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UNDERGROUND MINING METHOD SELECTION WITH THE APPLICATION OF TOPSIS METHOD

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ABSTRACT

Multi-criteria decision-making methods are widely used to solve various problems in the industry, as well as to support the planning and designing industrial processes. Mining is a very complex and responsible activity, so when making a major decision, it is necessary to take into account several parameters and perform their detailed analysis. Due to the importance of proper decision making, multi-criteria optimization methods have a very wide application in mining. One of the most complex and important things in mining is the choice of mining method for underground exploitation, where the application of multi-criteria decision-making methods can help a lot in making the right decision. This paper will present the choice of the method of mining excavation by the TOPSIS method, according to which it was obtained that the Sublevel Caving is optimal for a given case.

Keywords: Multi-criteria decision-making methods; TOPSIS method; Underground mining method selection.

1 INTRODUCTION

One of the biggest problems that every researcher or designer encounters when conducting research to open and operate a new mine or analyze an existing underground mine is mining method selection. When selecting a mining method for a particular underground mine, it is necessary to ensure safe and healthy working conditions. Also, one should always keep in mind the fact that the costs of excavation cover most of the total costs of mining, so the correct mining method selection will largely depend on whether the mine will operate with positive financial outcomes [1].

When making the final decision on which method of mining to use, several parameters should be taken into account, which can be quantitative or qualitative. Parameters influencing the choice of the method of mining excavation can be divided into three groups [2]:

- mining and geological parameters, such as: geometry of deposit (depth below surface, general shape, plunge, ore thickness), rock mechanics characteristics (ore zone, footwall and hanging wall, i.e. rock substance strength, fracture shear strength, fracture spacing, structures, stability, stress), ore variability (grade distribution, ore uniformity, ore boundaries), quality of resource, etc.;
- mining and technical parameters, such as: applied equipment, annual productivity, environmental impact, health and safety, mine recovery, ore dilution, machinery and mining rate, flexibility of methods; and
- economic parameters, such as: ore value, ore body grades, mineable ore tons, operating cost and capital cost.

2 METHODOLOGY

According to previous research, we can say that the choice of the method of mining excavation takes place in two phases [3] (see Fig. 1), as follows: rational and optimal choice of mining excavation method.

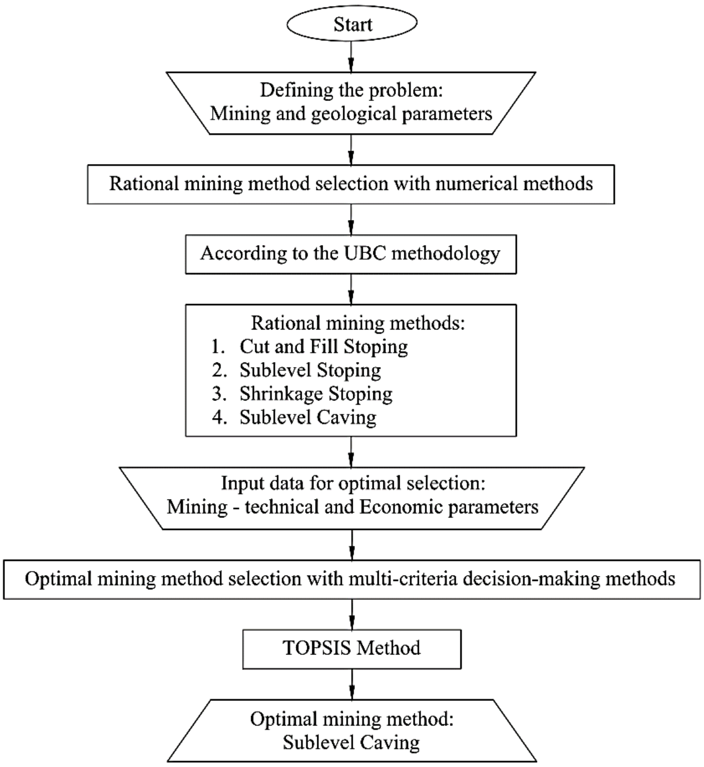

Figure 1. *Underground mining method selection*

When selecting a mining method rationally, the methods of mining are chosen according to mining and geological parameters that affect the choice of mining (geometry of deposit, rock mechanics characteristics, ore variability) [1]. Rational choice gives a group of mining methods that are favourable for application in this case, in order to reduce the number of mining methods in the next phase.

