UNDERGROUND MINING ENGINEERING 44 (2024) 1-10 UDK 62
UNIVERSITY OF BELGRADE - FACULTY OF MINING AND GEOLOGY ISSN 03542904

Original scientific paper

RANKING OF THE MOST IMPORTANT CRITERIA FOR THE SELECTION OF THE MINING METHOD FOR NON-STRATIFIED DEPOSITS

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Received: February 21, 2024 **Accepted:** March 8, 2024

Abstract: Selecting and planning of the mining method for non-stratified deposits is the most delicate and complex process on which the success of the mine depends. This procedure is basically a multi-criteria decision making problem in which the aim is to select the best mining method from many alternatives. The aim of this paper is to show the influence of many factors (criteria) in the selecting of the most suitable mining method and to determine their influence on this process. The eight groups of influencing factors, i.e. criteria, were taken into account – geometric data on the ore body, the mechanical characteristics of the massif, the ore reserves, the situation on the surface of the terrain, the workforce, the possible environmental hazards, the market conditions and the safe working conditions. The AHP method was used for ranking these criteria. The ranking was carried out by mining experts and managers of various underground mines in Serbia using the group decision method. The results obtained show a clear distinction between the individual criteria when selecting the best mining method. Furthermore, the results clearly show the importance of the ranking process in determining the most influential criteria in this very complex process.

Keywords: Criteria Ranking; Mining Method; AHP; Non-Stratified Deposits

1 INTRODUCTION

Mining method selection is a time-consuming and difficult process that requires a high level of expertise and experience. This process can be a difficult task for mining engineers and managers. For a proper and effective evaluation, the decision maker may need to analyze a large amount of data and consider many factors – criteria.

The criteria that influence the selection of mining method are not all equally important, nor are they all equally reliable; some change, others are constant. Some parameters

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exclude some methods or technologies, in some situations some of them have no meaning and so on.

There are numerous methods that have been developed in the past for the selection of mining methods. The first numerical approach for the selection of mining methods was proposed by Nicholas (1981 and 1992). In this method, different mining methods are evaluated based on the ranking of certain input parameters –criteria. The mining method with the highest summed result is selected. Later, Nicholas proposed some modifications that include the weighting of various categories, such as ore geometry, ore zone, hangingwall and footwall.

Miller et al. (1995) developed the UBC method as a modification of the Nicolas method. The main weakness of these approaches is that the importance of the individual selection criteria was not taken into account.

A modern approach views the selection of mining methods as a multi-criteria decision problem (MCDM) with a finite number of alternatives that must be ranked taking into account many different and conflicting criteria. The advantage of these methods is that they can take into account both financial and non-financial criteria. The best known of these methods are scoring models, Analytic Hierarchy Process – AHP, Analytic Network Process – ANP, TOPSIS, ELECTRE, PROMETHEE, ELECTRE, MAUT, MACBETH, VIKOR, TODIM, Grey, MULTIMOORA, and MAHP. Multi-criteria decision making methods (MCDM) such as AHP and Fuzzy AHP, which are used in the literature for mining method selection, make the evaluations using the same rating scale and preference functions based on the criteria. Accordingly, Ataei et al. (2008) used the AHP approach for mining method selection. On the other hand, Bitarafan & Ataei (2004) used various fuzzy methods as an innovative tool for criteria aggregation in mining decision problems. Alpay & Yavuz (2009) have also proposed a combination of AHP and fuzzy logic methods for mining method selection. Samimi Namin et al. (2008) used fuzzy TOPSIS method for optimal mining method selection. Also, Bogdanovic et al. (2012) used integrated AHP and PROMETHEE method for selection of the most appropriate mining method. Saki et al. (2020) proposed a new methodology to find the most suitable MCDA techniques for selecting the optimal underground mining method. First, a list of fifty parameters, including geomechanical, geometrical, technical, economic, environmental and social parameters, were considered for the selection of the optimal mining method. Then the most influential parameters, including the thickness, the RMR value of the hanging wall and the production rate, were selected as the most important parameters according to the experts' opinions on the subject.

All this indicates that the selection of the optimal underground mining method depends primarily on influential factors – criteria. Therefore, it is very important to identify all criteria and determine the degree of their influence on the selection of mining method. In order to determine their influence, they must be ranked, which is done in this paper. At this point, it must be noted that the ranking was generally done for for non-stratified ore deposits using the group decision method. For each individual case of mining method selection, the ranking should be made according to the conditions in the particular mine or deposit.

