UNDERGROUND MINING METHOD SELECTION WITH THE APPLICATION OF ELECTRE METHOD

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ABSTRACT – Solving complex problems in industry, as well as in mining, require the analysis of a large number of influential parameters when making a final decision. Multi-criteria decision-making methods are very suitable for solving such complex problems. Multi-criteria decision-making methods are widely used in mining to solve various problems, as well as to support the mine planning and design process. One of the most complex problems in underground mines is the choice of mining excavation method, where the application of one of the multi-criteria decision-making methods is of great importance for making the final decision.
In this paper, the scientific methodology for the selection of the mining excavation method using the ELECTRE method will be presented.

Keywords: underground mining method selection; multi-criteria decision-making methods; ELECTRE method

1. INTRODUCTION

One of the most complex problems in the underground exploitation of mineral raw materials is the choice of the method of mining excavation, especially if it is taken into account that the method of mining excavation primarily ensures safe and healthy working conditions. It should also be borne in mind that the costs of excavation occupy the largest part of the total costs of mine exploitation, so it follows that the correct choice of the method of mining excavation has a direct impact on the financial operations of the mine [1].
When solving the problem of choosing a mining excavation method for underground exploitation, several parameters 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). Parameters influencing the mining method selection can be divided into three groups [2]:

- mining-geological factors,
- mining-technical factors, and
- economic factors.

2. METHODOLOGY

The procedure for choosing a mining excavation method can be divided into two phases (Figure 1), that is: rational and optimal mining method selection [3].

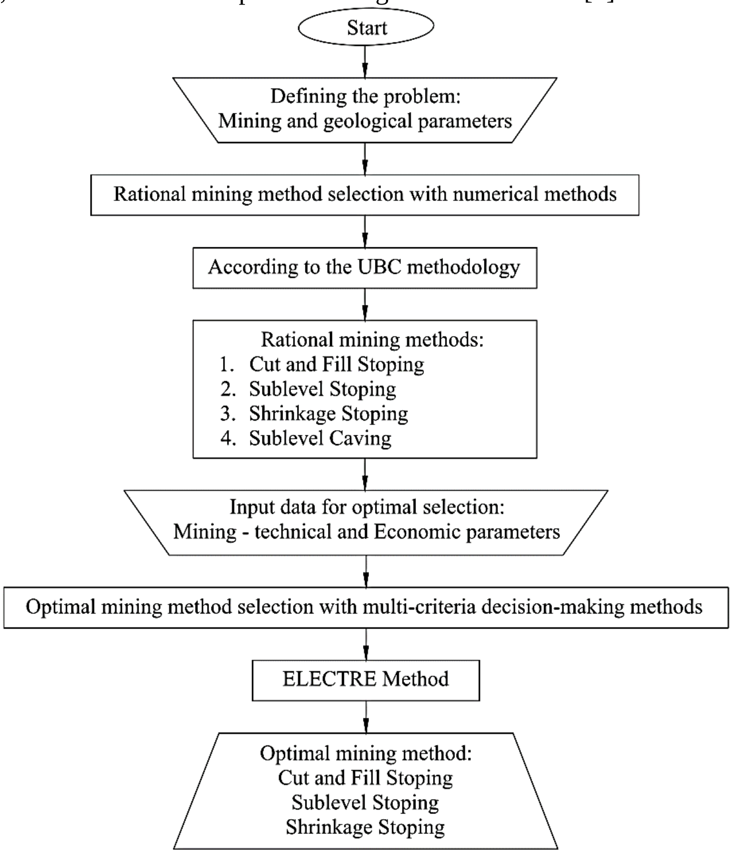

Figure 1 Methodology for underground mining method selection

In the rational choice of mining excavation methods, the choice of mining excavation methods is made according to the mining - geological parameters that influence the choice of mining excavation methods (geometry of the deposit, rock quality, ore variability) [4]. The main purpose of this choice is to reduce the number of mining methods, which will be discussed in the next section.

There are several procedures for rational selection, i.e. selection of mining excavation methods according to mining-geological parameters, such as: the procedure according to Boshkov and Wright, Morrison, Nicholas, Laubscher, Hartman, UBC, etc. For a rational choice of the mining excavation method, this paper used the procedure according to UBC [5] and the four best ranked mining excavation methods (Cut and Fill Stoping, Sublevel Stoping, Shrinkage Stoping and Sublevel Caving) were singled out, which represent alternatives in multi-criteria decision-making with application of the

ELECTRE method.
After a rational choice is made, i.e. the selection of the most acceptable methods of mining excavation according to the mining-geological parameters (the first four excavation methods of the highest rank), the optimal choice follows, i.e. the selection of the chosen methods of mining excavation according to the mining-technical and economic parameters that have an influence on the choice of method mining excavation. For the optimal choice of the mining excavation method, multi-criteria optimization methods can be used, such as: AHP, PROMETHEE, ELECTRE, TOPSIS, VIKOR and others [6, 7, 8]. In this case, the ELECTRE method will be used.

