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Original Research

RANKING OF THE MOST IMPORTANT GROUPS OF CRITERIA FOR THE SELECTION OF THE UNDERGROUND MINING METHOD FOR COAL DEPOSITS

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Abstract: The selection of the mining method for coal deposits is a very complex process that leads to the most important decision for future exploitation. This process is now implemented as a multi-criteria decision problem in which the best mining method is selected from many alternatives. In this paper, the most important groups of factors (groups of criteria) are considered to determine their influence on the mining method selection process. Six groups of criteria were considered: natural – geological conditions, technical conditions, economic conditions, technological (organisational) conditions, safety conditions and environmental protection. These criteria were ranked using the AHP method. The group decision method for ranking was applied by mining experts and managers of various underground mines in Serbia and Iran. The results show the importance of each group of criteria for selecting the best mining method for coal deposits and the differences between them. It also shows how important the process of ranking groups of criteria is for the selection of the best mining method.

Keywords: Group of Criteria Ranking, Mining Method, AHP, Coal Deposits.

1. INTRODUCTION

The selection of an appropriate mining method is a complex and time-consuming process that requires a high level of expertise and experience. This decision-making process is a major challenge for mining engineers and managers. To ensure an accurate and effective evaluation, decision makers must analyze extensive data sets and consider multiple criteria that influence the selection process.

The groups of criteria that influence the selection of a mining method for coal deposits vary in importance and reliability; some are dynamic, while others remain constant. Certain

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parameters may exclude certain methods or technologies, making some criteria irrelevant in certain contexts.

This emphasises that the optimal selection of an underground mining method is primarily determined by influencing factors — groups of criteria. Therefore, the identification and evaluation of these groups of criteria is of crucial importance. In order to quantify their influence on mining method selection, a ranking process as presented in this paper is required. In particular, the ranking for coal deposits was carried out using a group decision approach. When selecting mining methods on a case-by-case basis, the ranking should be adapted to the specific conditions of the particular mine or coal deposit.

2. LITERATURE REVIEW

Numerous methods have been developed in the past for the selection of mining methods. The most relevant scientific literature on this topic goes back to the first qualitative classification systems for the selection of mining methods proposed by Boshkov and Wright (1973). Later studies introduced classification systems that categorize underground mining into three groups based on ground conditions and assign appropriate support types accordingly (Morrison, 1976). Laubscher (1981) proposed a selection methodology for underground mining methods based on the Rock Mass Rating (RMR) system.

The first numerical approach to the selection of mining methods was proposed by Nicholas (1981, 1992). In this method, different mining techniques are evaluated based on the ranking of specific input parameters. The method with the highest overall score is selected.

Miller et al. (1995) further refined the Nicholas method by developing the UBC method as an extension. However, a major limitation of these approaches is that they do not take into account the relative importance of the individual selection criteria. Later Hartman (1987) developed a qualitative selection framework that takes into account the geometry of the reservoir and the ground conditions to determine the optimal mining method.

Within the framework of multi-criteria decision analysis (MCDA), various approaches have been used for the selection of mining methods. These include scoring models, the Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP) and methods such as TOPSIS, ELECTRE, PROMETHEE, MAUT, MACBETH, VIKOR, TODIM, Gray, MULTIMOORA and MAHP. In addition, multi-criteria decision making methods (MCDM) such as AHP and Fuzzy AHP enable evaluations based on standardized rating scales and preference functions. These methods often incorporate fuzzy logic (Bitarafan & Ataei, 2004) and are largely based on the Analytic Hierarchy Process (AHP) (Alpay & Yavuz, 2009; Azadeh et al., 2010; Bogdanovic et al., 2012).

Saki et al. (2020) proposed a novel method for selecting the optimal underground mining method by first identifying the most suitable MCDA techniques. For this purpose, a list of fifty parameters including geomechanical, geometrical, technical, economic, environmental and social factors was compiled. Subsequently, the most influential parameters — such as thickness, hanging wall RMR and production rate — were identified as critical selection criteria based on expert evaluations.

