indices for decision-making on the geology, equipment, site factor, and cost factor of a mineable block, correspondingly.

3.1. Correlation matrix

The effects of IFs on the following five decision components is evaluated by the correlation matrix:

- Conventionality of temporary production scheduling with enduring production planning (I),
- Controlling the blasting contrary influences (II),
- Enhancing the efficacy of drilling machines (III),
- Developed safety (IV),
- Decreasing drilling, blasting, and loading operations (V).

The nil, minimum, medium, and maximum in a matrix were used to express the impact weight of every IF on each decision component (DC). Considering the questionnaire in Table 1, these weights were obtained from a combination of attitudes of 30 researchers in the field of ore block modeling (questionnaire as Table 1). The elements of this matrix are quantified by defining the maximum effect, which is twice the medium effect, and medium effect, which is twice the minimum effect. Here, the sum of these coefficients for each DC equals to 10. With the contribution of the sorting indicated in Table 2, a suitable decision for the applicability size of mineable blocks can be made after the AS index is calculated.

Table 1. Questionnaire.

Impact factor (IF)		Decision component (DC)				
		(I)	(II)	(III)	(IV)	(V)
Geology	RD					
	SV					
	JF					
	G					
	D					
	W					
Equipment	FT					
	IFR					
	PS					
	IP					
	RR					
	DR					
	B					
Site factor	DF					
	SB					
	LH					
	IH					
	NR					
	WD					
	DS					

Table 2. Classification of applicability of mineable block size.

AS	150-200	100-150	<100
Quality	Good	Medium	Poor

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4. Necessity to determine optimal size of blast block

As mentioned earlier, the drilling and blasting operations consist of more than one-third of mining costs at open-pit minings. Figure 2 shows the diagram pertains between the operational costs in open-pit mines regarding the related factors [25]. Large blastings in open-pit mining enhance the mine productivity by improved amount of unproductive transfer time for all unit operations. The drilling rigs and shovels can work much time at a bench, and also charging the production holes is more efficient and safe. Increasing the dimension of blast block causes tramming and movement of drilling done with fewer delay. A better rock fragmentation is also expected with increasing the number of blasting holes in a blast block. As a rule of thumb, the blast block size should be as large as practicable. In this approach, the number of rows of blast holes is usually dictated by the working width of the bench and burden in open-pit mines [26]. In spite of the positive effects obtained by selecting a large blast block in an open-pit mine, the safety and environmental issues cause problems in this regard. Figure 3 shows the environmental considerations for an increased blasting effort in surface mining [27]. On the whole, as a rule, a better fragmentation is achieved in multi-row blasting than the small blocks, where the drilling rows are limited [28]. Therefore, for finding the optimal blast block size in open-pit mines, the mining engineers should make the account of all effective operational factors.

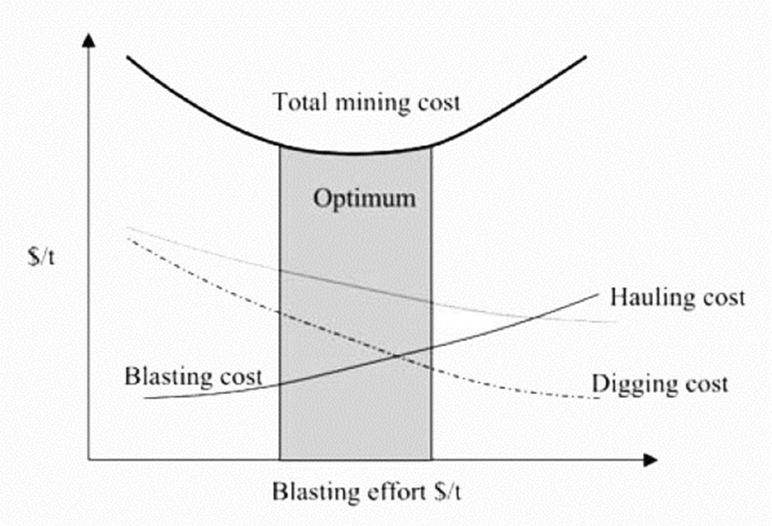

Figure 2. Optimum blasting with traditional approach [25].