There are several procedures for the selection, i.e., the selection of mining methods according to mining and geological parameters, such as: the procedure according to Boshkov and Wright, Laubscher, Morrison, Hartman, Nicholas, UBC and others. For the rational mining method selection, this paper uses the procedure according to UBC [4], according to which the best mining methods are ranked: Cut and fill stoping, Sublevel stoping, Shrinkage stoping and Sublevel caving. These methods of mining in the next phase will be alternatives in multi-criteria decision making. After the rational selection, the optimal choice and the underground mining method selection according to the economic and mining-technical parameters follows.

Many authors have conducted research on the underground mining method selection, using several methods of multi-criteria decision-making, such as: PROMETHEE, ELECTRE, AHP, VIKOR, WPM, EDAS, TOPSIS and others, together and separately. Ataei et al. in 2008 [5] used the TOPSIS method for developing a suitable mining method for Golbini No.8 of Jajarm, bauxite mine in Iran. Namin et al. in 2009 [6] used AHP, TOPSIS and PROMETHEE to solve a mining method selection problem. Mikaeil et al. in 2009 [7] used the Fuzzy AHP and TOPSIS methods to select the optimum underground mining method. Mijalkovski et al. in 2013 [1] used the PROMETHEE, AHP and AHP-PROMETHEE integrated method for mining method selection for lead and zinc mine Sasa in Macedonia. Shariati et al. in 2013 [8] used the Fuzzy AHP and TOPSIS method for mining method selection for Angouran mine in Iran. Balusa et al. in 2019 [9] used the TOPSIS, AHP, VIKOR, PROMETHEE, ELECTRE, WPM method for mining method selection at Tummalapalle uranium mine in India. Mijalkovski et al.

in 2020 [10] used the Fuzzy TOPSIS method for risk assessment at workplace in underground mine. Bouhedja et al. in 2020 [11] used the TOPSIS method for choosing the best supplier of quarry natural aggregate. In 2021 Mijalkovski et al. applied the PROMETHEE [12] and VIKOR methods [13] for mining method selection. Ali et al. in 2021 [14] used the TOPSIS method and modification of the UBC method for mining method selection.

The TOPSIS method will be used in this paper.

3 TOPSIS METHOD

One of the most commonly used multi-criteria decision-making methods are the TOPSIS method. The TOPSIS method was first developed by Hwang and Yoon [15], and later expanded by Chen [16]. According to this method, the best alternative is the one closest to the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). The Positive Ideal Solution (PIS) is a hypothetical alternative that maximizes the benefit criteria (BC) while minimizing the cost criteria (CC). The negative ideal solution (NIS) is the opposite of the positive ideal solution (PIS), i.e., it maximizes the cost criteria (CC), while minimizing the benefit criteria (BC). According to this method, the best alternative is the one with the shortest Euclidean distance from the PIS, and also the furthest from the NIS [17, 18]. According to this hypothesis, calculations involving eigenvectors, square roots, and sums are used to obtain relative proximity to the test criteria. Ranking the values for the relative proximity of the whole system is done by assigning the highest value for the relative proximity of the best attributes in the system. As already mentioned, the TOPSIS method takes into account the distance to both PIS and NIS at the same time. In the end, we get the ideal solution that is closest to the PIS, and furthest from the NIS. When the TOPSIS method is used, the calculations are performed according to the following steps [18, 19].

Step 1: Once the decision matrix is assembled, a normalized decision matrix is formed using the following equation:

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{j=1}^{J} y_{ij}^2}}, \; i = 1, \dots, n; \quad j = 1, \dots, J \qquad \textbf{\textit{(1)}}$$

where y_{ij} is the performance value of alternative *j* against criterion *i*.

Step 2: The weighted, normalized decision matrix is obtained by multiplying the normalized decision matrix and the weights of the criteria, using the following equation:

$$v_{ij} = w_i \cdot r_{ij}, \; i = 1, \dots, n; \quad j = 1, \dots, J \qquad \textbf{\textit{(2)}}$$

where w_i is the weight of the *i*-th criterion and $\sum_{i=1}^{n} w_i = 1$.

