Multiple-Criteria Decision-Making in Mine Development Planning

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UYAK 2023 ·istanbul·

PROCEEDINGS OF THE 5th INTERNATIONAL UNDERGROUND EXCAVATIONS SYMPOSIUM

5. Uluslararası Yeraltı Kazıları Sempozyumu Bildiriler Kitabı

5-6-7 June/Haziran 2023 - İstanbul

MADEN MÜHENDİSLERİ ODA

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5-6-7 June/Haziran 2023
ISTANBUL / TÜRKİYE

TMMOB
Chamber of Mining Engineers
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ISBN **: 978-605-01-1568-0**

Published by **:** Dinç Ofset Mat. Rek. San. ve Tic. Ltd. Şti.
Davutpaşa Cad. Emintaş Matbaacılar Sitesi No:103/580-581
Topkapı, Zeytinburnu-İstanbul (Tel: 0212 493 3300)

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ABSTRACT: The Borska Reka ore deposit is an experimental location where developed methodologies have been applied. It is the largest ore body within the Bor mining complex, which has been the subject of numerous studies and analyses for more than three decades. The paper focuses on the application of FAHP and the VIKOR method to address ranking of alternatives and select the optimal mining method by means of fuzzy multicriteria optimization.

1. INTRODUCTION

Multi-criteria decision-making methods are often combined with each other, in addition, they are also characterized by a combination with fuzzy methods. Multi-criteria decision-making methods are often combined with each other, in addition, they are also characterized by a combination with fuzzy methods. Namely, each of the methods has its own advantages and disadvantages in terms of emphasizing some and marginalizing other factors that influence the expression of decision-makers' preferences. By combining several methods, it is possible to more precisely determine the real relation of the influence of individual parameters on the overall performance.

Hence the idea to present in the paper a combination of classical and fuzzy multi-criteria methods and examine whether it is possible to create a hybrid model that will use of all the advantages of individual methods and give more reliable results.

The aim of the paper is to present the developed procedure method- algorithm, applied when choosing the mining method for mining raw material deposits in underground exploitation. The "classic" multi-criteria optimization method VIKTOR and the FAHP method were used for explorations.

Qualitative assessment is used for both multicriteria optimization methods, involving an evaluation scale to describe pairwise comparisons of elements of the criteria, subcriteria, and alternatives.

Figure 1 shows the algorithm used and the steps taken with both methods to define mining problems. Experience and expert judgment affect all steps of the algorithm. The algorithm is related to modeling of alternative mining technologies. The objective is to select the optimal mining method that would lead to positive results or, in other words, to determine the approach that would ensure economically viable ore extraction. Mining safety also needs to be considered.

