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APPLICATION OF UBC METHODOLOGY FOR UNDERGROUND MINING METHOD SELECTION

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Abstract: The total operating costs of each mine largely depend on the method of mining. Therefore, the appropriate choice of the method of mining excavation is very important and great attention is paid to this issue. There are several procedures for the selection of the mining method, among which the most important and most commonly used numerical method is the UBC methodology for the selection of the mining method. According to this methodology, the choice of the method of mining excavation is based on the mining-geological parameters of the ore and adjacent rocks. In this paper, the UBC methodology for the selection of the mining excavation method for a specific case will be applied. According to this methodology, it was obtained that Cut and Fill method is best ranked for specific conditions and the most appropriate way of mining.

Keywords: mining method, rational choice, UBC methodology, mining parameters, geological parameters

1 INTRODUCTION

When opening a new mine for underground exploitation or opening a new section in an already active underground mine, the correct choice of the method of mining excavation is of great importance. The correct choice of the method of mining excavation has the greatest direct impact on the total costs of exploitation of a given ore deposit, and thus affects the effect of the mine. The choice of the mining method depends on many parameters, and the more parameters are taken into account, the more adequate the choice of the mining method will be. The parameters that affect the choice of mining method can be divided into three groups (Bogdanovic et al., 2012):

- mining-geological parameters,

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- mining-technical parameters, and
- economic parameters.

Several authors have dealt with this issue, and it is widely believed that the procedure for choosing the method of mining excavation can be divided into rational and optimal choice of the method of mining excavation (Mijalkovski et al., 2021a).

In the rational choice of the method of mining excavation, the methods of mining excavation are distinguished according to the mining-geological parameters. The purpose of rational selection is to reduce the number of mining excavation methods, which will be considered later in the optimal choice. In the optimal choice of the method of mining excavation, the choice is made according to the mining - technical and economic parameters.

In practice, there are cases when mining-geological factors allow the application of a certain mining method of excavation, but its application is not economically justified. There are also cases that a certain way of mining excavation allows the use of certain mechanization, but this is not allowed by mining and technical factors (Bogdanovic et al., 2012). All this indicates complex and responsible work in choosing the method of mining excavation.

2 METHODOLOGY

Methodologies for the selection of the mining method (MMS) can be divided into three groups: qualitative methods, numerical methods and decision-making methods (Nourali et al., 2012). A comprehensive survey of literature on the first two groups can be found in Namin et al. (Namin et al., 2009).

The classification system proposed by Boshkov and Wright (1973), was one of the first qualitative classification schemes attempted for underground mining method selection. It uses general descriptions of the ore thickness, ore dip, strength of the ore, and strength of the walls to identify common methods that have been applied in similar conditions. Later, Morrison (1976), Laubscher (1981), Hamrin (1982, 1998), Hartman (1992), etc have suggested a series of approaches for mining method selection.

The first numerical approach for mining method selection was suggested by Nicholas (1981, 1992). This methodology numerically ranks deposit characteristics of ore geometry and rock mechanic characteristics of the ore zone, footwall and hanging wall. The rankings are then summed together whit the higher rankings being the more favorable or likely mining methods. In 1992 Nicholas made some modification to his selection procedure by introducing a weighting factor. The UBC (University of British Columbia) mining method selection algorithm developed by Miller, Pakalnis and Poulin (1995) is a modification to the Nicholas approach, which places more emphasis on stoping methods, thus better representing typical Canadian mining design practices (Miller et al., 1995).

Qualitative and numerical methods for selection of mining excavation method, selection of mining excavation method according to mining - geological parameters.

The most important mining-geological parameters that are taken into account when choosing a method of mining excavation are the following (Bogdanovic et al., 2012):

- geometry of deposit (general shape, ore thickness, dip, plunge, depth below the surface),
- rock quality (ore zone, hangingwall and footwall, i.e. rock substance strength, fracture spacing, fracture shear strength, rock quality designation, structures, strength, stress, stability),
- ore variability (ore boundaries, ore uniformity, continuity, grade distribution),
- quality of resource, etc.

In this paper, the UBC methodology will be applied to the selection of the most favorable method of mining excavation according to mining-geological parameters, ie the rational selection of a group of favorable methods for the exploitation of a certain ore deposit.