Step 3: In this step, the negative and positive ideal solutions are determined. The ideal solution, A^+ $(v^+_i, i=1,\dots,n)$, is made of all the best performance scores and the negative ideal solution, A^- $(v^-_i, i=1,\dots,n)$, is made of all the worst performance scores for the criteria in the weighted normalized decision matrix. They are calculated using equations 3 and 4.

$$A^+ = \{v_1^+, \; v_2^+, \dots, v_n^+\} = \{(max_j v_{ij} \mid i \in I'), (min_j v_{ij} \mid i \in I")\} \qquad \textbf{\textit{(3)}}$$

$$A^- = \{v_1^-, \; v_2^-, \dots, v_n^-\} = \{(min_j v_{ij} \mid i \in I'), (max_j v_{ij} \mid i \in I")\} \qquad \textbf{\textit{(4)}}$$

In these equations, the criteria are divided into two parts:

- the first part is an input or cost nature, denoted by the set *I'*, and smaller performance scores for these criteria are preferred;

- the second part is an output or benefit nature, denoted by the set I'' and larger performance scores for these measures are preferred.

Step 4: The distance of each alternative from PIS and NIS is calculated using the *n*-dimensional Euclidean distance, using the following equations:

$$D_j^+ = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_i^+\right)^2}, \ \ j = 1,2,\dots,J \tag{5}$$

$$D_j^- = \sqrt{\sum_{i=1}^{n}\left(v_{ij} - v_i^-\right)^2}, \ \ j = 1,2,\dots,J \tag{6}$$

Step 5: In this step, the relative proximity to the ideal solution is calculated. The relative closeness of the alternative a_j with respect to A^+ is defined as:

$$C_j^+ = \frac{D_j^-}{D_j^+ + D_j^-}, \ \ j = 1,2,\dots,J \tag{7}$$

Step 6: Rank the preference order in the decreasing order of C_j^+ values.

In the TOPSIS method, the chosen alternative has the maximum value of C_j^+ with the intention to minimize the distance from the positive ideal solution and to maximize the distance from the negative ideal solution.

4 CASE STUDY

The paper considers an active underground mine of lead and zinc. In the mine, a new part will be opened at depth and it is necessary to choose the appropriate method of excavation the new part [12, 13]. The geological parameters and physical-mechanical characteristics of the ore deposit are listed below (see Table 1).

Geological parameters

- The platy-tabular ore body;
- The thickness of the ore body is 15 m;
- The plunge is 37°;
- The depth below surface is 500 meters;
- The grade distribution is erratic.

Table 1. *Rock mechanics characteristics*

	Ore	**Hanging wall**	**Footwall**
Compressive strength, MPa	93	78	79
Number of fractures per meter	4	9	8
Rock Quality Designation (RQD), %	67	58	59
Rock Mass Rating (RMR), %	74	75	76

The following methods of mining excavation have been applied in the work of the mine so far: Sublevel caving, Sublevel stoping, Shrinkage stoping and Cut and fill stoping. There are orientation parameters for these mining methods, which have been confirmed in the available practice. These mining methods were also obtained as the best ranked mining methods according to rational choice, i.e., according to the UBC methodology [20]. These mining methods will be alternatives for the optimal choice of the mining method (see Table 2). We will use the

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TOPSIS method for the optimal choice of the mining method. For optimal choice, we will use eight mining-technical and economic parameters, which will be the criteria according to which we will compare alternatives (see Table 3). Each criterion has a different impact, i.e., weight on alternatives. In this paper, the weights of the criteria were adopted in consultation with a group of 15 experts in the field of underground mining, in order to minimize the subjectivity of optimization. Each expert gives their opinion on the weight of the criteria, and then the mean value is taken with which further calculations are performed with TOPSIS method (see Table 3). Table 3 shows the target targeted by the criteria (max or min) and the category of criteria classification (quantitative or qualitative). Some criteria are classified in the category of quantitative criteria (can be measured or calculated), and some criteria are classified as qualitative criteria (cannot be measured). The qualitative criteria are defined by descriptive estimates, so in order to be used for further calculations, they need to be transformed into numerical values. The transformation of descriptive estimates into numerical values can be performed in several ways, with the help of bipolar scale, qualitative scale, interval scale, linear transformation scale, etc. In this study, an interval scale was used to transform descriptive estimates into numerical values, i.e., qualitative into quantitative values.