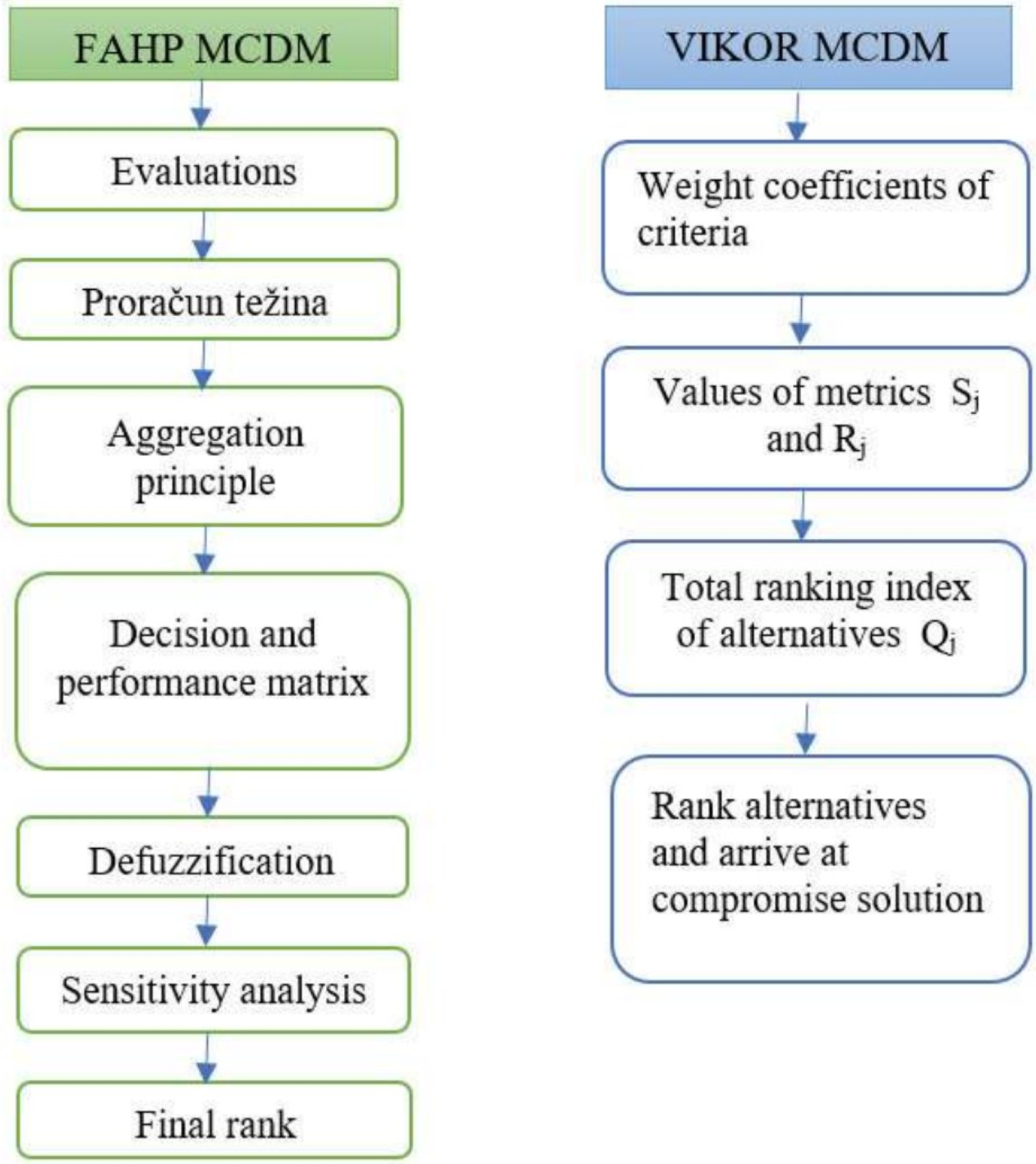

Figure 1. Algorithm to the creation of a sustainable mining plan

The criteria that influence the decision are analyzed and then FAHP and VICOR are used to create a decision matrix. The ultimate stage involves mathematical optimization calculations and final decision making.

2. GEOGRAPHICAL LOCATION AND GEOLOGICAL CHARACTERISTICS OF THE EXPERIMENTAL AREA

The mentioned study area is the Borska Reka copper ore deposit in eastern Serbia (Figure 2), which belongs to the Timok Igneous Complex on the northwestern outskirts of the City of Bor, beneath the valley of the Bor River. It is part of an active mine called Jama.

In geologic terms, the sediments are composed of volcanites and volcanoclastic rocks, pelites with tuffs and tuffites, conglomerates, sandstones, Quaternary alluvial sediments and technogenic deposits.

The prevalent ore is pyrite, the dominant copper mineral is chalcopyrite, and there are covellite, chalcosine, and bornite to a lesser extent.

Rutile, hematite, magnetite, sphalerite and galenite often occur. Of the non-ore minerals, quartz is dominant, and calcite, anhydrite, gypsum, zeolite, and rarely barite is also present. Past exploration has revealed that the ore body "Borska reka" is among very large deposits in the geometric sense, with elevated copper concentrations. The ore body is at an angle of 45°-55°. It is maximum length is 1.410 m and maximum width 635 m, and the average is about 360 m. The ore body is deep; the average ultimate depth is 920 m from the ground surface. This ore body has an irregular shape and resembles a deformed flattened fallen cone with a base to the southeast and a top to the northwest.

