MINING METHOD SELECTION FOR UNDERGROUND MINING WITH THE APPLICATION OF PROMETHEE METHOD

Stojance Mijalkovski[1,*] Zoran Despodov[1], Dejan Mirakovski[1], Vancho Adjiski[1], Nikolinka Doneva[1], Daniela Mijalkovska

[1]Faculty of Natural and Technical Sciences, GoceDelchev University, P. O. Box 201, 2000 Shtip, R. N. Macedonia

*Corresponding e-mail: stojance.mijalkovski@ugd.edu.mk

ABSTRACT

The mining method selection for underground mining of mineral resources is very complex and responsible job of every mining engineer and designer. Multi-criteria decision-making is widely used in mining to solve many problems, such as the mining method selection. When applying multi-criteria decision-making, a number of criteria are taken into account, according to which the most optimal alternative is selected.

This paper will present the scientific methodology for mining method selection for underground mining, using the PROMETHEE method. The mining method selection is divided into two parts: rational and optimal choice. When rationally mining method selection, the mining-geological factors of the deposit will be taken into account, while on the basis of technical and economic factors, the optimal mining method selection will be made by the PROMETHEE.

Keywords: mining method; multi-criteria decision-making; PROMETHEE method

INTRODUCTION

The biggest problem that every researcher encounters at the beginning when researching the opening and operation of a new mine or analyzing an existing underground mine is the choice of the method of mining excavation [1, 2].

When deciding which method of mining should be used, several factors should be taken into account, which can be quantitative (can be measured or calculated) or qualitative (cannot be measured and defined by descriptive values; they need to be transformed into numerical values so that they can be used for calculation). Factors influencing the mining method selection can be divided into three groups [3]:

- mining-geological factors, such as: 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.
- mining-technical factors, such as: annual productivity, applied equipment, health and safety, environmental impact, ore dilution, mine recovery, flexibility of methods, machinery and mining rate, and
- economic factors, such as: capital cost, operating cost, mineable ore tons, orebody grades and ore value.

METHODOLOGY

The procedure for mining method selection can be divided into two parts:

- Rational mining method selection.
- Optimal mining method selection.

Rational miningmethod selection

During the rational choice of the method of mining excavation, the methods of mining excavation are chosen according to the mining-geological factors that have an influence on the choice of the method of mining excavation (geometry of deposit, rock quality, ore variability) [4].

There are several procedures for mining methods selection by mining-geological factors, such as:

- Boshkov`sandWright`s procedure [5];
- Morrison`s procedure [6];
- Nicholas`s procedure [7, 8];
- Laubscher`s procedure [9];
- Hartman`s procedure [10];
- UBC procedure [11].

Optimal method selection using a multi-criteria evaluation technique

After rational mining methods selection and separation themost acceptable mining methods according to mining-geological factors (top four highestranked mining methods), follows optimal choice, ieselecting the separated mining methods according to mining-technicaland economic factors that influence when choosing mining method.
For the optimal selection of the mining excavation method, multi-criteria optimization methods can be used, such as: AHP, PROMETHEE, ELECTRE, TOPSIS, VIKOR and others. In this case, the PROMETHEE method will be used.

CASE STUDY

The optimal choice of the mining method for underground exploitation of lead and zinc will be made with the four best ranked methods according to the rational choice and there will be alternatives (Table 1). For this purpose, we will use multi-criteria decision-making (MCDM) method, i.e. PROMETHEE method [12, 13]. For the optimal mining method selection, we will use eight mining-technical and economic factors, which will be the criteria according to which we will compare the alternatives (Table 2). Each criterion has a different weight, i.e. an impact on alternative solutions. In this paper, the weights of the criteria were adopted by voting, i.e. in consultation with a group of 15 experts in the field of underground mining, in order to minimize subjectivity in optimization. Defining weights in consultation with experts is done in such a way that each expert has given their opinion on the weights of the criteria, and for further calculations a mean value is taken (Table 2). These weights will be used in the PROMETHEE II method calculations. Table 2 also sets the goal tendency of the criteria (max or min) and the category of classified in the category of quantitative (can be measured or calculated), and some criteria are classified as qualitative (cannot be measured). Qualitative criteria are defined by descriptive scores, so in order for them to be used for further calculations, they need to be transformed into numerical values. This transformation can be done in several ways, such as with the help of an interval scale, a qualitative scale, a bipolar scale, a linear scale of transformation, and so on. In this paper, the interval scale was used to transform qualitative into quantitative values (Table 3).