3. DATA AND METHODOLOGY

The studies are being carried out in various underground mines in Serbia and Iran. Serbia has nine underground coal mines. The annual production is up to 400,000 tons. The introduction of more modern mining methods is being considered in several mines. Iran, on the other hand, has a larger number of mines. Total coal production amounts to around 1.8 million tons and consumption to over 3.5 million tons. Coal reserves in Iran amount to several billion tons. Consequently, there is a constant need for the application of modern mining methods in existing mines and the opening of new mines.

In general, different mining methods are used in these mines. The conditions are also very different, from the ore geometry, ore type and reserves to the mechanical properties of the rock, market conditions and safe working conditions. In addition, many mining experts and managers were involved in this study, which provides a very good basis for obtaining high-quality results.

3.1. AHP method

The Analytic Hierarchy Process (AHP) is a quantitative decision-making technique developed by Saaty (1980). It is used to solve complex problems. It uses a multidimensional hierarchical structure of objectives, criteria and alternatives. It consists of nine steps: Defining the decision objective, structuring the hierarchy, defining the objective, defining the criteria, alternative options, comparing the criteria and alternatives by pairwise comparisons using the Saaty scale (Table 1), calculating the priorities where the matrices are normalized and the weighting coefficients are calculated, checking the consistency and selecting the best alternative (the alternative with the highest weighting coefficient).
Accordingly, only the first step is carried out in this work, with the aim of evaluating the most important group of criteria for the selection of the mining method for coal deposits.

Table 1. Pair-wise comparison scale for AHP method (Saaty, 1980)

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	

3.2. The research method

The original research method was developed to rank the criteria and evaluate the degree of their influence on the selection of the mining method for coal deposits. The research method includes the following four steps: (1) literature review, data collection, (2) determination of the most important groups of criteria for coal deposit mining method selection, (3) AHP calculations, and (4) results and discussion (Figure 1.).

The study began with a literature review to define the most important groups of criteria for the selection of the mining method for coal deposits. The literature is extensive and extensive research was carried out to cover all criteria groups. Additionally, structured interviews were carried out with mining experts and industry managers to collect high-quality data and gain insights into practical decision-making processes. The final list of the most important groups of criteria was then determined. The next step was to rank the identified criteria groups using the AHP to determine their influence on the mining method selection process. Once the results of the ranking were obtained, the most important groups of criteria were identified and analysed to provide a useful basis for future mining method selection and to better understand the priorities in this process.

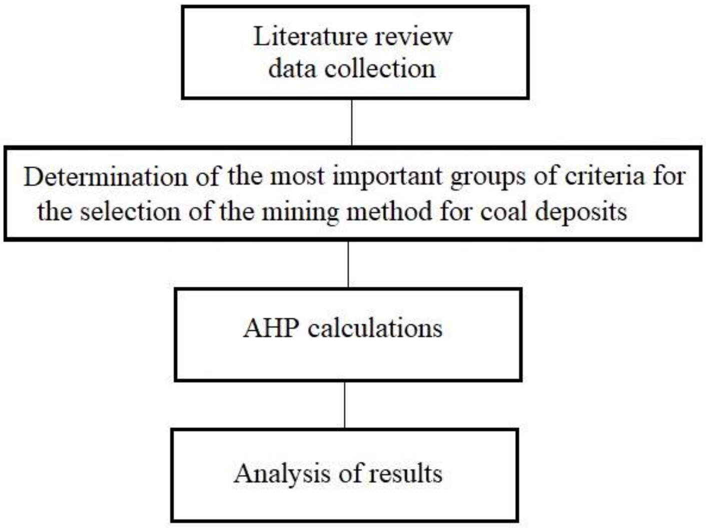

Figure 1. Schematic overview of the research method

4. RESULTS AND DISCUSSION

4.1. Literature review, data collection

As previously stated, the research commenced with a comprehensive literature review and interviews with mining experts and managers from Serbia and Iran. This phase was the most time-intensive and served as the foundation for subsequent research steps. Based on the collected data, a corresponding questionnaire was developed, structured in a manner that facilitated the identification and prioritization of key criteria derived from the responses received.

