VIIth INTERNATIONAL MULTIDISCIPLINARY GEOSCIENCES CONFERENCE (IMGC-2025)

FUTURE MINING: CRITICAL MINERALS, THE CIRCULAR ECONOMY, AND SUSTAINABLE DEVELOPMENT

16 and 17 of October 2025

Mitrovica, Republic of Kosovo

Mitrovice 2025

Volume I / Vëllimi I

APPLICATION OF NUMERICAL METHODS FOR THE UNDERGROUND MINING METHOD SELECTION

Stojance Mijalkovski[1],[*], Dimitar Kaykov[2], Aleksandar Petrovski[3]
[1]Faculty of Natural and Technical Sciences, Goce Delcev University, Stip, North Macedonia
[2]University of Mining and Geology “St. Ivan Rilski”, Sofia, Bulgaria
[2]Military Academy "General Mihailo Apostolski" (associate member), Goce Delcev University, Skopje, North Macedonia
[*]Corresponding e-mail: stojance.mijalkovski@ugd.edu.mk

ABSTRACT

The successful and efficient operation of any underground mine depends largely on the excavation method used. From this, the conclusion follows that the correct underground mining method selection is of great importance and therefore great importance is attached to it. To date, several descriptive and numerical methodologies have been developed in the literature for underground mining method selection. According to both groups of methodologies, the underground mining method selection is made based on the mining-geological parameters of the ore, hanging wall, and footwall.

In this paper, three numerical methods will be applied to underground mining method selection. After comparing the results obtained by the three numerical methods, it will be determined which mining excavation method ranks best or a group of the most suitable underground mining methods will be selected.

Keywords: Nicholas methodology, UBC methodology, Sh&B procedure.

INTRODUCTION

When opening a new underground mine or developing a new section in an already active underground mine, care must be taken to choose the correct mining method. The successful operation of any underground mine depends largely on the selected and applied underground mining method. When underground mining method selection, several influential parameters need to be taken into account. Parameters that have a direct or indirect impact on the choice of ore mining method can be divided into three main groups [1], namely: economic parameters, mining - technical parameters, and mining - geological parameters.

Due to the great importance of the correct choice of mining excavation method, many authors have investigated this issue and most of them have a common opinion that the process of choosing a mining excavation method can be divided into two steps, namely: rational and optimal selection of mining excavation method [2].

According to mining-geological parameters, mining exploitation methods are ranked as rational choices, and according to mining-technical and economic parameters, mining exploitation methods are ranked as optimal choices.

METHODOLOGY

The methodologies developed for underground mining method selection can be divided into three main groups: descriptive, numerical, and decision-making methods [3]. Descriptive and numerical methods are used in the rational selection of underground mining method selection [4], while decision-making methods are used in the optimal selection of the mining excavation method. There are several descriptive methods for underground mining method selection, such as: Boshkov and Wright, Laubscher, Morrison, Hartman, Hamrin, and others. Several numerical methods have been developed for underground mining methods selection, such as: Nicholas, UBC, Sh&B, and others.

When applying numerical methods to underground mining method selection, the most important mining and geological parameters are taken into account, such as [1]:

quality of resource,

ore variability (grade distribution, continuity, ore uniformity, ore boundaries),

rock quality (footwall, hanging wall and ore zone, i.e. stability, stress, strength, structures, rock quality designation, fracture shear strength, fracture spacing, rock substance strength),

geometry of deposit (depth below the surface, plunge, dip, ore thickness, general shape), etc.

In this paper, three numerical methods will be applied for underground mining method selection according to mining and geological parameters, namely the Nicholas, UBC, and Sh&B methods. The results obtained by the three methods will then be compared and an average ranking of the mining methods will be performed (Figure 1).