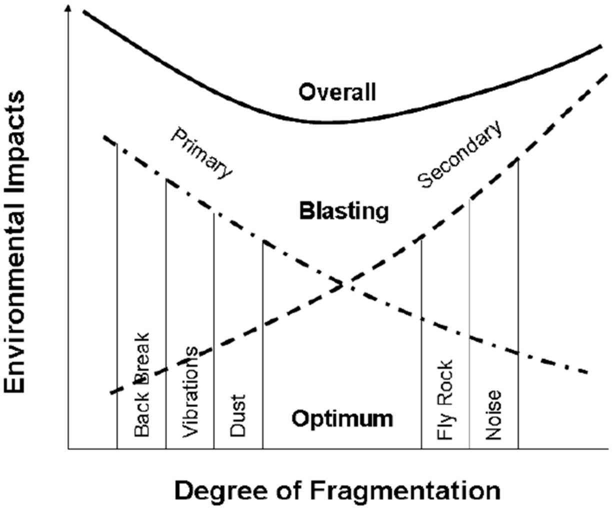

Figure 3. Environmental considerations for increased blasting effort [27].

5. Blast pattern planning using MIP model

The blast pattern planning module interacts with the size of mineable block for the model. It generates the blast planning MIP model and is solved to achieve the optimal blast size. In other words, by obtaining the optimal size of the mineable blocks in

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the previous step using the decision theory (fuzzy logic), in this section, using MIP, the size of the blast block (blast pattern) will be determined. The objective of the blast pattern planning module is to specify the blocks from the available benches of an open-pit mine to blast for the following production period so that the demand in terms of both quality and quantity of the period can be met. This situation is modelled as an MIP problem. The module maximizes the number of blocks to blast, subject to the operational and physical constraints. Thus the blast planning MIP model is formulated as follows:

$$\text{Maximize} \quad Z(X)=\sum_{ijk\in\Gamma}\sum_{s=1}^{S} X_{ijk}^{s} \tag{5}$$

In the constructed model, the following indications were accepted: ijk is the block identification number, ijk = 1, 2,…,Γ; Γ is the total number of blocks to be scheduled per month; s is the shift index, s = 1, 2,…, S; S is the total number of shifts, and X_{ijk}^{s} is a variable that takes the value of one if block ijk is fully to be; s is the shift index per month, s = 1, 2,…, S; S is the total number of shifts, and X_{ijk}^{s} is a variable that takes the value of one if block ijk is fully to be, s = 1, 2,…, S; S is the total number of shifts, and X_{ijk}^{s} is a variable that takes the value of one if block ijk is fully to be blasted and zero if it is not to be blasted.

5.1. Constraints

Grade blending constraints. One of most important problems in the blast blocks is the ore grade that has to be kept steady while sending to the processing plant. Due to this, the grade of ore that is being sent to mill should be defined between two bounds.

Upper Bound Constraints. The average grade of the material sent to the mill has to be less than or equal to the certain grade value G_{max} for each shift s:

$$\sum_{ijk\in\Gamma}\left(g_{ijk}-G_{max}\right)\times O_{ijk}\times X_{ijk}^{s}\le 0 \tag{6}$$

where g_{ijk} is the average grade of block ijk and O_{ijk} is the ore tonnage in block ijk.

