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DEVELOPMENT OF MULTI-CRITERIA DECISION-MAKING METHODS (MCDM) IN THE MINING INDUSTRY

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Abstract: *Over the years, mining engineering has been faced with various challenges, including here the technical - economic - environmental parameters, therefore the need has arisen to apply different methods on decision-making when based on several criteria, all this with the sole purpose of achieving the most efficient, reasonable and sustainable solutions.*
Multi-criteria decision-making methods (MCDM) have their own importance in the development of decision-making processes in the field of mining engineering, so this paper aims to present a review of the history of the development and applicability of some of the most important decision-making methods. with multiple criteria like AHP which in a hierarchical way provides the structure to evaluate/rank the available alternatives, TOPSIS offers a clear method for ranking the alternatives based on their progress in relation to the specified criteria with the aim of the best solution which is closer to the ideal solution, ELECTRE uses a double process of elimination to arrive at the most suitable alternative which best fulfills the given decision criteria and the PROMETHEE method integrates a broad approach and evaluation of the preferences of all alternatives and offers a structured solution for the best alternative according to preferences.
The study provides an understanding of the applicability of these methods in the field of mining engineering, how multi-criteria decision-making methods can be used to improve processes to achieve goals depending on different technical-economic-environmental parameters.

Key words: *Decision-making methods, multi-criteria, AHP, TOPSIS, ELECTRE, PROMETHEE.*

1. INTRODUCTION

Multi-criteria decision-making methods (MCDM) serve as the main form for mining engineers in determining important decisions related to the management of mining resources, the optimization of operations and the minimization of potential risks. In mining engineering, where the handling of complex data and the selection of optimal strategies are important for achieving project goals, MCDMs have shown a significant increase in use and development.
MCDMs provide a means to handle the complexities of such decisions by integrating a range of criteria and alternatives, determining their relative weights, and computing evaluations for each alternative based on these criteria. This structured definition of the decision-making process allows mining engineers to make informed decisions that can improve the efficiency, safety and sustainability of mining operations.
In this paper, the aim is to examine the history of the development of multi-criteria decision-making methods in mining engineering. To this end, we will use a systematic

approach to examine how the use and application of these methods has evolved over the last decades in the context of the mining field.

1.1. History of MCDM methods

The history of multi-criteria decision-making methods (MCDM) in mining engineering begins with the need for a more systematic and structured approach to address complex decision-making problems in this particular field.

In the beginning, basic MCDM methods such as "Weighted Sum Model" (WSM) and "Weighted Product Model" (WPM) were used to evaluate and fulfill the criteria set by mining engineers in decision-making processes. These methods provided a standardized way to combine information from different criteria and highlight the most favorable alternatives.

In the middle period of the 20th century, with the development of mathematics and computer science, other sophisticated methods such as "Analytic Hierarchy Process" (AHP), "Technique for Order Preference by Similarity to Ideal Solution" were developed and introduced. (TOPSIS), "Electre Method" (ELECTRE). These methods provide more flexibility in handling different weights of criteria and in assigning different ways to evaluate alternatives.

So, methods such as AHP, TOPSIS, ELECTRE, and Promethee were born as a response to the increased needs for a structured and objective approach to decision-making in situations of high complexity and with many criteria. Their evolution has been influenced by the development of mathematical theory, their application in various industrial fields and the continuous contribution of researchers to their improvement.

Modern MCDM methods often integrate techniques developed for big data analysis, artificial intelligence, and advanced data visualization and modeling methods.

2. MCDM METHODS

2.1. Electre (Elimination and Choice Expressing Reality)

Developed by Bernard Roy in 1968, Electre is a method to evaluate and select alternatives using a clear system to express reality in decision making. It is based on the concepts of elimination and choice to create a clear and structured model to evaluate alternatives. It has used advanced technologies to improve its use and application in various industrial and academic fields.

Electre is used to evaluate and select technologies and projects in the mining engineering sector, including criteria of risk, capital expenditure and implementation capability.

2.2. Analytic Hierarchy Process (AHP)

AHP was developed by Thomas L. Saaty in 1980 as a method to process and analyze complex decisions involving many criteria. It is based on the mathematical theory of ranking and weight matrices to structure and classify alternatives based on preferences and important criteria. It has evolved through the use of advanced data analysis technologies to improve its evaluation and use in various industrial and academic fields.

AHP has been used in mining engineering to evaluate and select appropriate technologies, including criteria of capital expenditure, risk, environmental impact, and applicability.