4.2. Determination of the most important groups of criteria for the selection of the mining method for coal deposits

In this stage, the identified groups of criteria are categorized based on their inherent characteristics and their impact on mining method selection. This classification is derived from an extensive literature review and expert discussions involving mining professionals and industry managers to establish a consensus for each criteria group. Based on this approach, six primary criteria groups have been defined, namely:

- C1 – natural – geological conditions (depth of the coal seam, thickness of the coal seam, inclination of the seam, geological structure, overburden characteristics, hydrogeological conditions, hanging-wall and foot-wall conditions, coal quality).
- C2 – technical conditions (geotechnical conditions, operational factors, equipment availability and infrastructure).
- C3 – economic conditions (capital and operating costs, coal market price and demand, resource recovery and reserves, productivity and labor costs, infrastructure and transportation costs, government policies, taxes and royalties).
- C4 – technological (organisational) conditions (mine layout and development requirements, mechanization and equipment availability, workforce skill and

experience, ventilation and gas management, material handling and transportation, production planning and flexibility).
- C5 – safety conditions (ground stability and roof control, gas hazards, dust and air quality, water ingress and flooding risks, fire and explosion risks, equipment and operational safety, emergency response and escape routes).
- C6 – environmental protection (land disturbance and habitat destruction, water pollution and acid mine drainage, air pollution, soil degradation and erosion, waste generation and management, noise and vibration impacts, energy consumption and carbon footprint)

4.3. AHP calculations

The AHP calculations were conducted using the group decision-making method, involving experts and managers from mining companies in Serbia and Iran. The aggregation of individual judgments (AIJ) method was employed to facilitate group decision-making. Figure 2. illustrates the hierarchical structure of the AHP problem. The criteria were deliberated and ranked until a consensus was achieved for each evaluation, utilizing the scale presented in Table 1. The comparison matrix (6×6) is provided in Table 2. The AHP calculations were performed using SuperDecisions software, and Figure 3 presents the results derived from the comparison matrix.

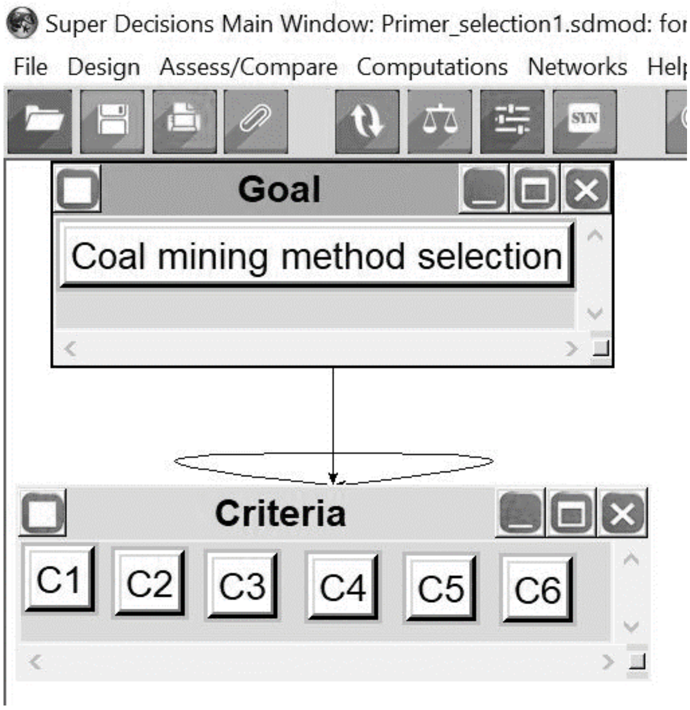

Figure 2. Hierarchical structure of the AHP problem

Table 2. Criteria comparison matrix

Criteria	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**
C1	1	2	2	5	1	2
C2		1	2	3	1	2
C3			1	1	1	2
C4				1	1/2	2
C5					1	1
C6						1