Lower Bound Constraints. The average grade of the material sent to the mill has to be greater than or equal to the certain value G_{max} for each shift s:

$$\sum_{ijk\in\Gamma}\left(g_{ijk}-G_{min}\right)\times O_{ijk}\times X_{ijk}^{s}\ge 0 \tag{7}$$

Reserve constraint. Reserve constraints are constructed for each blasted block to state that all considered blocks in the model have to be mined once.

$$\sum_{s=1}^{S} X_{ijk}^{s}=1 \qquad \forall ijk=1,2,3,\ldots,\Gamma \tag{8}$$

Processing capacity constraint. Total tons of processed ore cannot be more than the processing capacity (PC_{max}) in every shift s:

$$\sum_{ijk\in\Gamma}\left(O_{ijk}\times X_{ijk}^{s}\right)\le PC_{max} \tag{9}$$

Transport capacity constraint. Total amount of material (waste and ore) to be mined cannot be more than the total available equipment capacity (PC_{max}) for each shift s:

$$\sum_{ijk\in\Gamma}\left(O_{ijk}+W_{ijk}\right)\times X_{ijk}^{s}\le MC_{max} \tag{10}$$

where W_{ijk} is the tonnage of waste material within block ijk.

Safety width constraints. The blast block is based on the permissible width of the extracted bench.

$$\begin{gathered}\left(J_{max:k}-j\right)\times X_{ijk}^{s}\ge BW\times X_{ijk}^{s}\\ \forall ijk=1,2,3,\ldots,\Gamma\end{gathered} \tag{11}$$

where BW is the minimum bench width to be maintained for any bench in terms of blast block width.

6. Framework of proposed model

A Flow chart for the proposed model is given in Figure 4. The designed model integrates that mineable block has a user interface, a central database, a block model, and an optimal blast block. The blast block model generates blast plans and reports to the blasting and production shift in-charge. In order to consider these two different decision-making purposes, the simplest method is to formulate a full space optimization model, where in every shift of the blasting operation horizon, the availability constraints are incorporated into the model. In other words, it is assumed that the initial model of the large-scale blast block is as shown in Figure 5. Based on the fuzzy logic model, the extractable blocks will be identified, and in the next step will be to determine the optimal blast blocks using the MIP and available constraints in the proposed model.

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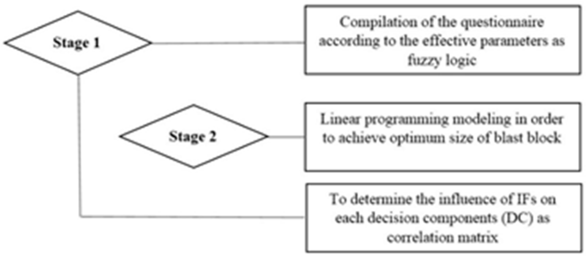

Figure 4. Framework of the proposed hybrid method.

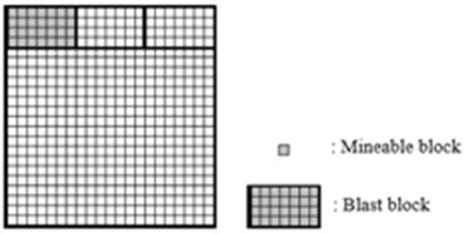

Figure 5. Schematic representation of block model including mineable block and blast block.

7. Evaluation of proposed model for Chadormalu Iron mine

The iron ore mine of Chadormalu is situated at the center of the Iran Desert, 180 km farther from NE Yazd Province, and 300 km away from the south of Tabas City (Figure 6). The deposit comprises roughly 317 Mt of ore with an average grade of 53% Fe and 1% P. The mineable block model holds 17921 blocks with the dimensions of 25 × 25 × 12.5 m.

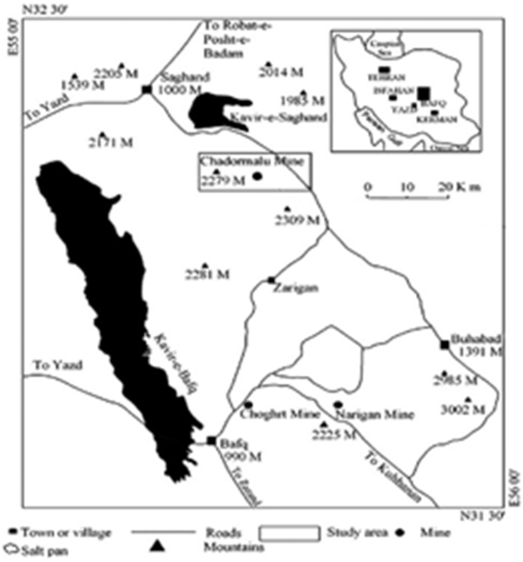

Figure 6. Geographical location of the Chadormalu Iron Ore mine.