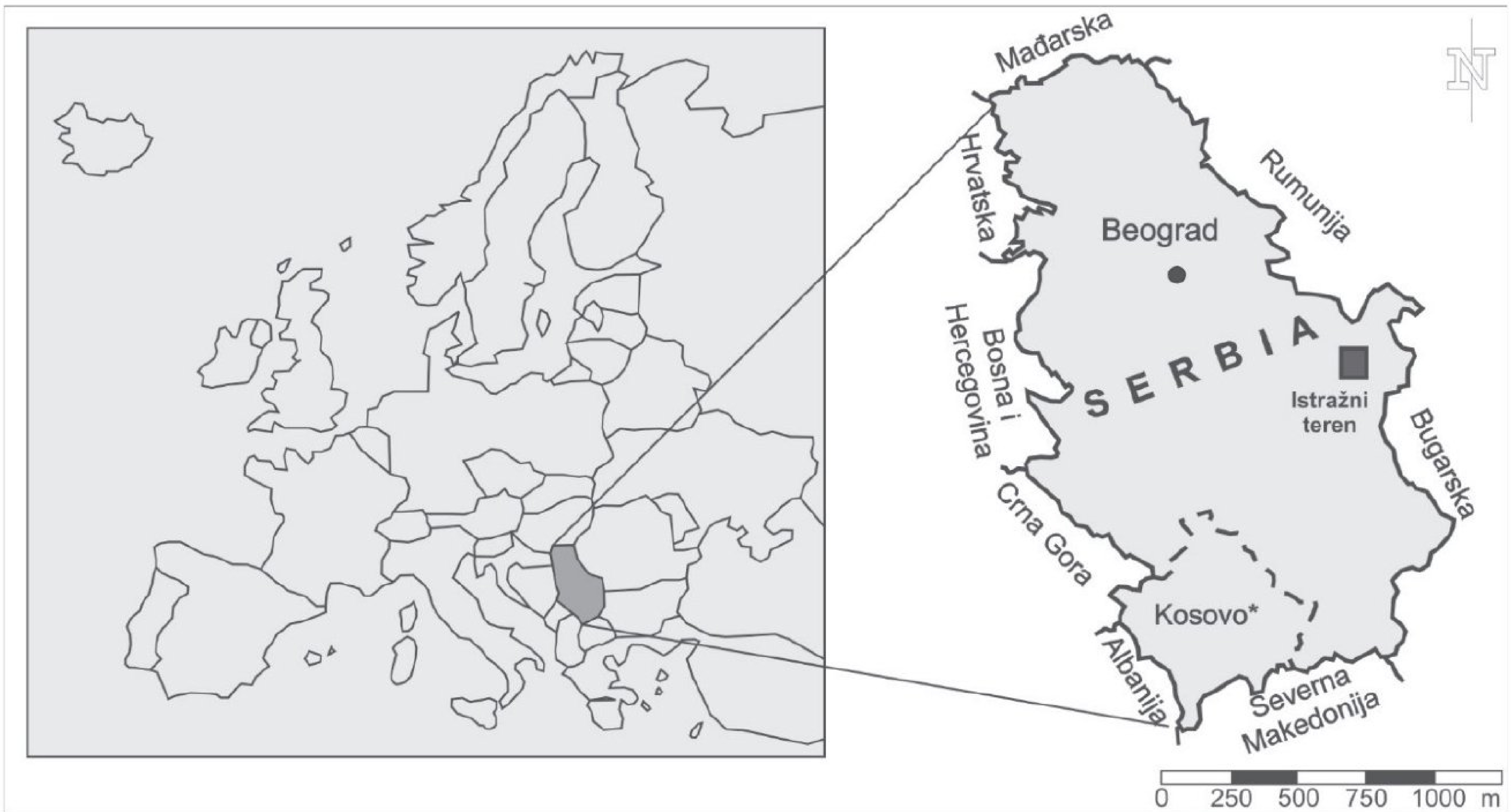

Figure 2. Geographical location of the study area: "Borska reka" copper mine

3. METHODOLOGY

They were applied: the FAHP method, which enables the assessment and analysis of individual criteria and sub-criteria using the FAHP evaluation scales, as well as the VIKOR method using the Saaty scale (Bajić at al., 2020).

The FAHP method represents a combination of the classical AHP method (Saaty, 1980) and the theory of sets of triagular fuzzy numbers (Zadeh, 1965), and is implemented by using triangular fuzzy numbers (Chang, 1996).

In the continuation of the text, for the purposes of the paper, these methods were used, according to which the problem solving procedures were given. (Zhu et al., 1999; Lamata, 2004; Van Broekhoven, 2004; Liou & Wang, 1992; Kwang & Lee, 1999).

