Application of VIKOR method in the selection of an optimal splution of excavation “Borska Reka” ore deposit

Sanja Bajić, Dragoljub Bajić, Branko Glušćević, Radmila Gaćina

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FOREWORD

After the consultations with business entities in the field of mining and environmental protection, faculties and scientific institutes, an initiative for organizing a scientific meeting on mining and environmental protection was taken in 1996. The Faculty of Mining and Geology in Belgrade, CENTER FOR ENVIRONMENTAL ENGINEERING, have organized the First Yugoslav Conference with International participants held from 25 to 27 April 1996. in Belgrade, Serbia. The second International Symposium was held in Belgrade from 25 to 27 May 1998. The third Symposium was held in Vrdnik from 21 to 23 May 2001. The fourth International Symposium was held in Vrdnik from 23 to 25 June 2003. Due to the large number of subjective and objective reasons organization of the symposium was discontinued in 2003. Fifth International Symposium was held in Vrdnik from 10 to 13 June 2015. The sixth International Symposium was held in Vrdnik from 21 to 24 June 2017. The seventh International Symposium was held in Vrdnik from 25 to 28 September 2019. and the eighth International Conference was held in Soko Banja from 22 to 25 September 2021.

On the basis of the conclusions made at the 8th Conference MEP 2021 and great interest of domestic and foreign scientific and professional public, the Faculty of Mining and Geology in Belgrade, in cooperation with co-organizers (Berg Faculty TU Košice, Slovakia, University of Ljubljana, Faculty of Natural Sciences and Engineering, Slovenia, Goce Delčev University in Štip, N. Macedonia, Geological Survey of Slovenia, Ljubljana, Slovenia, University in Banja Luka, Faculty of Mining, Prijedor, Republic of Srpska, Bosnia & Herzegovina and Association of Mining and Geology Engineers), shall organize the 9th International Conference Mining and Environmental Protection – MEP 2023.

The previous Symposium, were very successful and scientist and companies from many countries gathered to exchange information and research results. The objective of this Conference is to bring together engineers, scientists and managers working in mining industry, research organizations and government organizations, on development and application of best practice in mining industry in the respect of environment protection.

At the Book of Proceedings of 9th International Conference on Mining and Environmental Protection are 56 Papers. Almost half is from abroad, or their authors is from different countries. At least 166 authors and co-authors took part in the preparation of these papers. The papers were reviewed by Reviewers. Only high-quality papers were selected, from two side, one from the scientific basis and the second from point of view of applicability in resolving problems at the development of mining.

We are very grateful to the authors of the papers, who contributed to a great extent to the success of this meeting by having sent enough number of high-quality papers, and thereby made the work of the reviewers a pleasant one in respect of selecting the best quality papers. Also, we would like to thank all of the participants in the Conference, as well as the sponsors who helped and enabled us to hold such a great meeting.

Editor

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APPLICATION OF VIKOR METHOD IN THE SELECTION OF AN OPTIMAL SOLUTION OF EXCAVATION "BORSKA REKA" ORE DEPOSIT

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Abstract: *The possibilities and methods for economic and safe exploitation of the "Borska Reka" ore deposit have been considered in previous researches. In addition to the optimal method of opening the deposit, optimal solutions for mining methods were also sought to obtain positive results, and that means determining the most economical method of ore mining. Subject mine represents an experimental area where a developed scientific methodological procedure has been applied that has a heuristic meaning. This model enables the discovery of new knowledge and develops creativity by requiring a certain independence from the subjects, while respecting the level of prior knowledge of each subject in his domain individually, using qualitative assessments - that is of linguistic variables for describing the comparison of pairs of elements of criteria, sub-criteria and alternatives in a classic method such as VIKOR. An ore deposit is a complex system because of its geology conditions. As such, problem solving requires a heuristic approach and includes tasks involving expert judgment, intuition, estimation, and experience. Through mathematical optimization calculations, a final decision was made on the optimal method of underground excavation.*