Ghazdali et al. In 2021, used the UBC to select the optimal mining method for shallow-dip vein deposits hosted in poor-quality rock (Ghazdali et al., 2021). Namin et al. In 2003, used the UBC for Mining Method Selection in Third Anomaly of Gol-E-Gohar Iron Ore Deposit (Namin et al., 2003). Ali and Kim in 2021, used the selection mining methods via multiple criteria decision analysis using TOPSIS and modification of the UBC method (Ali and Kim, 2021).

3 UBC METHODOLOGY

The UBC methodology for the selection of mining methods is a modified version of the Nicholas approach (Miller et al., 1995). This methodology was proposed by the University of British Columbia - Canada. The UBC methodology is primarily used for deep ore deposits to eliminate or limit the use of surface mining methods. Surface digging methods are quite diverse methods of excavation, which are seemingly always applicable excavation methods when the depth of ore deposits is not large.

The choice of mining methods according to the UBC methodology is a numerical ranking, to determine the method of mining or a group of excavation methods that are suitable for excavation of a given ore deposit. The choice of excavation method is based on:

- parameters for deposit geometry,

- grade distribution and
- mechanical characteristics of rock mass.

The adoption of parameters for the geometry of the ore body and grade distribution is done on the basis of the data shown in Table 1.

Table 1 Definition of Deposit Geometry and Grade Distribution (Miller et al., 1995)

General shape / width	equi-dimensional	all dimensions are on the same order of magnitude
	platy-tabular	two dimensions are many times the thickness, which does not usually exceed 35 m
	irregular	dimensions vary over short distances
Ore thickness	very narrow	< 3 m
	narrow	3 ÷ 10 m
	intermediate	10 ÷ 30 m
	thick	30 ÷ 100 m
	very thick	> 100 m
Plunge	flat	< 20º
	intermediate	20 ÷ 55º
	steep	> 55º
Depth below surface	shallow	0 ÷ 100m
	intermediate	100 ÷ 600 m
	deep	> 600 m
Grade distribution	uniform	the grade at any point in the deposit does not vary significantly from the mean grade for that deposit
	gradational	grade values have zonal characteristics, and the grades change gradually from one to another
	erratic	grade values change radically over short distances and do not exhibit any discernible pattern in their changes

The adoption of parameters for mechanical characteristics of ore, hanging wall and footwall is done on the basis of data shown in Table 2.

Table 2 Rock Mechanics Characteristics (Miller et al., 1995)

Rock Mass Rating (RMR)	very weak	0 ÷ 20
	weak	20 ÷ 40
	moderate	40 ÷ 60
	strong	60 ÷ 80
	very strong	80 ÷ 100
Rock Substance Strength (RSS)	very weak	< 5
	weak	5 ÷ 10
	moderate	10 ÷ 15
	strong	> 15

The UBC methodology for mining method selection classifies rock mechanics into two parameters, namely: Rock Mass Rating (RMR) and Rock Substance Strength (RSS). The Rock Mass Rating (RMR) consists of the Bieniawski's Rock Mass Rating (CSIR-1973).

This classification or ranking uses six input parameters that can be obtained from the research holes, and they are: strength of intact rock material, Rock Quality Designation (RQD), intermediate spacing of joints, condition of joints, ground water conditions and discontinuity orientation.

The Rock Substance Strength can be determined based on the value of the uniaxial compressive strength of the rock mass (σ_c, MPa).

The Fracture Spacing is defined by the number of fractures per meter and the RQD classification (Rock Quality Designation). Qualitative description of the rock mass fracture was obtained by defining the number of fractures per meter.

The Fracture Shear Strength is determined by observing existing fracture systems.

For a given ore body, it is necessary to adopt parameters for deposit geometry and grade distribution, and rock mechanic characteristics (ore, hanging wall and footwall) according to the divisions shown in Table 1 and Table 2.

Based on the previously mentioned parameters for the ore body, the following excavation methods are selected:

- Block Caving;
- Sublevel Stoping;
- Sublevel Caving;
- Room and Pillar Mining;
- Shrinkage Stoping;

- Cut and fill Stoping;
- Top Slicing;
- Square Set Stoping;
- Longwall Mining;
- Open pit Mining.