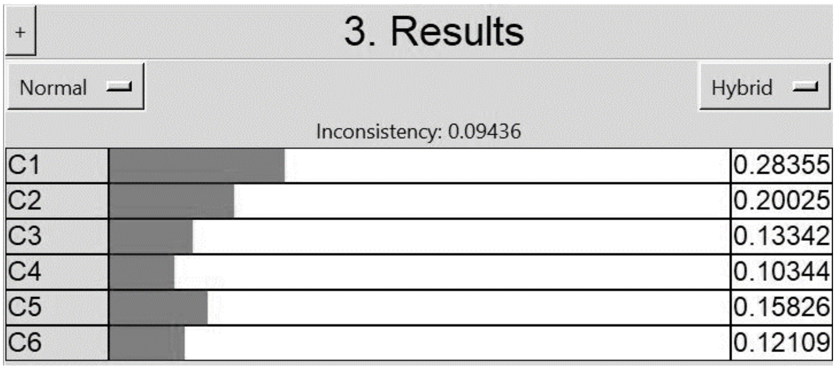

Figure 3. Results obtained by AHP calculations

4.4. Results and discussion

The obtained results clearly indicate which group of criteria has the most significant influence on the selection process of mining methods for coal deposits. The results suggest that the criteria can be categorized into two distinct categories based on their impact on the selection process. The first category comprises criteria with weighting coefficients exceeding 0,2 (20%), including C1 – natural – geological conditions and C2 – technical conditions. Conversely, the second category consists of criteria with weighting coefficients below 0.2.

In the first category, the most influential group of criteria is C1 with a weighting coefficient of 0.28355. The natural – geological conditions — such as the depth and thickness of the seam, the inclination of the seam, the geological structure, the characteristics of the overburden, the hydrogeological conditions, the stability of the slope and footwall and the coal quality — are of decisive importance for the choice of the appropriate mining method. The second most important group of criteria is C2 with a weighting coefficient of 0.20025. The selection of a mining method is largely determined by the technical conditions, including geotechnical parameters, operational factors, availability of equipment and infrastructure. For example, operational factors such as production capacity, efficiency, mine layout and accessibility play a decisive role in the selection of the mining method.

The second major category of criteria is much less influential than the first. Within this category, safety conditions (C5) have the highest priority in determining the mining method. Underground coal mining is a major challenge due to numerous hazards such as the presence of hazardous gases (e.g. methane, carbon dioxide), coal dust, water and mud ingress, underground fires, spontaneous combustion of coal and the risk of coal, rock and roof collapses. All of these factors have a direct impact on the choice of mining method, as the safety risks must be effectively managed. The third group of criteria, C3 (economic conditions), ranks second within this category. Economic factors such as capital and operating costs, coal market prices, resource recovery and reserves, productivity, labor costs, government policies, taxation, and royalties must be carefully assessed to ensure the selection of a mining method that maximizes profitability while maintaining operational feasibility. Environmental protection (C6) is an increasingly critical factor in mining method selection. Potential environmental hazards must be carefully considered, with a primary objective of minimizing the ecological impact of mining activities. Preference should be given to mining methods that pose the least environmental risk. Lastly, technological and organizational conditions (C4) also play a significant role in mining method selection. These include mechanization levels, equipment availability, workforce skill, and operational experience, all of which directly influence the feasibility and efficiency of a given mining method.

5. CONCLUSION

The AHP method was employed to assess the most critical groups of criteria for selecting the appropriate mining method for coal deposits. Six criteria groups were analyzed: C1 (natural and geological conditions), C2 (technical conditions), C3 (economic conditions), C4 (technological conditions), C5 (safety conditions), and C6 (environmental protection).

Based on the ranking results, the criteria can be categorized into two distinct categories according to their influence on mining method selection. The first and most influential category encompasses C1 (natural and geological conditions) and C2 (technical conditions). The second category, which has a comparatively lower impact on the selection process, includes C5 (safety conditions), C3 (economic conditions), C6 (environmental protection), and C4 (technological conditions).

The ranking outcomes of these key criteria groups provide valuable guidance for mining experts and decision-makers in selecting the optimal mining method for coal deposits in their operations.

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