Table 1. Alternatives for mining method selection

Alternatives	Symbol
Cut and Fill Stoping	A_1
Sublevel Stoping	A_2
Shrinkage Stoping	A_3
Sublevel Caving	A_4

Table2. Criteria for mining method selection

Criteria	Symbol	Weights of criteria	Goal	Category
Value of mined ore	K_1	0.1900	max	Quantitative
Occupational safety and health conditions	K_2	0.1200	max	Qualitative
Coefficient of preparation works	K_3	0.1150	min	Quantitative
Ore recovery	K_4	0.1400	max	Quantitative
Coefficient of ore dilution	K_5	0.0900	min	Quantitative
Cost of one ton (1 t) of ore	K_6	0.1850	min	Qualitative
Effect of mining	K_7	0.0975	max	Quantitative
Terrain degradation and other environmental impacts	K_8	0.0625	min	Qualitative

Table 3. Interval scale

Qualitative value	Very poor	Poor	Average	High	Very high	Type of criterion
Quantitative	1	3	5	7	9	max
value	9	7	5	3	1	min

Decision-making analysis using PROMETHEE model

The PROMETHEE method, which was initially proposed by Brans [14], is another outranking method for a finite set of alternatives that is to be ranked and selected. The original method was further extended by Brans et al. [15]. A finite set of predetermined alternatives are evaluated under multiple criteria. Each independent criterion is weighted, and an appropriate preference function should be selected. The preference function describes the difference between the evaluations of an alternative to another into a preference degree [15]. Since its introduction, six methods developed within the PROMETHEE family have been applied for solving MCDM problems, namely PROMETHEE I, II, PROSA (an extension of the PROMETHEE II method), III, IV, V and VI. The PROMETHEE II method was used in this paper.

The PROMETHEE method uses six generalized criteria to show the preferences of the decision maker for certain criteria, where the types of these criteria are shown in Figure 1 [15].

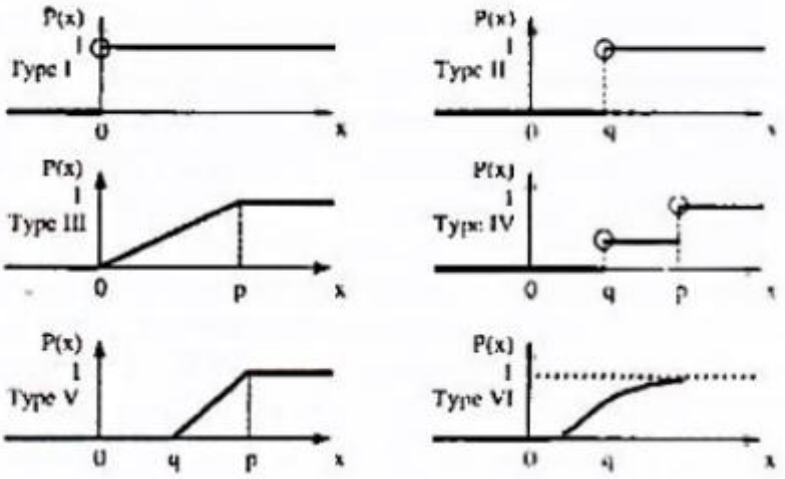

Figure 1. Type of generalized criteria in PROMETHEE

After the analysis for evaluation of the individual criteria for each alternative solution, and based on the theory, the equations for the PROMETHEE II method and based on our assessment, the types of generalized criteria have been adopted and the definition of the multi-criteria model has been performed (Table 4).

Table 4. Input model for PROMETHEE II method

Alternatives		Criteria							
		K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8
Goal		max	max	min	max	min	min	max	min
A_1		93.3	7	8.65	94	6	9	15	3
A_2		81.6	5	23.9	80	18	7	22	5
A_3		88.2	7	17.55	85	12	7	10	3
A_4		77.3	9	2.56	75	22	3	30	9
Criteria features	Weights	0.190	0.120	0.115	0.140	0.090	0.185	0.097	0.062
		0	0	0	0	0	0	5	5
	Type	Linear	Level	Linear	Quasi	Level	Level	Linear	Level
	q	-	2	-	5	4	2	-	2
	p	4.3	4	6.09	-	6	4	5	6

By solving the given problem, a complete ranking of the alternatives according to the PROMETHEE II method (Table 5) is obtained.

Table 5. Complete ranking of alternatives according to the PROMETHEE II method

Alternatives	Positive flow	Negative flow	Net flow	Rank
A_1	0.3960	0.1695	0.2266	1
A_2	0.1021	0.3780	-0.2759	4
A_3	0.2159	0.2177	-0.0018	3
A_4	0.3700	0.3188	0.0511	2

From Table 6 we can conclude that the most acceptable alternative is "A_1", i.e. Cut and Fill Stoping (Figure 2). The alternative "A_4" is second in rank, followed by the alternative "A_3", and the last ranked alternative is A_2 ($A_1 \rightarrow A_4 \rightarrow A_3 \rightarrow A_2$).