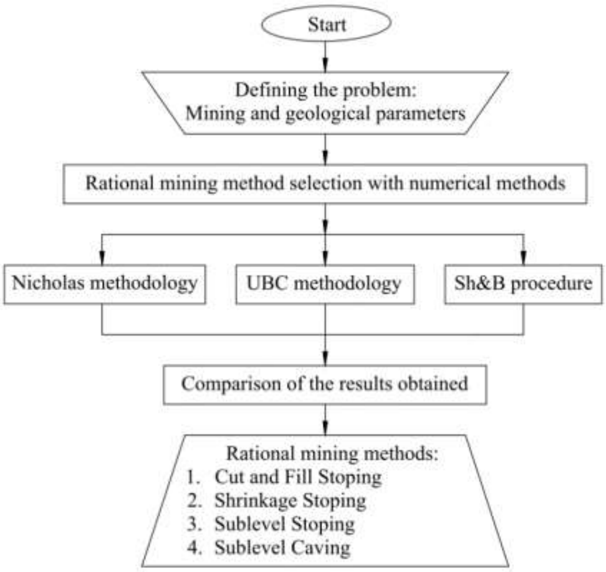

Figure 1 Methodology for underground mining method selection

The first numerical method for underground mining method selection is the Nicholas methodology [5, 6]; the UBC methodology is a modification of Nicholas [7]; the Sh&B procedure is a new numerical approach proposed by the authors Shahriar and Bakhtavar [8].

The selection procedure for the three numerical methods: Nicholas, UBC, and Sh&B is the same; the difference is in the numbering system and the range of input parameters. All of these methods use input parameters to evaluate different mining methods and select the most appropriate mining method or group of most appropriate mining methods for a given case. The underground mining method selection is made according to the geometry of the ore body and the mechanical characteristics of the rock massif.

When we have a specific ore body, it is necessary to adopt parameters for the geometry of the ore body and the mechanical characteristics of the rock mass (ore, hanging wall, and footwall). Based on the adopted parameters for the ore body, the following underground mining methods are ranked:

- 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 underground mining method selection is carried out in the following manner: for each mining method, separate point values are adopted, and their sum results in a total point value, which is entered into a special table. Based on these total score values, an underground mining method selection is made. The goal of this selection is to identify all favorable mining methods that, according to the geometry of the ore body and the mechanical characteristics of the rock massif, represent the most efficient mining methods. The efficiency of each mining method is defined by its total point value. The mining method that has the highest total point value is the most efficient mining method in a given case. Based on this principle, a ranking of underground mining methods is performed and the results are presented in the table.

If any underground mining method has a negative total point value, then it is eliminated, i.e. it is an unacceptable underground mining method.

The underground mining method that has a total point value of zero (0) is not recommended for the extraction of a given ore body, but cannot be ruled out.

The set of favorable methods for the exploitation of a given ore body consists of underground mining methods with total score values greater than zero (0) and which do not differ significantly from each other.

Underground mining methods differ from each other in terms of excavation costs, i.e., some mining methods have higher and some lower excavation costs [9]. A comparison of the relative excavation costs of different mining methods is carried out in the case when each mining method is applied in conditions that are suitable for it. For this purpose, it is necessary to take into account mining-technical and economic parameters, i.e., to make an optimal choice of mining excavation method [2], which is a separate methodology that is not the subject of research in this paper.

NICHOLAS methodology

The first numerical method for underground mining method selection is the Nicholas methodology [5,6,10]. The parameters for the geometry of the ore body are adopted based on the data shown in Table 1, and the parameters for the mechanical characteristics of the rock mass (ore, footwall, and hanging wall) are adopted based on the data shown in Table 2.

Table 1 Parameters for ore body geometry [5, 10]

General shape	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 100 m
	irregular	dimensions vary over short distances
Ore thickness	narrow	< 10 m
	intermediate	$10 \div 30$ m
	thick	$30 \div 100$ m
	very thick	> 100 m
Plunge	flat	$< 20^{\circ}$
	intermediate	$20 \div 55^{\circ}$
	steep	$> 55^{\circ}$
Depth below surface		
	/	provide actual depth
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

Table 2 Mechanical characteristics of the rock massif [5, 10]

Rock Substance Strength	weak	< 55 MPa	
	moderate	55 ÷ 110 MPa	
	strong	> 110 MPa	
Fracture Spacing (Fracture Frequency)		No. of fractures / m	% RQD
	very close	> 16	0 ÷ 20
	close	10 ÷ 16	20 ÷ 40
	wide	3 ÷ 10	40 ÷ 70
	very wide	< 3	70 ÷ 100
Fracture Shear Strength	weak	clean joint with a smooth surface or fill with material with strength less than rock substance strength	
	moderate	clean joint with rough surface	
	strong	joint is filled with a material that is equal to or stronger than rock substance strength	

Note: *Deere rock mass classification

UBC methodology

The UBC methodology for ranking underground mining methods is a modified version of the Nicholas methodology [7, 11]. This methodology was proposed by the University of British Columbia, from where it got its name UBC. The basic parameters for the geometry of the ore body are adopted based on the data shown in Table 3, and the parameters for the mechanical characteristics of the rock mass (ore, hanging wall, and footwall) are adopted based on the data shown in Table 4.