In the first step, problems are defined, which include defining a set of criteria and sub-criteria for the evaluation of alternatives. Then the criteria and subcriteria are assessed and their weights are also determined in the form of a fuzzy number (Bajić at al., 2020). Evaluations were performed by comparing pairs of elements (criteria, subcriteria, alternatives) using linguistic variables and their numerical values according to the FAHP evaluation scales. (Zhu et al., 1999; Lamata, 2004). A relative significance scale described the linguistic variables by numerically ranking their significance, as follows: equal (1), equal to moderate (2), moderate (3), moderate to high (4), high (5), high to very high (6), very high (7), very high to extremely high (8), and extremely high (9). When comparing fuzzy pairs, the decision maker examines two alternatives considering one criterium and points to the advantage. The results of the comparison, as numbers from FAHP scale (Tolga et al., 2005; Zhu et al., 1999; Lamata, 2004) are included into the adequate matrix on the basic of which are calculated local vectors of priority that is weight coefficient of compared elements. In the next step, the values of the vector of weight priorities are determined, using „ fuzzy extent analysis. Also, for all 5 alternatives by the fuzzy extent analysis the fuzzy decision matrix and fuzzy performance matrix are now calculated. Fuzzy performance matrix represents the overall performance of each alternative relative to all of the decision matrix.Then the ultimate values of the alternatives are calculated, defuzzification and selection of the optimal method. After that, a sensitivity analysis is done through the equation and the final ranking of the alternatives is done.

The VIKOR (multicriteria optimization and compromise solution) method is based on the assumption that a compromise is acceptable for resolving conflicts and that the decision maker is looking for the solution closest to the ideal, where alternatives are evaluated against set criteria (Opricović, 1998). Based on already known information about alternatives a decision matrix was constructed according. Then the most favorable values of all the criteria (highest maximization and lowest minimization values) are determined. A fuzzified Saaty scale proposed by (Zhu et al., 1999; Lamata, 2004) was used to assess the alternatives relative to the criteria. The weight coefficients of the criteria were determined such that w_i=1. The Also values of weight v were determined. Given that the number of criteria in this case is n = 18, and the value of the weight v depends on the number of criteria, v is selected, $v = 0.7$ for $n \geq 11$. The values of the metrics Sj and Rj were determined. Then, according to the next step, calculations of the total ranking index of the alternatives were given, as well as the value of Qj that represents a linear combination of metrics Sj and Rj. The alternatives were analyzed and ranked according to the values of S_j, R_j and Q_j, and a compromise solution was proposed. All steps in detail and calculations are given in the doctoral dissertation (Bajić, 2020).

4. RESULTS AND DISCUSSION

The ore deposit is highly specific because its great depth and low copper concentration necessitate many criteria to be considered. The criteria and subcriteria that govern the selection of the optimal mining approach need to be defined. Then, the criteria and sub-criteria that influence of choice the optimal alternative were defined. Three criteria were identified: technical, production and economic. The criteria were subdivided into sub-criteria, in this case 18, as shown in Table 1.

Given the different types of criteria, which contradict each other, the application of multi-criteria decision-making (MDC) methods in the process of their prioritization is logical and justified.

In addition, five different alternatives (underground mining methods) were defined, including: Alternative 1—sublevel caving; Alternative 2—cut and fill; Alternative 3—shrinkage stopping; Alternative 4—block caving; Alternative 5—vertical crater retreat (VCR).

From several proposed variants, depending on the technical, production, economic and environmental criteria, the most optimal system will be selected for the selection of the optimal method of excavation of the underground mine and application in the experimental area.

In Table 2 final values of all five alternatives in the form of a triangular fuzzy number were shown, obtained by the operation of adding the element of the fuzzy matrix performance. Then are displayed the final values of the „weight“ alternative in the form of a non-fuzzy number, obtained by the defuzzification. After that, a sensitivity analysis was performed and the final ranking of the alternatives was performed. The best result is represented by the highest value of the weight of the alternative. Based on the results, when calculating using the FAHP method alternative 5 is the optimal underground mining method (vertical crater retreat).

Table 3 shows the total ranking index of the alternatives, as the value Qj. Based on calculations carried out according to the classic VIKOR method alternative A_5 was selected as the optimal solution and in that case.

The results showed that the adopted excavation methods and the corresponding predicted excavation methods were the same in both cases. (Bajić, 2020).