2 MATERIALS AND METHODS

The studies are being carried out in various underground mines in Serbia and Iran. Different mining methods are used in these mines. The conditions are also very different, from ore geometry, ore type and reserves, mechanical properties of the rock to market conditions and safe working conditions. In addition, many mining experts and managers were involved in this study, providing a very good basis for obtaining high-quality results.

2.1 AHP method

AHP is a quantitative technique proposed by Saaty (1980). This technique develops and analyzes a multidimensional hierarchical structure of goals, criteria and alternatives. It calculates the strength of each criteria, compares the alternatives with each criteria, and ranks all alternatives. AHP uses a comparison matrix to evaluate each criteria and the alternatives based on scores from 1 to 9 (Table 1). On this basis, the evaluation leads to a final ranking of the alternatives.

Accordingly, only the first step is carried out in this paper with the aim of evaluating the most important group of criteria for the selection of the mining method for non-stratified deposits.

Table 1 Pair-wise comparison scale for AHP method

Verbal Judgement	Numerical Rating
Equally preferred	1
Moderately preferred	3
Strongly preferred	5
Very strongly preferred	7
Extremely preferred	9
2, 4, 6 and 8 are intermediate values	

2.2 The research method

The original research method was developed to rank the criteria and evaluate the degree of their influence on the selection of mining method for non-stratified deposits. The research method comprises the following four steps: (1) data collection, (2) defining the most important criteria for the selection of the mining method for non-stratified deposits, (3) AHP calculations and (4) results and discussion (Figure 1).

The research began with interviews with mining experts and managers. The questions were designed to collect the necessary data on the most important criteria for the selection of the mining method. The final list of the most important criteria was then determined. In the next step, the most important criteria were ranked using the AHP to determine their influence on the mining method selection process. Once the results of the ranking were obtained, the most important criteria were identified and analysed to provide a useful basis for future mining method selection and to better understand the priorities in this process.

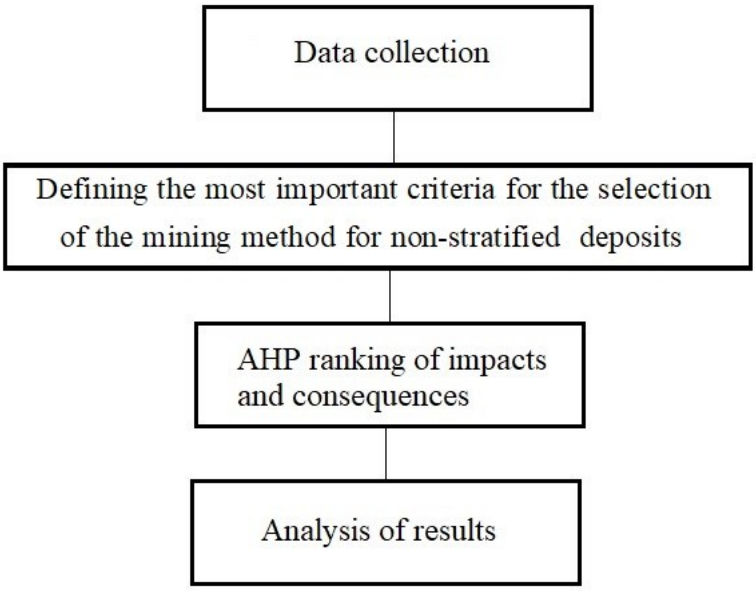

Figure 1 Schematic overview of the research method

3 THE OBITAINED RESULTS

3.1 Data collection

As already mentioned, the research began with interviews with mining experts and managers. This step took the longest and represents the basis for the further research steps, whereby the corresponding questionnaire was compiled in such a way that the most important criteria were achieved on the basis of the answers received.

3.2 Defining the most important criteria for the selection of the mining method for non-stratified deposits

In this step, the criteria identified are grouped according to their nature and their influence on the choice of mining method. This is done through a discussion between mining experts and managers until a consensus is reached for each group of criteria. On this basis, eight criteria groups were identified, namely:

- C1 – geometric data about the ore body (the shape – morphological type of the ore body, its dimensions and its spatial location),
- C2 – the physical-mechanical characteristics of the massif (strength and deformability, rupture assembly and stress state as well as hydrogeological conditions),
- C3 – the ore reserves, the content and distribution of the usable components of the ore, the mineralogical composition and other data that determine the value of the ore and its primary processing,
- C4 – the situation on the surface of the land (the presence of infrastructure, residential, industrial or other buildings under protection, as well as the presence of permanent or occasional watercourses and reservoirs),
- C5 – the workforce (presence of trained or untrained miners, their level of training and the cost of the workforce under the given conditions),
- C6 – the potential environmental hazards (impact on the existing ecosystem and hydrological system, etc.),
- C7 – the market conditions (value of the useful component, price stability, expected supply and demand, risks, etc.),
- C8 – the safe working conditions (safety conditions, occupational health and safety risks and their prevention, health protection of workers).