Key words: *decision making, optimization, underground exploitation, underground mining methods*

1. INTRODUCTION

Making decisions in order to obtain adequate results is based on qualitative or quantitative principles. The qualitative method generally refers on a person (expert), on his opinion, knowledge, skill, experience, wisdom, intelligence, intuition. Regardless of which method we apply, it is impossible to avoid subjectivity when making decisions with this approach [1]. Quantitative decision-making includes the metrics of factors such as risk, predicting and comparing the outcomes of alternative decisions. In both cases, the objective is to help the decision maker to make the best decision. Decision-making in mining is in principle complex engineering tasks, often of high sensitivity and low risk tolerance [2]. The choice of one between several possible solutions is part of the task of decision-making and management, which refers to the "recognition" one of the number of alternatives, which will give the best results in real conditions. In this procedure, it is necessary to define the objective of solving the task, the criteria used to measure the achievement of the objective and, between the available alternatives, the choice of the solution that best achieves the set objective. In such a procedure, decision-making is preceded by the evaluation of possible alternative solutions [3].

The aim of the paper is to present a methodical approach – algorithm, which is applied when making decisions to select the most appropriate mining method for an ore deposit in underground mining. The "classical" method of multi-criteria optimization VIKOR was used.

During the calculation using the VIKOR method, a qualitative evaluation was used to select the optimal variant of underground mining of copper deposits.

Figure 1 shows the algorithm in which the procedures performed in the method are given. First, the problems during mine excavation are defined. Then the alternatives that are considered as possible solutions are defined, a set of criteria and sub-criteria is defined, which are determined on the basis of data on the characteristics of the deposit. A matrix is formed where the evaluation of criteria is approached and finally the ranking of alternatives and the final solution. Experience and subjective assessment affect each step of the algorithm. The algorithm models alternative underground mining solutions. The final goal is to determine the optimal mining method which will ensure positive results, and that means determining the method that gives the highest production with the most useful components, in the shortest time, with complete safety of the employees, and without unfavorable consequences for the further development of the mine.