Since Tables 1, I, II, III, IV, and V are measurable standards, their values for several options have been specified based on the comprehensive calculations. Standards are qualitative, and experts' outlooks have been applied to conclude their values for various choices. Due to Table 1, the fivefold range controlled the performance of rating and scoring in relation to the value of each one of the qualitative criteria (I to V) for each one of the options. Accordingly, Table 3 specifies the decision matrix.

Table 3. Decision matrix for the case study.

Block size (m)	Decision component				
	(I)	(II)	(III)	(IV)	(V)
2.5*2.5*2.5	122.76	170.78	222.06	145.21	86.41
5*5*5	122.54	170.67	221.72	145.27	86.44
7.5*7.5*7.5	123.15	170.52	222.34	145.28	86.47
10*10*10	122.84	170.62	221.07	145.32	86.9
12.5*12.5*12.5	123.17	170.64	222.3	145.3	87.02
15*15*15	123.22	170.68	222.36	145.29	87.11
20*20*12.5	127.14	171.21	223.42	145.37	87.2
20*20*15	131.15	171.32	222.43	145.41	87.32
20*20*20	142.78	171.38	223.47	145.42	87.39
25*25*12.5	143.15	171.41	223.48	145.44	87.41
25*25*15	143.02	171.34	223.44	145.42	87.4
25*25*25	143.14	171.32	222.43	145.43	87.41

In the current work, 20 factors influencing the dimensions of the ore blocks were recognized, and the associated scenarios were expressed in fuzzy forms. In the correlation matrix, the application that obtained the uppermost general influences was known as the most proper one. Furthermore, each shared application was assessed in terms of these constraints. It is recommended to measure all the factors presented in the model, although there are sometimes situations where it is impossible to measure one or more technical properties or it may be necessary to add or eliminate factors according to the shortage of sufficient laboratory facilities. These changes become possible by the model proposed as a dynamic one. Nonetheless, it is essential to re-calculate the new correlation

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constants. A number of decision components confine the limits of Table 3; therefore, they do not vary with the change in factors that may require to be changed. In this manner, the last standardized weight of each standard was gained. Table 4 shows the results. Consequently, Table 5 illustrates that the weighed normal matrix is achieved through multiplying the normal matrix features by means of the comparative importance of the standards.

After optimally selecting the mineable block in the previous step, the blasting pattern was obtained using the mathematical programming model presented in Section 4 (Eqs. 1 to 7). In other words, the size of the blast block was determined for each shift. The suggested models were then solved using the Risk Solver Platform V11.5 [29]. The idea was to technically develop a blast block model that would result in reduced costs due to reduced drilling equipment displacement per shift and transportation system. On the other hand, the blasting risk in the blast pattern was reduced by choosing the optimal size of blast block. As it can be clearly seen in Figure 7, the start and end points of the blast block size are identified by the possibility of developing probabilistic points to increase the blast block.

Table 4. Final weight of DC.

DC	Final weight
I	0.07545
II	0.04895
III	0.13963
IV	0.26371
V	0.09747

Table 5. Normal weight matrix.