Table 3 Parameters for ore body geometry [7, 11]

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
	shallow	0 ÷ 100m

Depth below surface	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

Table 4 Mechanical characteristics of the rock massif [7, 11]

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

Sh&B procedure

The Sh&B procedure is a new numerical approach proposed by Shahriar & Bakhtavar [8, 12]. In this procedure, all input parameters are the same as in the UBC procedure; only the "Grade Quantity" is added. This parameter was added due to its great importance in assessing ore deposits. The parameters for the geometry of the ore body are adopted based on the data shown in Table 5, and the parameters for the mechanical characteristics of the rock mass (ore, footwall, and hanging wall) are adopted based on the data shown in Table 6.

Table 5 Parameters for ore body geometry [8, 12]

General shape / width	massive	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	< 15º
	low dip	15 ÷ 30º

	intermediate	30 ÷ 45º
	rarely steep	45 ÷ 60º
	steep	> 60º
Depth below surface	shallow	0 ÷ 200m
	intermediate	200 ÷ 500 m
	rarely deep	500 ÷ 800 m
	deep	> 800 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
Deposit grade value	low grade	depends on kind of mineral and its market price
	medium	depends on kind of mineral and its market price
	high grade	depends on kind of mineral and its market price

Table 6 Mechanical characteristics of the rock massif [8, 12]

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

CASE STUDY

In this paper, we will consider an active underground lead and zinc mine, in which a new section is being opened and a new mining method needs to be chosen [2, 10, 11, 12]. The input data for the ore deposit are given below. Table 7 shows the geological parameters, i.e., the geometry of the ore body, and Table 8 shows the physical and mechanical characteristics of the rock mass in the ore deposit.

Table 7 Geological parameters of the ore deposit

General shape	platy-tabular
Ore thickness, m	13 (1 ÷ 25)
Plunge, °	36 (22 ÷ 50)
Depth below surface, m	550 (540 ÷ 560)
Grade distribution	erratic
Deposit grade value	medium
The surrounding rocks in the footwall	slate
The surrounding rocks in the hanging wall	slate

Table 8 Physical and mechanical characteristics of rock mass

	ore	hanging wall	footwall
Volume mass of the rock mass, t/m3	3,5	2,7	2,7
Average compressive strength of the rock mass, MPa	95 (48 ÷ 142)	80 (33 ÷ 127)	81 (35 ÷ 127)
Average number of fractures per meter of the rock mass	5 (4÷6)	10 (9÷11)	9 (7÷11)
Average value of the RQD index of the rock mass, %	69 (66÷72)	59 (57÷61)	60 (59÷61)

Average value of the RMR index of the rock mass, %	75	76	77

In the case under consideration, we are talking about an underground lead and zinc mine, that is, about the underground exploitation of metallic mineral raw materials; therefore, we will not take into account the Longwall Mining and Open Pit Mining method.

Based on the given input data on the geometry of the ore deposit and the physical and mechanical characteristics of the rock mass (ore, hanging wall, and footwall), a calculation is performed according to three numerical methods for underground mining method selection (Nicholas, UBC, and Sh&B). After calculation according to the three numerical methods, the total results are shown in Table 9 and Figure 2.

Table 9 Total point values for underground mining methods

Serial number	Underground mining method	Total point value		
		Nicholas	UBC	Sh&B
1	Block Caving	23,5	20,0	15,0
2	Sublevel Stoping	13,4	35,0	30,5
3	Sublevel Caving	21,5	23,0	22,5
4	Room and Pillar Mining	19,7	21,0	-1,4
5	Shrinkage Stoping	24,0	25,0	23,5
6	Cut and Fill Stoping	33,2	36,0	29,7
7	Top Slicing	20,7	14,0	11,3
8	Square Set Stoping	31,2	13,0	17,2