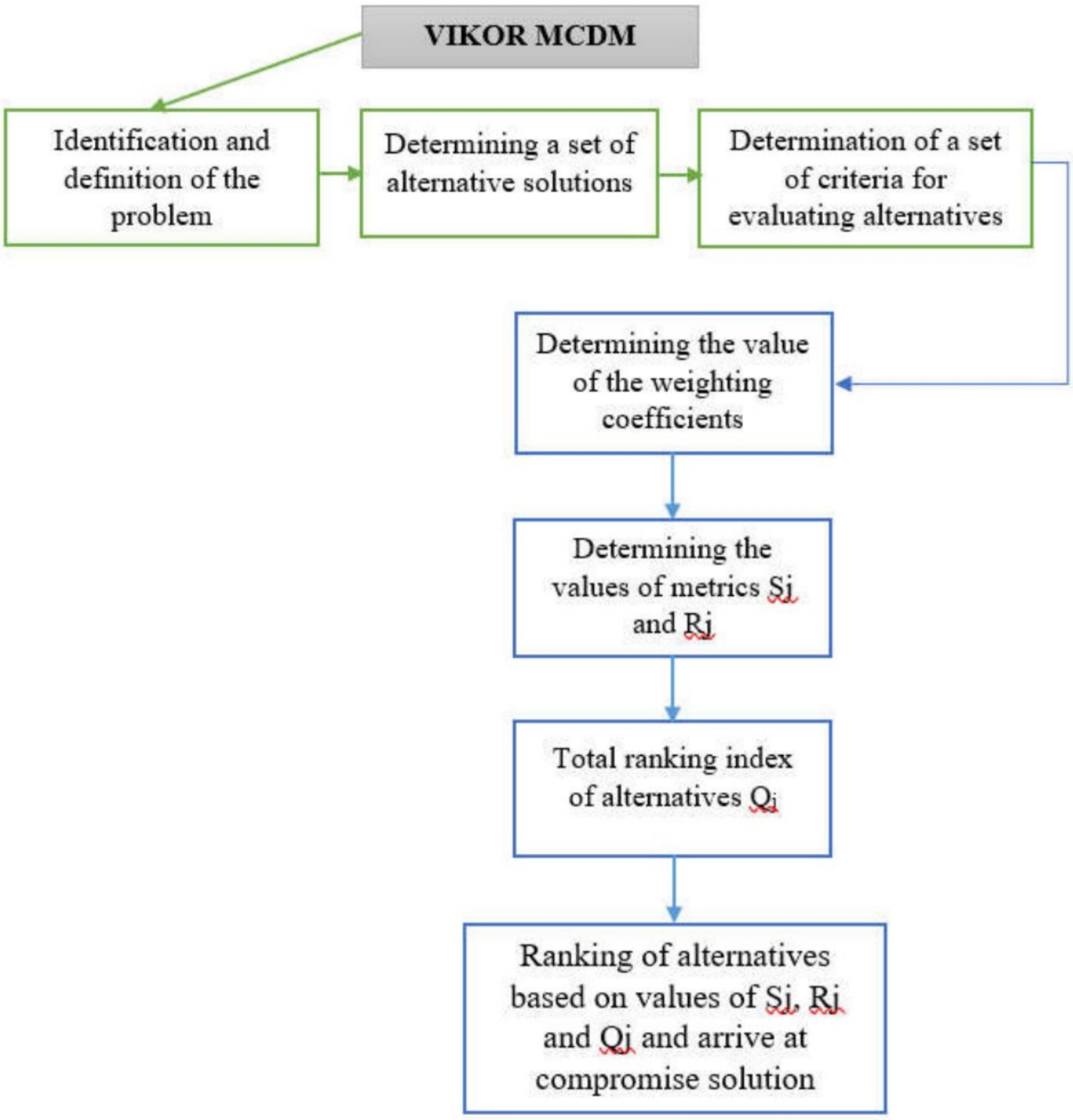

Figure 1. *Algorithm to the creation of a sustainable mining plan*

2. METHODOLOGY

The VIKOR method (Method for Multi-Criteria Compromise Ranking) is a very frequently used method for multi-criteria ranking, suitable for solving various decision-making problems. It was developed on the basis of elements from compromise programming. [4]. This method was developed by Serafim Opricović (1998) [5], for the purposes of solving decision-making problems when ranking alternatives with conflicting and different criteria.

In the continuation of the text, for the purposes of the paper, a method was used, according to which the problem solving procedures were given [6], [7].