The choice of excavation methods is made in such a way that for each method of excavation special point values are adopted, the sum of which gives the point value which is entered in a special table and on the basis of those point values the mining method selection. It should be noted that this methodology does not choose the mining method for excavation, ie it does not favor any of the mining methods used in the excavation of a given ore body. The purpose of this selection is to single out all the favorable methods of mining excavation which, based on the characteristics of the ore body shown in Table 1 and Table 2, stand out as the most efficient. The efficiency of a certain method of mining excavation, according to the mentioned methodology, is defined by the total point value. The highest total value of points indicates the most efficient method of excavation. According to this principle, the methods of mining excavation are ranked and the results are shown in the table.

In case any method of excavation has a negative total point value, it should be eliminated as an unacceptable method of excavation of a given ore body.

The method of excavation, which has a total point value of zero (0), is not excluded, but its use for excavation of a given ore body is not recommended.

The group of possible excavation methods consists of excavation methods with total point values higher than the stated ones (conditionally less than 23)**.**

The group of favorable excavation methods consists of excavation methods with total point values greater than 23 and which do not differ significantly from each other.

Excavation methods differ based on the cost of excavation, with some excavation methods low and some high (Balt and Goosen, 2020). The comparison of the relative cost of excavation, for individual excavation methods, is based on the fact that each of the excavation methods is applied in conditions that suit it. For this purpose, it is necessary to take into account the mining-technical and economic factors, ie to make the optimal choice of the method of mining excavation (Mijalkovski et al., 2021a).

4 CASE STUDY

This paper examines the active underground mine of lead and zinc, where a new part is opened and it is necessary to choose the appropriate method of excavation (Mijalkovski et al., 2021a; Mijalkovski et al., 2021b). The input data for the ore deposit are given below.

Geological factors

- The platy-tabular lead-zinc ore body;
- The surrounding rocks: footwall – slate and hanging wall – slate;
- The average thickness of the ore body is 15 m (thickness ranges from a few meters to 30 meters);
- The average plunge is 37° (from 25 to 49°);
- The depth below surface is 500 meters;
- The grade distribution is erratic.

Rock mechanics characteristics

Mechanical characteristics of the ore

- Volume mass of ore is 3,5 tons per meter cubic;
- The average compressive strength of the ore is 93 MPa (the compressive strength ranges from 46 to 140 MPa);
- The average number of fractures per meter is 4 (the number of fractures per meter ranges from 3 to 5);
- The average value of the RQD index is 67% (the value of the RQD index ranges from 64 to 70%);
- The average value of the RMR index is 74%;
- The fractures are clean joint with a smooth surface or fill with material with strength less than rock substance's strength

Mechanical characteristics of the hanging wall

- Volume mass of hanging wall (slate) is 2,7 tons per meter cubic;
- The average compressive strength of the hanging wall is 78 MPa (the compressive strength ranges from 31 to 125 MPa);
- The average number of fractures per meter is 9 (the number of fractures per meter ranges from 8 to 10);
- The average value of the RQD index is 58% (the value of the RQD index ranges from 56 to 60%);

- The average value of the RMR index is 75%;

- The fractures are clean joint with a smooth surface or fill with material with strength less than rock substance's strength.

Mechanical characteristics of the footwall

- Volume mass of footwall (slate) is 2,7 tons per meter cubic;

- The average compressive strength of the footwall is 79 MPa (the compressive strength ranges from 33 to 125 MPa);

- The average number of fractures per meter is 8 (the number of fractures per meter ranges from 6 to 10);

- The average value of the RQD index is 59% (the value of the RQD index ranges from 58 to 60%);

- The average value of the RMR index is 76%;

- The fractures are clean joint with a smooth surface or fill with material with strength less than rock substance's strength.

Based on the given input data on the deposit geometry and grade distribution, and rock mechanical characteristics of the ore and adjacent rocks (hanging wall and footwall), Table 3 is completed.

Table 3 Input data for mining method selection according to UBC methodology

Parameters for the deposit geometry and grade distribution	
General shape	platy-tabular
Ore thickness	intermediate
Plunge	intermediate
Depth below surface	intermediate
Grade distribution	erratic
Rock mechanical characteristics	
Ore	
Rock Mass Rating (RMR)	strong
Rock Substance Strength (RSS)	moderate
Hanging wall	
Rock Mass Rating (RMR)	moderate
Rock Substance Strength (RSS)	moderate
Footwall	
Rock Mass Rating (RMR)	moderate
Rock Substance Strength (RSS)	moderate

As it is an underground lead and zinc mine, i.e. underground exploitation of metal mineral raw materials, the mining methods of excavation is not taken into account: Longwall Mining and Open pit Mining.