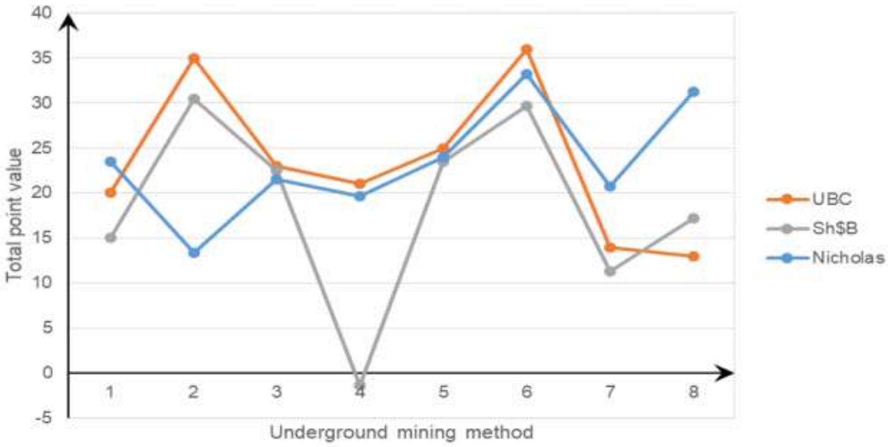

Figure 2 Total point values for underground mining methods

From Table 9 and Figure 2, it can be observed that only the mining method with ordinal number 4, i.e., Room and Pillar Mining, according to the Sh&B procedure, has a negative total point value. The remaining mining methods have positive total score values and represent favorable mining methods that can be applied in a specific case.

This is followed by a ranking of underground mining methods and calculation of the average value for the ranking, and the resulting order of mining methods is shown in Table 10 and Figure 3.

Table 10 Ranking of underground mining methods

Serial number	Underground mining method	Ranking			
		Nicholas	UBC	Sh&B	Average
1	Block Caving	4	6	6	5.3
2	Sublevel Stoping	8	2	1	3.7

3	Sublevel Caving	5	4	4	4.3
4	Room and Pillar Mining	7	5	8	6.7
5	Shrinkage Stoping	3	3	3	3.0
6	Cut and Fill Stoping	1	1	2	1.3
7	Top Slicing	6	7	7	6.7
8	Square Set Stoping	2	8	5	5.0

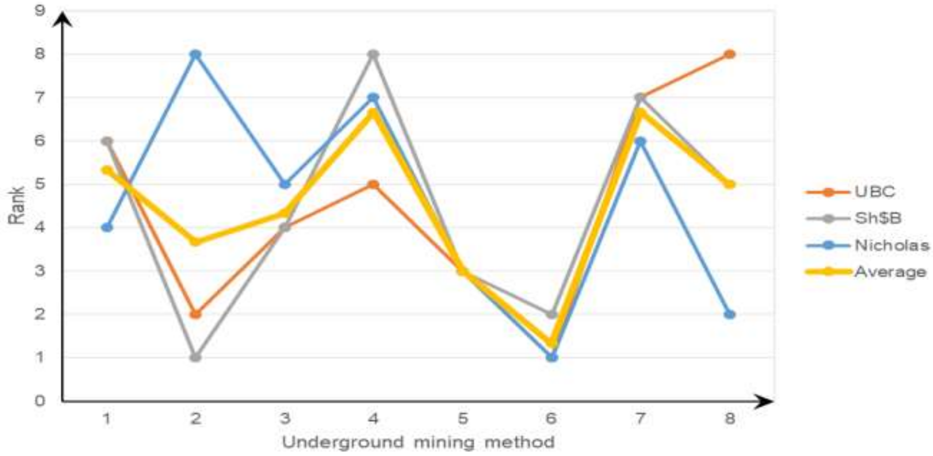

Figure 3 Ranking of underground mining methods

From Table 10 and Figure 3, it can be seen that according to Nicholas and UBC methodologies, the Cut and Fill Stoping is ranked highest, i.e., number 6, and according to the Sh&B procedure, this mining method is ranked second. According to the average ranking, it was determined that the Cut and Fill Stoping (serial number 6) is at the highest rank and represents the most favorable mining method in the given case (Figure 4).

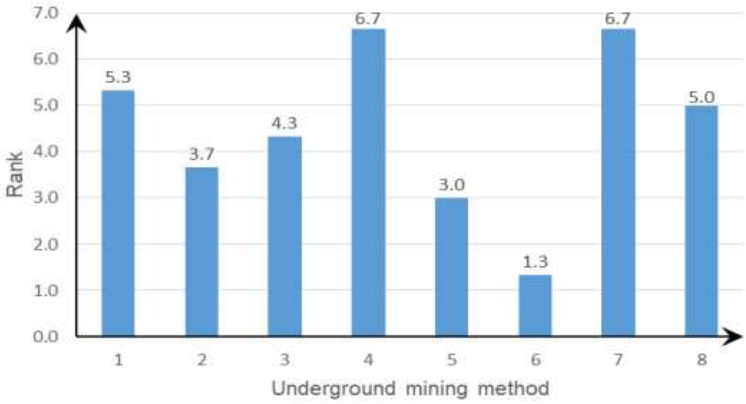

Figure 4 The final ranking of underground mining methods

The best-ranked mining methods can be distinguished as the most favorable underground mining methods for application in a specific case. The top four or five mining methods can be distinguished as the best-ranked mining methods; for example, underground mining methods ranked lower than 5 (underground mining methods with ordinal numbers 6, 5, 2, and 3). These underground mining methods can be taken into account when optimal underground mining method selection is based on mining-technical and economic parameters, which may be the subject of research in a future study.