***Table 1**. Calculation steps using the VIKOR method*

Determination of the objective and define evaluation relevant criteria for the evaluation of alternatives	Technical criteria (8): depth, thickness and shape of ore body, value of ore, slope angle, rock hardness and stability, ore body form, contact with adjacent rocks ,mineral and chemical composition of ore Production (7): productivity of the mining technology and production capacity, safety at work, environmental impact, ore dilution, ore impoverishment, ventilation, hydrology Economic (3):capital expenditure, excavation costs and maintenance costs
Create a decision matrix, according to the following equation:	$X = [x_{ij}] = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$ x_{ij} is the performance of the *i*-th alternative relative to the *j*-th criterion, *m* is the number of alternatives, *n* is the number of criteria.
Determine the most suitable values of all criteria (the highest value at maximization, the lowest at minimization, or the target value for criterion j:	$T = \{T_1, T_2, T_3, \dots, T_j, \dots, T_n\}$ = most desirable element *xij* or target value of criterion *j*
Determine the relative significance of the criteria, in other words the weight coefficients of the criteria for which the following holds true:	$\sum_{i=1}^{n} w_i = 1$
Determine weight *v*. *V* depends on the number of criteria (*n*): v = 0.5 for $n \leq 4$, $v = 0.6$ for a $5 \leq n \leq 10$, $v = 0.7$ for $n \geq 11$. In the VIKOR software package, the value of v is the setpoint ($v = 0.5$)	
Calculation values of metrics S_j and R_j : S_j is the deviation metric that expresses the requirement to maximize group utility, R_j - R_j is the deviation metric that expresses the requirement to minimize the longest distance of the alternative from ideal.	$S_j = \sum_{i=1}^{n} w_i = \frac{f_i^* - f_{ij}}{f_i^* - f_i^-}$ (p = 0) $R_j = max\left(w_i \frac{f_i^* - f_{ij}}{f_i^* - f_i^-}\right)$ ($p = \infty$) f_i^* i f_i^- - the maximum and minimum values of the criteria function of the alternatives, respectively : $f_i^* = \max_j f_{ij}$ i $f_i^- = \min_j f_{ij}$ (i = 1,2,......,n)
Calculation of total alternative ranking index :	$Q_j = v\frac{S_{j-S^*}}{S^- - S^*} + (1-v)\frac{R_{j-R^*}}{R^- - R^*}$ (j = 1,2,....., J) where are: $S^* = \min_j S_j$, $R^* = \min_j R_j$, $S^- = \max_j S_j$, $R^- = \max_j R_j$, The relation for metric Q_j can also be written as: $Q_j = vQS_j + (1-v)\,QR_j$
Rank alternatives three times, based on S_j, R_j and Q_j. The best alternative according to the compromise ranking list is the one with the lowest Q_j	
Propose, as a compromise solution, the alternative A(1),which is ranked best according to the compromise ranking list (the smallest value for Qj)	

VIKOR is a useful decision support method in situations where the decision maker does not know how to express the weighting coefficients for the criteria when forming the initial matrix of the model.

3. RESULTS AND DISCUSSION

In order to obtain an adequate solution, five different alternatives (underground mining methods) were defined, including: Alternative 1—sublevel caving; Alternative 2—cut and fill; Alternative 3—shrinkage stoping; Alternative 4—block caving; Alternative 5—vertical crater retreat (VCR). From several proposed variants, depending on the technical, production, economic and environmental criteria, the optimal system will be selected for the selection of the method of excavation of the underground mine. A fuzzified Saaty scale proposed by Zhu et al. (1999) and Lamata (2004) was used to assess the alternatives relative to the criteria [6] [7].

By calculating the values QSj , QRj and Qj , three independent ranking lists can be formed. The values Q_j represents the establishment of a compromise ranking list that unites the values QS_j and QR_j. By choosing a smaller or larger value for v (the weight of the strategies satisfying most of the criteria), the decision maker favors the influence of the value of QSj or the value of QRj in the compromise ranking list [4]. Hereafter, the results and ranking of the alternatives are presented in tables and graphics [8].