3.3 AHP calculations

The AHP calculations were carried out using the group decision method (authors with mining experts and managers of mining companies). The aggregation of individual judgments (AIJ) method was used for group decision making. Figure 2 shows the hierarchical structure of the AHP problem. The criteria were discussed and ranked until a consensus was reached for each evaluation using the scale shown in Table 1. The comparison matrix (8x8) is shown in Table 2. SuperDecisions software was used for the AHP calculations. Figure 3 shows the calculation results obtained from the comparison matrix.

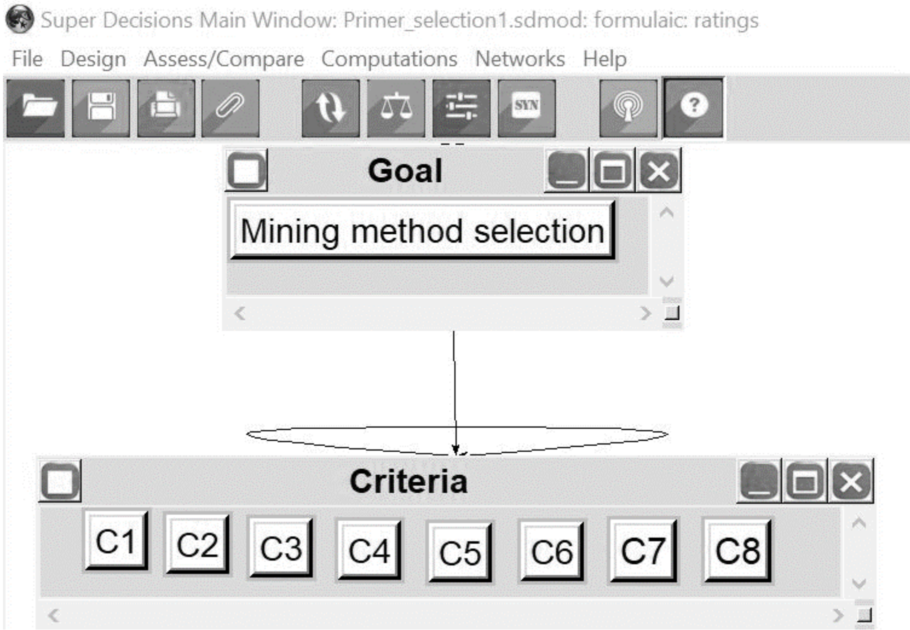

Figure 2 Hierarchical structure of the AHP problem

Table 2 Criteria comparison matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8
C1	1	2	3	4	5	4	1	4
C2		1	3	4	4	4	2	3
C3			1	3	4	2	1/4	1
C4				1	1	1/2	1/6	1
C5					1	1/4	1/5	1/2
C6						1	1/2	1
C7							1	3
C8								1