CONCLUSIONS

The choice of mining excavation method for underground exploitation of each mine has a very large impact on the financial performance of the mine itself, which is why the correct choice of mining excavation method is of great importance and responsibility. A large number of authors have studied this issue, with the common opinion of most authors being that the mining method selection consists of two steps: rational and optimal choice.

So far, several procedures have been developed for the rational mining methods selection according to mining and geological parameters, such as: the procedure according to Boshkov and Wright, Nicholas, Morrison, Hartman, Laubscher, UBC, Sh&B, and others.

In this paper, the underground mining method selection was carried out using numerical methods. Three numerical methods (Nicholas, UBC, and Sh&B) were used to rank underground mining methods and identify the most favorable mining methods, i.e., identify a group of favorable methods for mining a given ore deposit. Almost the same results were obtained according to the three numerical methods, i.e., there is a small change in the ranking order of the mining methods. The main goal of applying three numerical methods for the rational underground mining method selection is to compare the obtained results and thus obtain the most appropriate group of mining methods, which is of great importance for solving this very complex issue.

A group of four or five best-ranked underground mining methods is identified as favorable mining methods for application in a specific case and can be used in the second step, i.e., for the optimal underground mining method selection, where mining-technical and economic parameters will be taken into account. For the optimal underground mining method selection, multi-criteria decision-making methods or fuzzy multi-criteria decision-making methods can be used, which is the subject of research in a future study.

REFERENCES

Bogdanovic, D., Nikolic, D., Ilic, I., Mining method selection by integrated AHP and PROMETHEE method, Annals of the Brazilian Academy of Sciences, 84(1), 219–233, 2012.

Mijalkovski, S., Peltecki, D., Despodov, Z., Mirakovski, D., Adjiski, V., Doneva, N., Methodology for underground mining method selection, Mining science, 28, 201-216, 2021.

Nourali, H., Nourali, S., Ataei, M., Imanipour, N., A hierarchical preference voting system for mining method selection problem, Archives of mining sciences, 57(4), 925-938, 2012.

Namin, F.S., Shahriar, K., Bascetin, A., Ghodsypour, S.H., Practical applications from decision-making techniques for selection of suitable mining method in Iran, Mineral Resources Management, 25(3), 57-77, 2009.

Nicholas, D.E., Method Selection — A Numerical Approach, Design and Operation of Caving and Sublevel Stoping Mines, Chap.4, D. Stewart, (ed.), SME-AIME, New York, 1981, pp. 39–53.

Nicholas, D.E., Selection method, SME Mining Engineering Handbook, Howard L. Hartman (ed.), 2nd edition, Society for Mining Engineering, Metallurgy and Exploration, Inc., 1992, pp. 2090–2106.

Miller, T.L., Pakalnis, R., Poulin, R., UBC Mining Method Selection, Mine planning and equipment selection. (MPES), SINGHAL R.K. et at. (Eds), Balkema, Rotterdam, 1995, pp. 163-168.

Shahriar, K., Bakhtavar, E., Saeedi, Gh., A new numerical method and AHP for mining method selection, Conference: Aachen International Mining Symposia (AIMS), Germany, 2007, pp. 289-305.

Balt, K., Goosen, R.L., MSAHP: An approach to mining method selection, Journal of the Southern African Institute of Mining and Metallurgy, 120(8), 451-460, 2020.

Mijalkovski, S., Zeqiri, K., Despodov, Z., Adjiski, V., Underground mining method selection according to Nicholas methodology, Natural Resources and Technology, 16(1), 5-11, 2022.

Mijalkovski, S., Despodov, Z., Mirakovski, D., Adjiski, V., Doneva, N., Application of UBC methodology for underground mining method selection, Underground mining engineering, 40(1), 15-26, 2022.

Mijalkovski, S., Despodov, Z., Adziski, V., Doneva, N., Underground mining method selection according to the Shahriar&Bakhtavar procedure, PODEX-POVEX, Ohrid, 2023, pp. 63-71.