After the calculation according to this methodology, the following order was obtained for the methods of mining excavation (Table 4):

Table 4 Ranking of mining methods according to UBC methodology

Serial number	Mining method	Total value points	Rank
1	Block Caving	20	6
2	Sublevel Stoping	35	2
3	Sublevel Caving	23	4
4	Room and Pillar Mining	21	5
5	Shrinkage Stoping	25	3
6	Cut and Fill Stoping	36	1
7	Top Slicing	14	7
8	Square Set Stoping	13	8

Table 4 shows that the Cut and Fill Stoping method has the highest value (Figure 1), which is the most efficient method of excavation.

The first four best ranked methods of mining excavation can be singled out as favorable methods of mining excavation for application in this case. The group of favorable mining methods includes the following mining methods:

1. Cut and Fill Stoping,
2. Sublevel Stoping,
3. Shrinkage Stoping
4. Sublevel Caving.

These methods of mining excavation can be taken into account in the optimal choice of mining methods based on mining-technical and economic factors, which will be the subject of research in the next study.

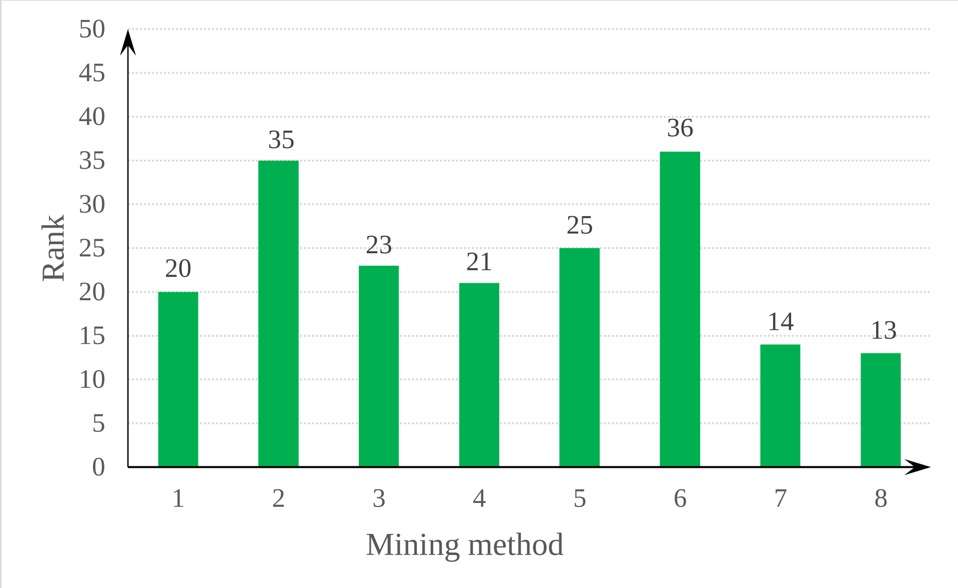

Figure 1 Ranking of mining methods

5 CONCLUSION

The financial effects that are achieved during the operation of each underground mine, largely depend on the applied method of mining, therefore it is of great importance for the correct choice of the method of mining. A number of authors have dealt with this issue, and the common opinion of most authors is that the choice of the mining method consists of two phases: rational and optimal choice of the mining method.

There are several procedures for the rational choice of mining methods, i.e. the choice of mining methods according to mining and geological factors, such as: procedure according to Boshkov and Wright, Morrison, Nicholas, Laubscher, Hartman, UBC etc.

This paper uses the UBC methodology of rational choice of the mining method, which represents the numerical ranking of mining methods and determining the most efficient method of excavation, as well as a group of favorable methods for excavation of a given ore body.

We have singled out the four best ranked mining methods as favorable mining methods for application in this case and can be used for the optimal choice of the mining method, which will take into account mining-technical and economic factors. Multi-criteria optimization methods can be used for optimal selection of the mining excavation method.

Multi-criteria optimization methods enable the choice of the method of mining excavation, taking into account a number of influencing factors, and thus enable the selection of the most appropriate method of mining excavation for a specific case, which will be the subject of research in the next study.

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