3. CASE STUDY

In this paper, an active underground mine of lead and zinc is considered, where a new part is opened and it is necessary to choose an appropriate method of exploitation. Four mining methods of excavation have been applied in the mining work so far, which were obtained as the best ranked according to the UBC methodology, that is, according to rational choice (choice according to mining-geological parameters) and that they will represent alternatives for choosing the method of mining excavation (Table 1). Because these mining excavation methods were used to excavate some sections in this ore deposit, there are orientation parameters for these mining excavation methods. For the optimal selection of the mining excavation method, we will use the multi-criteria decision-making method, that is, the ELECTRE method [3]. For this purpose, we will use eight mining-technical and economic parameters, which will represent the criteria according to which we will compare the alternatives (Table 2). Each criterion has a different weight, ie influence on alternative solutions. In this study, the weights of the criteria were adopted by voting, i.e. in consultation with a group of 15 experts in the field of underground exploitation, in order to minimize the subjectivity of the optimization. The definition of weights was adopted in consultation with experts in such a way that each expert gave his opinion on the weights of the criteria, and for further calculations the mean value was taken (Table 2). These weights will be used in calculations with the ELECTRE method. Table 2 also shows the goal the criteria aim for (max or min) and the category of their classification (quantitative or qualitative). Some criteria are classified as quantitative (can be measured or calculated) and some criteria are classified as qualitative (cannot be measured). Qualitative criteria are defined by descriptive ratings, so they can be transformed into numerical values to be used for further calculations. This transformation can be done in several ways, using interval scale, qualitative scale, bipolar scale, linear transformation scale, etc. This study used an interval scale to transform qualitative in 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

Table 2 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 value	1	3	5	7	9	max
	9	7	5	3	1	min

3.1. Decision-making analysis using ELECTRE method

The ELECTRE was initially created in the 1960s [9, 10] as a response to limitations of existing decision-making methods for resolving the choice problem. Since the introduction of the method, eight further variations have been applied for solving MCDM problems, namely ELECTRE I, IS, Iv, II, III, IV, III-H and Tri. All these methods were developed on the same fundamental concept but differ in their stages. Each of the ELECTRE family methods has a specific function regarding the type of problem [11]. The ELECTRE I method was used in this study.

After the analysis for the assessment of individual criteria for each alternative solution, based on theory and based on our assessment, a multi-criteria model was defined (Table 4).

Table 4 Input model for ELECTRE I 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	93.300	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

By solving the given task, a partial order of alternatives according to the ELECTRE I method was obtained (Table 5).

Table 5 Partial sequence of alternatives according to the ELECTRE I method

Alternatives	**Prefers**	**Total prefers**	**Rank**
A_1	A_3, A_4	2	1
A_2	A_3, A_4	2	1
A_3	A_2, A_4	2	1
A_4	does not prefer	0	2

From Table 6 and Figure 2, it can be noted that alternatives A_1, A_2 and A_3 are equally acceptable, i.e. the following excavation methods: Cut and Fill Stoping, Sublevel Stoping and Shrinkage Stoping.

Table 6 Ranking of alternatives

Alternatives	Rank	Ranking
A_1	1	1,00
A_2	1	1,00
A_3	1	1,00
A_4	2	0,50

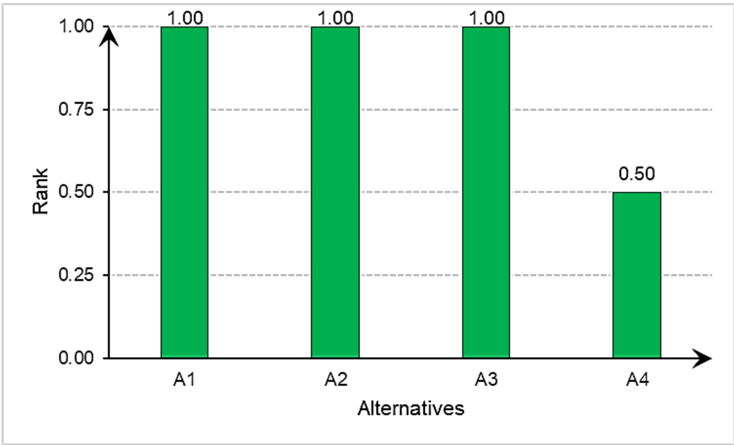

Figure 2 Ranking of alternatives

4. CONCLUSIONS

The choice of mining excavation method for underground exploitation is a very complex problem that requires a lot of attention. The importance of the correct choice of mining method for a given underground mine stems from the fact that the mining method itself has a very large impact on the working effect, the costs of mining, losses and dilution of the ore and final financial effects of the mine.

The great importance of the correct choice of mining excavation method for underground exploitation causes great interest of many authors to study this issue. As a general opinion of a large number of authors dealing with this issue, the procedure for choosing a mining excavation method can be divided into two phases: rational choice of mining excavation method and optimal choice of mining excavation method.

When making a decision about which method of mining excavation will be applied, one should take into account as many parameters as possible that influence the choice of mining excavation method. If more relevant parameters are included, the chosen method of mining excavation will correspond more to the specific mining-geological, mining-technical and economic parameters.

Multi-criteria optimization methods enable the selection of the best alternative, considering a large number of influential criteria. In this paper, the ELECTRE method was used for the selection of the mining excavation method, where several influential parameters were considered and the conclusion was reached that the mining excavation methods are equally acceptable: Cut and Fill Stoping, Sublevel Stoping and Shrinkage Stoping. From here we can conclude that to determine the optimal mining method, it is necessary to apply at least one more multi-criteria decision-making method and then compare the obtained results. If, even then, different, equally acceptable mining methods are obtained, then it is necessary to apply more methods for multi-criteria decision-making and compare the obtained results.

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