Table 2. *Alternatives for underground mining method selection*

Alternatives	Symbol
Cut and fill stoping	A_1
Sublevel stoping	A_2
Shrinkage stoping	A_3
Sublevel caving	A_4

Table 3. *Criteria for underground mining method selection*

Criteria	Symbol	Weights of criteria	Goal	Category
Value of mined ore	C_1	0.1900	max	Quantitative
Occupational safety and health conditions	C_2	0.1200	max	Qualitative
Coefficient of preparation works	C_3	0.1150	min	Quantitative
Ore recovery	C_4	0.1400	max	Quantitative
Coefficient of ore dilution	C_5	0.0900	min	Quantitative
Cost of one ton (1 t) of ore	C_6	0.1850	min	Qualitative
Effect of mining	C_7	0.0975	max	Quantitative
Terrain degradation and other environmental impacts	C_8	0.0625	min	Qualitative

The value of mined ore is the net value of the useful component contained in 1 t of ore, after flotation and metallurgical processing, reduced by the costs of metallurgical processing. The values for criterion C_1 were calculated for each alternative and then entered in table 4.

The criterion C_2 is qualitative, so qualitative marks are assigned to it for each alternative (see Table 4).

The value for the criterion C_3 was taken from the literature [21], i.e., for each alternative (see Table 4).

The ore recovery coefficient is the ratio of the excavated ore from the deposit and the total amount of ore in the deposit. The value for criterion C_4 was taken from the literature [21], i.e. for each alternative (see Table 4).

The coefficient of ore dilution is the ratio of unplanned ore and tailings mixed with ore and the total amount of run of mine ore. The value for criterion C_5 was taken from the literature [21], i.e. for each alternative (see Table 4).

The criterion C_6 is cost of one ton (1 t) of ore. The total cost of producing one ton of ore is called the "cost price". Thus, the term cost of ore production means the sum of all costs of production and flotation processing of ore (see Table 4).

The effect of mining represents the productivity of the worker in the excavation process. The value for criterion C_7 was taken from the literature [21], i.e. for each alternative (see Table 4).

The criterion C_8 is qualitative, so qualitative marks are assigned to it for each alternative (see Table 4).

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When the analysis of the influence of criteria on each alternative is performed, then based on the theory and on the basis of our assessment, a multi-criteria model is defined (see Table 4).

Table 4. *Input model for TOPSIS method*

Alternatives	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Goal	max	max	min	max	min	min	max	min
A_1	93.300	7.000	8.650	94.000	6.000	9.000	15.000	3.000
A_2	81.600	5.000	23.900	80.000	18.000	7.000	22.000	5.000
A_3	88.200	7.000	17.550	85.000	12.000	7.000	10.000	3.000
A_4	77.300	9.000	2.560	75.000	22.000	3.000	30.000	9.000
Weights of criteria	0.1900	0.1200	0.1150	0.1400	0.0900	0.1850	0.0975	0.0625

Table 5. *The normalized decision matrix*

Alternatives	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Goal	max	max	min	max	min	min	max	min
A_1	0.5468	0.4901	0.2791	0.5609	0.1909	0.6564	0.3628	0.2694
A_2	0.4782	0.3501	0.7711	0.4774	0.5727	0.5105	0.5322	0.4490
A_3	0.5169	0.4901	0.5663	0.5072	0.3818	0.5105	0.2419	0.2694
A_4	0.4530	0.6301	0.0826	0.4475	0.6999	0.2188	0.7257	0.8082

Table 6. *The final weighted normalised matrix*

Alternatives	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Goal	max	max	min	max	min	min	max	min
A_1	0.1039	0.0588	0.0321	0.0785	0.0172	0.1214	0.0354	0.0168
A_2	0.0909	0.0420	0.0887	0.0668	0.0515	0.0944	0.0519	0.0281
A_3	0.0982	0.0588	0.0651	0.0710	0.0344	0.0944	0.0236	0.0168
A_4	0.0861	0.0756	0.0095	0.0627	0.0630	0.0405	0.0708	0.0505