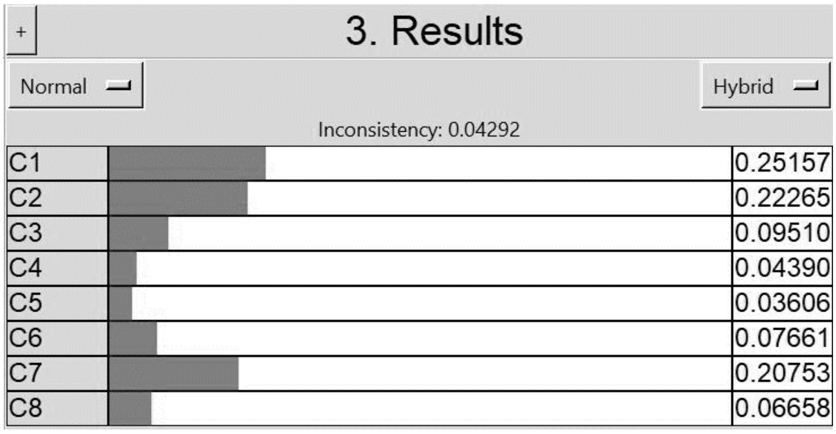

Figure 3 Results obtained by AHP calculations

3.4 Results and discussion

The results obtained clearly show which criteria have the greatest influence on the selection process of mining methods. The results show that it is possible to divide the criteria into three groups in terms of their influence on the mining method selection process. The first group includes criteria whose weight coefficients are greater than 0.2 (20%). These are the criteria C1 – geometric data about the ore body, C2 – physical-mechanical characteristics of the massif and C7 – market conditions. The second group of criteria comprises those whose weighting coefficients are between 0.05 and 0.1 (5% to 10%). These are C3 – ore reserves, C6 – potential environmental hazards and C8 – safe working conditions. The third group comprises the least influential criteria – C4 – the situation on the surface of the land and C5 – the workforce.

In the first group, the strongest criteria is C1 with a weighting coefficient of 0.25157. The shape of the ore body, its dimensions and its spatial location are of essential importance for the selection of the appropriate mining method, the construction and dimensions of the pit, its layout and the possible mining capacity. In second place is criteria C2 (weight coefficient 0.22265). Which mining method is used depends largely on the physical-mechanical characteristics of the massif (ore body and surrounding rock). For example, it is possible to use unsupported methods in hard and solid rock. Otherwise, it is possible to apply other methods (unsupported methods or caving methods) in accordance with the given characteristics of the rock massif. In third place is criteria C7 – the market conditions. The value of the useful component, price stability, expected supply and demand and risks are all elements that influence the choice of mining method. For example, the value of the useful component in the ore affects the selection process, so that richer deposits allow the use of more expensive methods that have a higher utilization rate, less impact on the surface of the land, less impact on the environment, etc., and vice versa.

The second group of criteria is significantly weaker than the first. Criteria C3 is in first place here. The ore reserves are an important factor in the selection of mining method, and it depends on them whether or not a method is used that enables a high production capacity. The planning process, the duration of mining, etc. also depend on the ore reserves. Criteria C6 is in second place. Potential environmental hazards are a factor that is becoming increasingly important. The aim is to operate mines in such a way that the impact on the environment is minimized. Accordingly, when selecting the mining method, preference should be given to the mining method that poses the least risk to the environment. Criteria C8 is in third place. Safe working conditions (safety conditions, occupational health and safety risks and their prevention, health protection) are a very important criteria that must be taken into account when selecting the excavation method. Which excavation method is chosen depends on which measures and how they are applied, how high the risks are in the workplace, etc.

The third group comprises the least influential criteria – C4 and C5. The situation on the surface of the land (the presence of infrastructure, residential, industrial or other buildings under protection, as well as the presence of permanent or occasional watercourses and reservoirs) is a factor that influences the selection of mining method. If it is necessary to protect surface objects, this significantly limits the choice of the optimal mining method. Otherwise, additional costs for relocation of facilities or reimbursement of costs will be incurred if methods are selected that jeopardize the surface of the site. As for the workforce, it was ranked as the least influential criteria. The reason for this is that this criteria can be highly influenced by the process of recruitment, provision of good training, adequate wages, good working conditions, etc.

4 CONCLUSION

Here, the AHP method was used to evaluate the most important criteria for selecting the mining method for non-stratified deposits. Eight criteria were considered: – C1 (geometric data on the ore body), C2 (physical-mechanical characteristics of the massif), C3 (the ore reserves), C4 (the situation on the surface of the land), C5 (the workforce), C6 (the potential environmental hazards), C7 (the market conditions) and C8 (the safe working conditions).

Based on the ranking results obtained, the criteria can be divided into three groups according to how influential they are on the selection of mining method. The first, most influential group includes the following criteria: C1 (geometric data about the ore body), C2 – physical-mechanical characteristics of the massif) and C7 (market conditions). The second group, which is in the middle in terms of influence on the choice of mining method, comprises the following criteria: C3 (ore reserves), C6 (potential environmental hazards) and C8 (safe working conditions). The third group comprises the least influential criteria: C4 (the situation on the surface of the land) and C5 (the workforce).

The results of the ranking of the most important criteria for the selection of the mining method for non-stratified deposits can serve as a guide for mining experts and managers for the correct selection of the optimal mining method in their mines.

ACKNOWLEDGMENTS

The research presented in this paper was done with the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia, within the funding of the scientific research work at the University of Belgrade, Technical Faculty in Bor, according to the contract with registration number 451-03-65/2024-03/200131.

This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract on realization and financing of the scientific research work of the Mining and Metallurgy Institute Bor in 2024, contract number: 451-03-66/2024-03/ 200052.

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