Table 6. Ranking of alternatives

Alternatives	Rank	Ranking
A_1	1	1,00
A_2	4	0,25
A_3	3	0,33
A_4	2	0,50

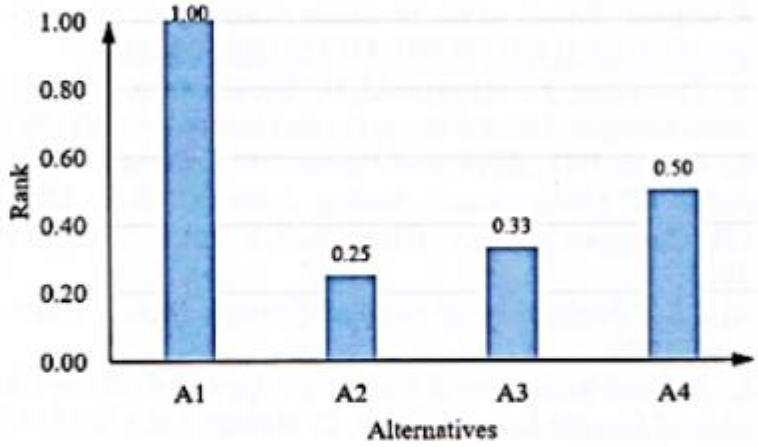

Figure 2. The overall ranking of the alternatives

CONCLUSIONS

Very important indicators for exploitation of an ore deposit depends on the selected mining method, such as: working effect, the costs of mining, losses and dilution of ore and final financial effects which are exercised thereby.

The problem of underground mining method selection, because of its importance was studied by many authors. As acommon stage of the proceedings which the individual authors was proposed, in orderto select the underground mining methodcan be distinguished two stages: a rational mining method selection and optimal mining method selection.

When making the decision about which mining method will apply should take into account many factors that influence on the mining method selection. The selected mining method will be more suited to specific mining-geological, mining-technical and economic conditions if a number of relevant factors are included.

Multi-criteria optimization methods allow the selection of the best alternative, taking into account a number of influential criteria. In this paper, the

PROMETHEE method was used to select the method of mining excavation during which several influencing factors were taken into account and it was concluded that the most acceptable way of excavating the mine is Cut and Fill Stoping.

REFERENCES

[1] Mijalkovski, S., Despodov, Z., Mirakovski, D., Zendelska, A., *Methodology for selection of mining excavation methods*, Natural resources and technology, V (5), pp. 29-38, 2011;

[2] Mijalkovski, S., Despodov, Z., Mirakovski, D., Hadzi-Nikolova, M., Doneva, N., Gocevski, B., *Mining method selection by integrated AHP and PROMETHEE method*, PODEKS-POVEKS 2012, pp. 121-127, 2012;

[3] Bogdanovic, D., Nikolic, D., Ilic, I. *Mining method selection by integrated AHP and PROMETHEE method*, Annals of the Brazilian Academy of Sciences. 84(1), pp.219–233, 2012:https://doi.org/10.1590/S0001-37652012005000013

[4] Mijalkovski, S., Despodov, Z., Mirakovski, D., Mijalkovska, D., *Rational selection of mining excavation methods*, Natural resources and technology, VI (6), pp. 15-23, 2012;

[5] Boshkov, S.H., Wright, F.D., *Basic and Parametric Criteria in the Selection, Design and Development of Underground Mining Systems*. SME Mining Engineering Handbook, A.B. Cummins and I.A. Given, (eds.), Vol.1. SME-AIME., New York, 12.2–12.13., 1973;

[6] Morrison, R.G.K., *A Philosophy of Ground Control*, McGill University, Montreal, Canada, 125–159, 1976;

[7] 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, 39–53, 1981;

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

[9] Laubscher, D.H., *Selection of Mass Underground Mining Methods. In: D. Stewart, ed. Design and Operation of Caving and Sublevel Stoping Mines*. New York: SME-AIME, 23-38, 1981;

[10] Hartman, H.L., *Selection Procedure*. SME Mining Engineering Handbook. New York: AIME Vol. 2, No. 23.4, 2090-2106, 1992;

[11] Miller, T.L., Pakalnis, R., Poulin, R., *UBC Mining Method Selection*, Mine planning and equipment selection. (MPES), SINGHAL R.K. (Eds). Balkema, Rotterdam, 163-168, 1995;

[12] Mijalkovski, S., Despodov, Z., Mirakovski, D., Hadzi-Nikolova, M., Doneva, N., Gocevski, B., *Practical example for mining method selection by integrated AHP and PROMETHEE method*, PODEKS-POVEKS 2012, pp. 128-133, 2012;

[13] Mijalkovski, S., Despodov, Z., Mirakovski, D., Hadzi-Nikolova, M., Doneva, N., Gocevski, B., *Mining method selection for deeper parts of "SvinjaReka" ore deposit – "SASA" mine*. 5th Balkan mining congress, pp. 133-136, 2013;

[14] Brans, J., *L'ingénièrie de la décision; Elaboration d'instruments d'aide à la décision. La méthode PROMETHEE*, Québec, Canada: Presses del'Université Laval, pp. 183-214, 1982;

[15] Brans, J.P., Vincke, P., *A Preference Ranking Organisation Method: (The PROMETHEE Method for Multiple Criteria Decision-Making).* Management Science. Vol.31, No.6, pp. 647–656, 1985.