2.3. Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

Developed by Hwang and Yoon in 1981, TOPSIS is a method to determine a preference ranking based on similarity to the ideal and worst possible solution. It is based on the mathematical concepts of rank analysis and normalized data to create a corresponding weighting matrix. It has used data analysis technology to improve the matrix and its application in the various fields of engineering and management.
TOPSIS is used to select mining technologies and projects based on a number of criteria such as efficiency, operating costs, and environmental impact.

2.4. Promethee (Preference Ranking Organization Method for Enrichment Evaluations)

The Promethee method was originally developed by Brans in 1982 as a method to address the problem of preferences and ranking alternatives using a structured rating system. It is based on concepts from valuation theory and preference analysis, including discrete mathematics and ranking theory. Over the years, Promethee has benefited from advances in data analysis and mathematical modeling, being widely used in various fields to optimize decision-making in situations of high complexity.
The Promethee method has numerous applications in mining engineering to evaluate and select different alternatives in mining projects. It is used for the selection of relevant technologies, mine development planning, and risk management. This allows applicants to evaluate alternatives based on a range of criteria, using mathematics to create an efficient ranking and selection.

Table 1. SWOT analysis of MCDM methods

Methods	Advantages	Weaknesses	Opportunities	Risks
AHP (Analytic Hierarchy Process)	Organizes the criteria and alternatives in a clear hierarchy, providing for a clear and structured reflection of the evaluations. Allows applicants to use structured mathematical calculations to evaluate alternatives objectively.	There can be challenges in determining weights and consistency of ratings, especially when users have different perceptions of the importance of criteria. Needs considerable time and good knowledge of the method to use effectively.	Using information technologies to improve the timeliness and efficiency of the decision-making process. The ability to more broadly include user preferences and priorities in the assessment using developed hierarchical analysis models.	Sensitivity to subjective assessments and their impact on decision-making results, increasing the possibility of errors in determining weights.

TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution)	It evaluates the performance of alternatives by comparing them to an ideal and a non-ideal solution. It enables the identification of the best alternatives using a structured mathematics based on pre-preferred criteria.	It can be sensitive to changes in criteria weights and in the ranking of alternatives, requiring special care in determining the weights. Difficulty in the ranking model of alternatives in the practical application of mining engineering.	Using data analysis technologies to identify and improve the performance of alternatives based on developed models. The possibility for deeper integrations of sustainability criteria and environmental impacts in the decision-making process in mining engineering.	Complexity in the use of weight calculations and the ranking model of alternatives, which can lead to inaccurate results in cases of incorrect use of the method.
ELECTRE (Elimination and Choice Expressing Reality)	It provides a structured method to model and understand user preferences through measures of evaluation and elimination of unsuitable alternatives. It allows for the inclusion of a large number of criteria and to address the complexity of decision making in mining engineering.	It needs a series of assessments and analyzes to ensure accurate and reliable results, requiring a good preparation of data and assessments. Difficulty in using appropriate measures and criteria for evaluating high complexities in mining projects.	Increasing the use of sustainability and environmental impact criteria to include in decision-making processes and to address the increased needs of society for sustainable projects. The use of data analysis technologies to improve the presentation and analysis of information in the decision-making process.	Difficulty in determining appropriate measures and criteria for evaluating high complexities in mining projects, increasing the possibility of errors in the decision-making process.
Promethee (Preference Ranking Organization Method for	Uses priority matrices to compare and evaluate alternatives in a	It can be complex for new users to understand and implement,	Using big data analytics and artificial intelligence to improve the presentation	High competition from new methods and the need to adapt existing

Enrichment Evaluations)	structured and systematic way. It enables applicants to use a clear mathematical calculation to evaluate and identify the most favorable alternatives.	requiring a good preparation and deep knowledge of the method. The high complexity of the mathematics and the model can make the methods difficult to use effectively and efficiently.	and analysis of information in the decision-making process. The opportunity to develop and adapt Promethee methods to new technological and academic developments in the field of data analysis.	methods to new technological and academic developments.