Table 2. *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	

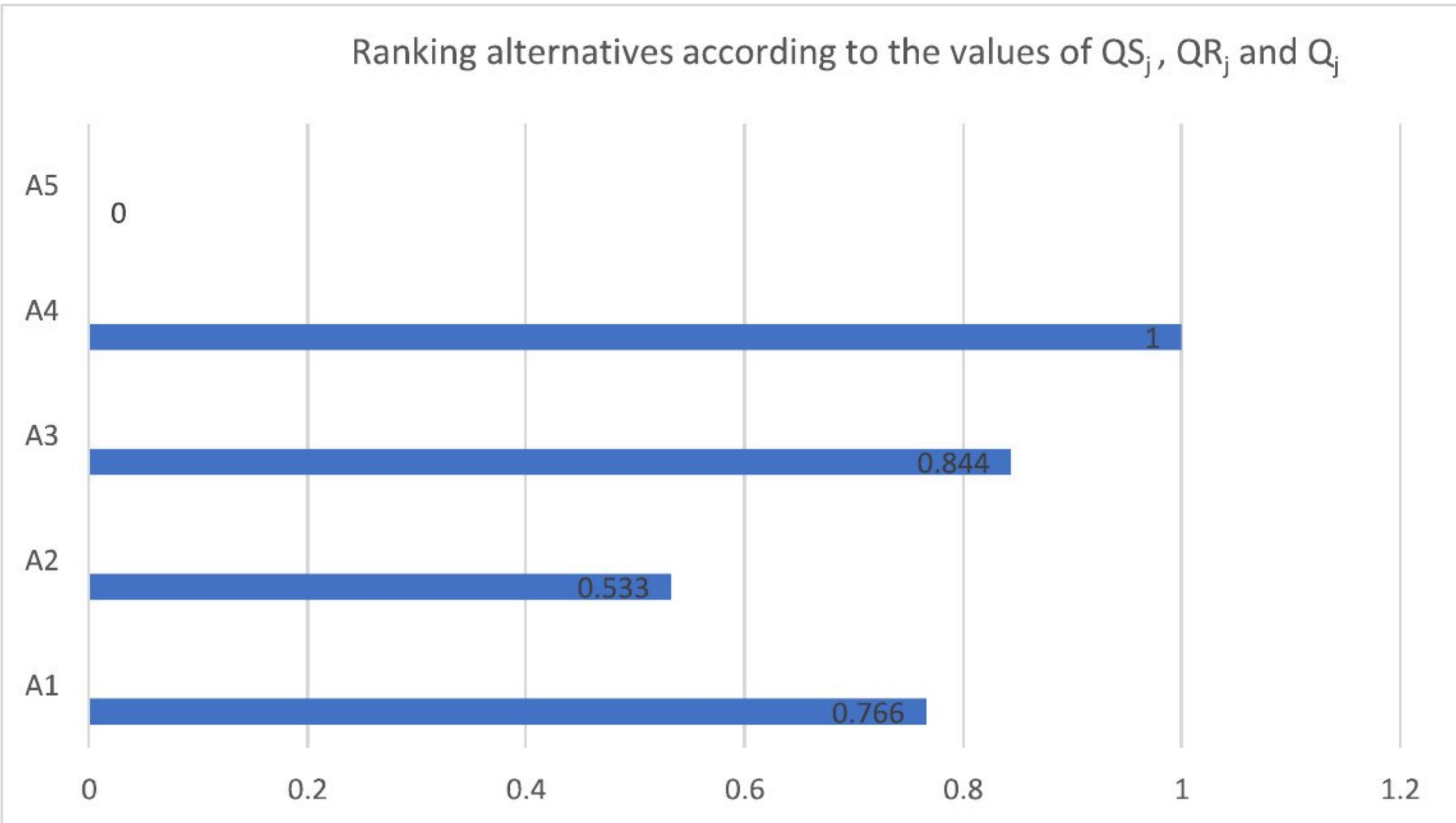

Figure 2. *Graphic representation the ranking of alternatives*

The best alternative, ranked according to the compromise ranking list, is the one with the smallest value of Qj. Based on the calculations performed according to the classic VIKOR method, alternative A5 was chosen as the optimal solution [8].

4. CONCLUSIONS

One of the most complex tasks of mining engineering is the selection of the excavation method.

In order to make this decision, it is necessary to know all the parameters of the ore deposit as reliably as possible. In mining, we often encounter complex structured problems where the selection of the best from a group of possible alternative solutions is performed on the basis of several criteria. The choice of criteria depends on the natural conditions of the ore deposit and on techno-economic factors.

The developed specific algorithm, whose contribution is reflected in the selection of the optimal method of excavation the underground ore deposit, was formed on the basis of previously defined criteria (sub-criteria) and an alternative based on the natural characteristics of the deposit considered. It is an introduction to further calculations, from which variant solutions are obtained first and then the optimal solution using the classic VIKOR multi-criteria decision-making method.

After the analysis and application of the VIKOR method, the optimal result obtained in terms of choosing the optimal excavation method for the considered ore deposit is the VCR excavation method.

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