Block size (m)	Decision component				
	(I)	(II)	(III)	(IV)	(V)
2.5*2.5*2.5	0.0462	0.0194	0.0121	0.0261	0.0186
5*5*5	0.0421	0.0197	0.0364	0.0264	0.0188
7.5*7.5*7.5	0.0435	0.0195	0.0607	0.0267	0.0192
10*10*10	0.0431	0.0198	0.0364	0.027	0.0194
12.5*12.5*12.5	0.0448	0.0196	0.0193	0.0274	0.0195
15*15*15	0.0458	0.0195	0.0121	0.0277	0.0199
20*20*12.5	0.0421	0.0175	0.0855	0.0281	0.0207
20*20*15	0.0431	0.0176	0.0721	0.0283	0.0208
20*20*20	0.0441	0.0173	0.0723	0.0287	0.0223
25*25*12.5	0.0419	0.0172	0.0719	0.0288	0.0228
25*25*15	0.0422	0.0174	0.0748	0.0286	0.0226
25*25*25	0.0423	0.0173	0.0771	0.0288	0.0224

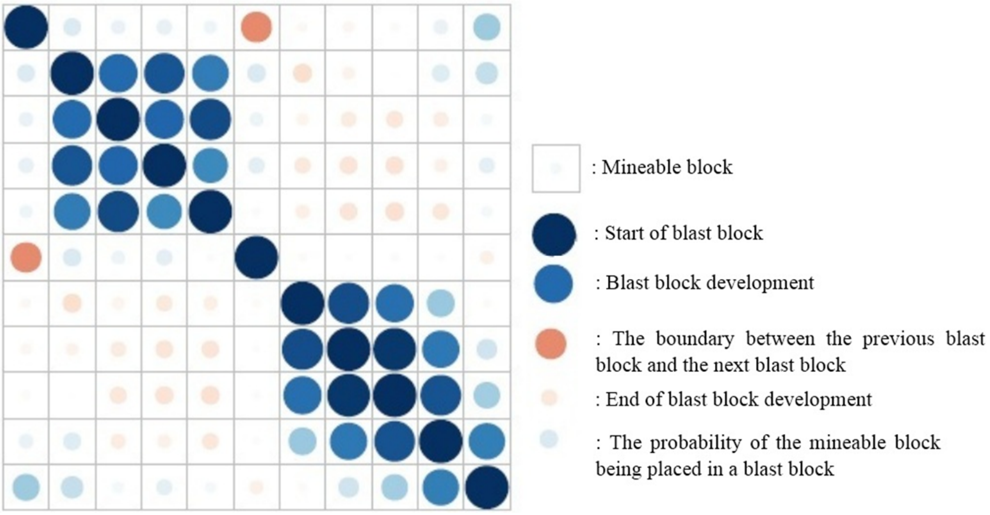

Figure 7. Blast block obtained from the proposed model for mineable blocks at each shift from Chadormalu iron ore mine.

8. Conclusions

Optimally choosing the blast block size is a challenging issue faced in different phases of mine planning and exploration projects, and should be based on the requirements of the specific phase. Without using a scientific and efficient approach, the appropriate block size cannot be determined based on a mere engineering judgment. In addition

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to good compliance with geostatistical and spatial distribution principles of data, an optimal block size should have a 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 the simultaneous impact of different criteria by taking into account their different relative importance. In this paper, a comprehensive set of effective criteria to determine the appropriate size of a mineable block was introduced using the multi-criteria decision-making method. Furthermore, a complete set of actual principles was presented to specify the applicable size of the blast block by means of the multi-criteria decision-making method of fuzzy logic. By the way, the applicability score (AS) was developed based on an engineering approach. Additionally, it is served as a means of decision-making to figure out the assortment of the functional blast block. This decision-making model contributes to predict the mineable block size for the purpose of product development. Moreover, it is applied to economically benefit and avert the forfeiture of natural resources. This model was executed for the Chadormalu Iron Ore mine. The fallouts of various scenarios indicate that the optimum blast block size of the extraction block holds 25*25*12.5 m. After optimally selecting the mineable block, the blasting pattern was obtained using the mathematical programming model. The results obtained show that the proposed model, considering the operational constraints, can determine the blast block size by defining the boundaries in each blast pattern.

References

[1]. Gokhal, V.B. (2010). Cost analysis of rotary blasthole drilling, CRC Press, Chapter 14.