Table 7. *The ideal positive and negative solutions for each criterion*

Ideal solutions	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Ideal positive solution (A^+)	0.1039	0.0756	0.0095	0.0785	0.0172	0.0405	0.0708	0.0168
Ideal negative solution (A^-)	0.0861	0.0420	0.0887	0.0627	0.0630	0.1214	0.0236	0.0505

Table 8. *Alternative distances and their relative closeness criteria*

Alternatives	D_j^+	D_j^-	C_j^+
A_1	0.0927	0.0862	0.4817
A_2	0.1108	0.0470	0.2976
A_3	0.0943	0.0611	0.3932
A_4	0.0617	0.1272	0.6735

Table 9. *Ranking of alternatives*

Alternatives	C_j^+	Rank
A_1	0.4817	2
A_2	0.2976	4
A_3	0.3932	3
A_4	0.6735	1

From Table 9 it can be seen that the alternative "A_4" has the highest values, i.e., the Sublevel caving (see Fig. 2) and it was chosen as the most acceptable. Alternative "A_1" is in the second rank, then alternative "A_3", and the last ranked alternative is "A_2" ($A_4 \rightarrow A_1 \rightarrow A_3 \rightarrow A_2$).

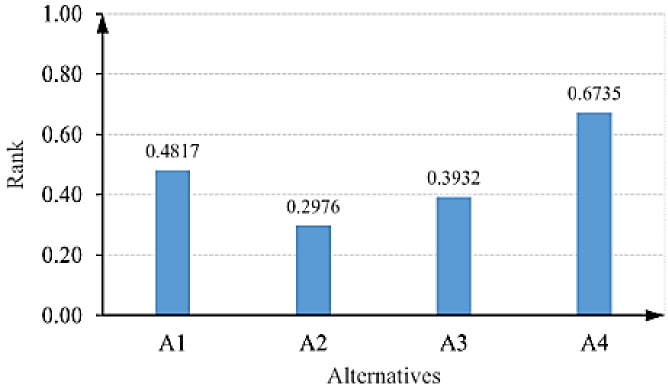

Figure 2. *The overall ranking of the alternatives*

5 CONCLUSION

Properly selected and applied method of mining excavation has a direct impact on very important parameters in the exploitation of a given ore deposit, such as: the size of the losses and dilution of the ore, the mining costs, the working effect and finally the financial outcomes that are achieved.

The fact that the correct choice of the method of mining excavation is of a great importance and that it is a very complex process, many authors have expressed interest in studying this issue. Several methodologies and procedures for the selection of the mining excavation method have been developed and proposed, taking into account the most influential factors. It can be concluded that according to the opinion of most authors who research this issue, there are two phases in the choice of the method of mining excavation: rational and optimal mining method selection.

When deciding which method of mining excavation will be applied, as many factors as possible that influence the choice of the method of mining excavation should be taken into account, because in that case the chosen method of mining excavation will be the most suitable according to the mining-geological, mining-technical and economic parameters.

Multi-criteria decision-making methods enable the selection of the most appropriate method of mining excavation, taking into account a number of influential parameters. The underground mining method selection can be done by applying several multi-criteria decision-making methods, such as: VIKOR, TOPSIS, PROMETHEE, ELECTRE, AHP and others. In this paper, the mining method selection by the TOPSIS method, which considered several influencing factors and came to the conclusion that the most acceptable mining method is Sublevel caving. In the previous research, several multi-criteria methods were applied for the underground mining method selection for the given mine and almost the same results were obtained, that is, there is a slight change in the ranking of mining methods. Using the methods: AHP, PROMETHEE II, AHP-PROMETHEE, ELECTRE I, the top ranked mining

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method is Cut and fill stoping. By applying the VIKOR method, Shrinkage stoping was obtained as the most acceptable method of mining.

If several methods of multi-criteria optimization are used, the obtained results will be compared and in this way the most appropriate method of mining will be obtained, which is of great importance for solving this very complex issue. The next step in researching this issue is the application of FUZZY methods for multi-criteria decision-making, as well as their mutual comparison of the obtained results.

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