Table 1. Defining of criteria and sub-criteria

Criterion	Symbol	Subcriteria	Symbol
Technical	T	Depth of ore body	T1
		Thickness of ore body	T2
		Shape of ore body	T3
		Value of ore	T4
		Ore body slope (angle)	T5
		Rock hardness and stability	T6
		Form of ore body and contact with neighboring rocks	T7
		Mineral and chemical composition of ore	T8
Production	P	Mining method productivity and output	P1
		Safety at work	P2
		Adverse environmental impact	P3
		Ore dilution	P4
		Ore impoverishment	P5
		Ventilation	P6
		Hydrologic conditions	P7
Economic	E	Capital expenditure	E1
		Mining costs	E2
		Maintenance costs	E3

Table 2. Ranking and selection of the optimal alternative

FUZZY NUMBER					REAL NUMBER	FINAL RANK	OPTIMAL SOLUTION
	L	S	D				
A_1	0.020	0.196	1.955		0.198	3	0.271
A_2	0.023	0.222	2.019		0.205	2	
A_3	0.016	0.173	1.814		0.183	4	
A_4	0.014	0.133	1.407		0.142	5	
A_5	0.028	0.275	2.684		0.271	1	
OPTIMAL ALTERNATIVE					A_5		

Table 3. Intermediate results (QS_j and QR_j), and ranking of alternatives (Q_j)

	(Sj-minSj)/(maxSj-minSj)	(Rj-minRj)/(maxRj-minRj)	Q_j	v = 0.7
A_1	0.666667	1	0.766667	
A_2	0.333333	1	0.533333	
A_3	0.777778	1	0.844444	
A_4	1	1	1	
A_5	0	0	0	

5. CONCLUSIONS

In order to make the process work as efficiently as possible, different methods of multi-criteria optimization are applied, which serve to simplify the decision-making process. Some of this methods is FAHP, as well as the VIKOR method, which are suitable for understanding imprecise and incomplete data, as well as for detection mutual relationships between these data.

When method VIKOR is used to select the optimum mining method, a qualitative assessment approach is followed to describe pairwise comparison of criteria, subcriteria and alternatives, or linguistic variables, as reflected in a expert judgment, intuition, and experience.

Based on the objective and scope of the research, the conclusion is that multicriteria analysis can be applied effectively to solve problems associated with the selection of an optimal mining technology, as demonstrated by an example of the application of the VIKOR method.

The FAHP method is characterized that each problem is solved hierarchically, gradually, until the purpose is reached. On the other hand, the FAHP method is characterized by a constant "process" of learning, then the discussion of experts and the assessment of priorities when solving problems. Therefore, by applying the FAHP method, its types of use as a qualitative technique based on the assessment and experience of decision-makers in evaluating information, to reach an optimal decision between several underground excavation methods, were pointed out.

Based on the solutions proposed by the multi-criteria decision-making method (FAHP and VIKOR), it can be concluded that in both cases, for the choice of the underground mining method of the "Borska reka" copper deposit, the same results were obtained, i.e. the same optimal alternative A5 (VCR mining method).

REFERENCES

Bajić S. (2020). Comprehensive modeling of underground mining impacts to support decision making. University of Belgrade-Faculty of mining and geology, Doctoral Dissertation.

Bajić S. Bajić D., Gluščević B. & Ristić Vakanjac V. (2020). Application of Fuzzy Analytic Hierarchy Process to Underground Mining Method Selection. Symmetry, 12(2):192, DOI: https://doi.org/10.3390/sym12020192

Chang D.Y. (1996). Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research, pp. 649-655.

Kwang H.C. & Lee H.J. (1999). A method for ranking fuzzy numbers and its application to decision making. IEEE Transaction on Fuzzy Systems, 7(6) pp. 677-685.

Lamata M.T. (2004). Ranking of alternatives with ordered weighted averaging operators. International Journal of Intelligent Systems, 19, pp. 473-482, DOI: https://doi.org/10.1002/int.20002.

Liou T.S. & Wang M.J.J. (1992). Ranking fuzzy numbers with integral value. Fuzzy Sets and Systems, 50(3) pp. 247-256.

Opricović S. (1998) Multi – criteria system optimization in construction industry. University of Belgrade-Faculty of Civil Engineering, pp. 142-158, ISBN 86-80049-82-4.

Saaty, T. L. (1980). The Analytic Hierarchy Process. McGraw Hill, New York

Zadeh, L. A. (1965). Fuzzy sets. Information and control, 8 (3), pp. 338-353.

Zhu K., Jing Y. & Chang D. (1999). A discussion on extent analysis method and applications of fuzzy AHP. European Journal of Operational Research, pp. 450-456,
http//dx.doi.org/10.1016/S0377-2217(98)00331-2.

Van Broekhoven E. (2004). A comparison of three methods for computing the center of gravity defuzzification. Proceedings of the International Conference on Fuzzy Systems, 3(3), pp. 1537-1542, DOI: 10.1109/FUZZY.2004.1375403.