[2]. Olofsson, S.O. (1988). Applied explosives technology for construction and mining, Nora Boktryckeri AB, Sweden, 315 P.

[3]. Bozic, B. (1998). Control of fragmentation by blasting. Rudarsko-geoloiko-nafini zbornik. 10: 49-57.

[4]. Shurygin, A.M. (1976). The probability of finding deposits and some optimal search grids. Journal of the International Association for Mathematical Geosciences. (8): 323-330.

[5]. Chou, D. and Schenk, D.E. (1983). Optimum locations for exploratory drill holes. International Journal of Mining Engineering. 1: 343–355.

[6]. Szidarovszky, F. (1983). Multi objective observation network design for regionalized variables. International Journal of Mining Engineering. 1: 331-342.

[7]. Gershon, M., Allen, L.E. and Manley, F. (1998). Application of a new approach for drill holes location optimization, International Journal of Mining Reclamation and Environment. 2: 27-31.

[8]. Qahwash, A.L.A. (1987). An optimal algorithm for drilling strategy. Energy. 12 (6): 423-425.

[9]. Kim, Y.C., Myers, D.E. and Kundson, H.P. (1977). Advanced geostatistics in ore reserve estimation and mine planning, Washington, DC, US Department of Energy.

[10]. Kim, Y.C., Martino, F. and Chopra, I. (1981). Application of geostatisticsin a coal deposit, Mining Engineering. 33 (11): 1476-1481.

[11]. Walton, D.R. and Kauffman, P.W. (1982). Some practical considerations in applying geostatistics to coal reserve estimation, Dallas, SME-AIME.

[12]. Gershon, M.E. (1983). Optimal drillhole location using geostatistics, Atlanta, SME-AIME.

[13]. Hassanipak, A.A. and Sharafodin, M. (2003). Get: A function for preferential site selection of additional borehole drilling, Exploration Mining Geology. 13 : 139-146.

[14]. Soltani, S. and Hezarkhani, A. (2009). Additional exploratory boreholes optimization based on three-dimensional model of ore deposit, Archives of Mining Sciences. 54: 495-506.

[15]. Afeni T.B. (2009). Optimization of drilling and blasting operations in an open pit mine the SOMAIR experience, Mining Science Technology. 19: 736-739.

[16]. Afum, B.O. and Temeng, V.A. (2015). Reducing drill and blast cost through blast optimisation case study, Ghana Mining Journal. 15 (2): 50-57.

[17]. Sontamino, P. and Drebenstedt, C.A. (2012). A prototype dynamics model of bench blasting design, The 10th international conference on mining, materials and petroleum engineering, Sciences and Technologies Towards, Songkhla, Thailand. 9-11 May.

[18]. Bowa, V.M. (2015). Optimization of blasting design parameters on open pit bench a case study of Nchanga open pits. International Journal of Scientific & Technology Research Res. 4 (9): 45-51.

[19]. Tosun, A. and Konak, G. (2015). Determination of specific charge minimizing total unit cost of open pit quarry blasting operations. Saudi Society for Geosciences. 8 (8): 6409-6423.

[20]. Jara, R.M., Couble, A., Emery, X., Magri, E.J. and Ortiz, J.M. (2006). Block size selection and its impact on open-pit design and mine planning. Journal of the South African Institute of Mining and Metallurgy. 106 (3): 205-212.

[21]. Folchi, R. (2003). Environmental impact statement for mining with explosives: A quantitative method, 29th Proceedings annual conference on explosives and

www.SID.ir

Archive of SID

blasting technique, Tennessee, U.S.A. ISEE, 2-5, February. pp. 285-296.

[22]. Sereshki, F. and Saffari, A. (2016). Environmental impact assessment and sustainability level determination in cement plants (Case study: Shahrood cement plant). Iranian Journal of Earth Sciences. 8 (2): 90-101.