3. COMMONALITIES AND DIFFERENCES OF MCDM METHODS

Multi-criteria decision-making methods (MCDM) that have been mentioned as Analytic Hierarchy Process (AHP), TOPSIS, ELECTRE and Promethee method have some commonalities in their approach to solve decision-making problems in mining engineering. These commonalities include:

1. All these methods use a hierarchical structure to organize criteria and alternatives. This helps in determining the importance of each criterion and in identifying the most suitable alternatives.
2. MCDM methods allow the inclusion of subjective evaluations of experts or users, namely for criteria weights and their preferences for alternatives. In addition, they also include objective evaluations of the performance of the alternatives in accordance with the established criteria.
3. Most of these methods use priority matrices to compare and evaluate alternatives according to different criteria.
4. MCDM methods have mechanisms to evaluate and address the consistency of estimates and the stability of their results.
5. These methods are suitable for a wide range of engineering and management applications, including complex decision-making processes such as those in mining engineering. They provide a systematic and structured approach to handle important and complex decisions in difficult and changing environments.
6. MCDM methods include risk and safety assessment in the selection of alternatives. This includes assessing potential risks and identifying measures to reduce these risks in mining operations. Using these methods helps determine the safest and most efficient strategies.
7. Mining engineers are increasingly incorporating aspects of sustainability and environmental impact into their decision-making processes. MCDM methods provide the means to incorporate environmental and social criteria into the selection of alternatives, ensuring that mining operations are sustainable in the long term.
8. MCDM methods are also suitable to address social and ethical responsibility in decision making of mining projects. Incorporating appropriate social and ethical

criteria ensures that decisions are acceptable to local communities and comply with the country's regulatory standards.

The differences between multi-criteria decision-making (MCDM) methods mainly involve the approach and techniques used to evaluate and select alternatives. These differences may be in aspects such as the structure of the model, the mathematics used, and the specific ways of handling data and preferences. Some key differences:

1. Each method has a different structure to organize the criteria and alternatives. For example, AHP uses a hierarchy of criteria and a rough evaluation matrix, while TOPSIS uses a priority matrix to compare alternatives relative to the ideal and non-ideal solution.
2. Methods may use different mathematics and models to calculate the ranking of alternatives. For example, AHP uses calculations of priority matrices and consistency of estimates, while TOPSIS uses calculations of distances from the ideal and non-ideal solution.
3. Another difference is in the way each method handles and determines criteria weights and preferences. Some methods such as ELECTRE can use a knowledge system to evaluate user or expert preferences, while AHP can use a hierarchical method to determine the relative weights of criteria.
4. The methods also differ in terms of specific applications and opportunities to address particular decision-making challenges. For example, the Promethee method has a particular focus on the use of priority matrices and decision complexity analyses, making it suitable for certain applications in mining engineering.
5. Nowadays, several methods are used to incorporate information technologies and automation to improve decision-making processes. These may include big data analytics, artificial intelligence and predictive models to enable deep analysis and informed decision-making.

3.1. The importance of Methods

Multi-criteria decision-making methods provide a clear and convenient structure to evaluate and select alternatives in mining engineering. These methods help to determine the sustainable and efficient way of solutions based on a large number of important criteria, such as capital costs, production capacity, environmental impact, and operational risk, so the use of these methods enables the inclusion of all variables. relevant and important criteria in the decision-making process.

Structured methods provide a high level of objectivity and transparency in the decision-making process. The use of these methods enables the balancing of different preferences and interests, minimizing the influence of personal and subjective perceptions in the selection process. The use of advanced methods of data analysis and decision-making mathematics contributes to improving the consistency and efficiency of the decisions made. This helps in minimizing potential risks and increasing the performance of projects in mining engineering.

3.2. Challenges and Difficulties

The implementation of such methods requires in-depth knowledge and good technical preparation. Users must have a good understanding of the mathematics of data analysis and decision-making concepts to apply the methods successfully. The use of these methods requires detailed and accurate data to ensure reliable and consistent results. The lack of sufficient or accurate data can reduce the efficiency and reliability of the analyzes made. Therefore, the interpretation of the results given by these methods can be a challenge, requiring a careful and critical evaluation of the methods used. This includes assessing possible errors and the accuracy of the conclusions reached.

4. CONCLUSIONS

The Promethee method and other multi-criteria decision-making methods such as AHP, TOPSIS, and ELECTRE provide a wide range of analytical tools to improve the decision-making process in mining engineering. Their successful use depends on the adaptation to the specific context of the projects and the needs of the organizations to achieve sustainable and optimized solutions. Their development continues to be closely related to advances in data analysis technologies and increased needs for integrating sustainability aspects into decision-making processes.
However, to achieve these goals, it is important to address the challenges and difficulties of their implementation in the context of mining engineering. Improving knowledge and skills in the use of these methods will contribute to increasing project performance and minimizing potential risks in this critical area. Their use in accordance with the context and specific needs of the mining field can bring significant benefits in the technical, economic, and social aspects of mining projects.
The use of a particular method may depend on project characteristics, complexity of requirements, and user preferences for the most appropriate method for the specific situation in mining engineering.

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