[23]. Phillips, J. (2013). The application of a mathematical model of sustainability to the results of a semi-quantitative environmental impact assessment of two iron ore opencast mines in Iran. Applied Mathematical Modeling. 37 (14-15): 7839-7854.

[24]. Saffari, A., Ataei, M., Sereshki, F. and Naderi, M. (2019). Environmental impact assessment (EIA) by using the Fuzzy Delphi Folchi (FDF) method (case study: Shahrood cement plant, Iran). Environment, Development and Sustainability. 21 (2): 817-860.

[25]. Kanchibotla, S.S. (2010). Optimum blasting? Is it minimum cost per broken rock or maximum value per broken rock? 35-48.

[26]. Hammes, J.K. (1966). The economics of producing and delivering iron ore pellets from North American taconite type resources. Proceedings of the 27th Annual Mining Symposium, University of Minnesota. pp. 9-16.

[27]. Da Gama, C.D. and Jimeno, C.L. (1993). Rock fragmentation control for blasting cost minimization and environmental impact abatement", FRAGBLAST, Rossmanith (ed.), Balkema, Rotterdam. pp. 273-280.

[28]. William Hustrulid, (1999). Blasting Principles for Open Pit Mining, A. A. Balkema. 185 P.

[29]. Premium solver platform version 11.5. (2011). User guide by frontline systems, Inc. www.solver.com.

www.SID.ir

Archive of SID

بکارگیری مدل برنامه‌ریزی عدد صحیح مختلط با هدف دستیابی به ابعاد بهینه بلوک انفجاری در روش استخراج روباز با در نظرگیری ابعاد بلوک استخراجی با استفاده از رویکرد منطق فازی

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چکیده:

در این پژوهش، یک مدل یکپارچه برای یافتن اندازه مطلوب بلوک انفجار ارائه می‌شود که طی آن در گام نخست با استفاده از یک روش تصمیم‌گیری چند معیاره اندازه بلوک معدنی قابل‌استخراج احصاء شده و متعاقباً با روش برنامه‌ریزی خطی برای انتخاب بلوک انفجاری به منظور حفاری و تصمیم‌گیری در مورد مقدار سنگ معدن و باطله در هر یک از بلوک‌های منتخب اقدام می‌شود. این دو روش با استفاده از داده‌های چال‌های تولیدی علاوه بر گمانه‌های معمول اکتشافی برای بهبود ارزیابی و تعیین دقیق‌تر خصوصیات سنگ معدن و بلوک انفجاری استفاده می‌شود. این پژوهش با هدف ایجاد یک مدل ریاضی برای شناسایی طول و عرض بهینه بلوک به منظور کاهش هزینه‌های حفاری و انفجار در معادن روباز انجام شده است. در نتیجه، اندازه بلوک انفجاری مؤثر با هدف کاهش هزینه‌های حفاری و انفجار مورد توجه قرار می‌گیرد. علاوه بر این، مجموعه کاملی از اصول کاربردی برای تعیین ابعاد مناسب بلوک قابل‌استخراج با استفاده از روش تصمیم‌گیری چند معیاره با رویکرد منطق فازی ارائه شده است. مدل فوق برای پیش‌بینی اندازه بلوک مورد نیاز برای برنامه‌ریزی تولید استفاده می‌شود. در مرحله بعد مدلی مبتنی بر برنامه‌ریزی عدد صحیح مختلط تبیین شد تا به وسیله آن با در نظر گرفتن برنامه‌ریزی انفجار، امکان تعیین ابعاد بهینه بلوک انفجار فراهم شود. مدل ارائه شده در معدن سنگ‌آهن چادرملو مورد استفاده قرار گرفت و روایی و پایایی آن با نتایج حاصل در شرایط متفاوت نشان داده شد.

کلمات کلیدی: اندازه بلوک انفجاری، بلوک قابل‌استخراج، بهینه‌سازی، معدن روباز، برنامه‌ریزی عدد صحیح مختلط، منطق فازی.

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