MINING AND METALLURGY INSTITUTE BOR
UDK: 622

ISSN: 2334-8836 (Štampano izdanje)
ISSN: 2406-1395 (Online)

UDK: 622.271/.33(045)=111

doi:10.5937/mmeb1704155S

Saša Stepanović[*], Nikola Stanić[*], Dejan Bugarin[*], Miljan Gomilanović[*]

SELECTION THE OPTIMAL DEVELOPMENT OPTIONS OF MINING OPERATIONS IN THE GACKO COAL BASIN

Abstract

For a concrete example of development the "Strategy of Mining-Technological Opening, Development, Optimization and Maintenance the Continuos Coal Production with Introduction the Process of Coal Enrichment of Dry Separation at the OP - GACKO", it is necessary to carry out the ranking and evaluation the variant solutions and on the basis of fiven estimation to choose the optimal solution for further development of the Open Pit Gacko. This work describes the process of ranking and evaluation the variant solutions.

Keywords: *multicriteria decision making, ranking, OP Gacko*

INTRODUCTION

Operating conditions at the OP Gacko are very complex and expressed through the mining-geological, mining-technical and techno-economic indicators.

For an insight into the current issues and future directions of development the open pit coal mining in the Gacko coal basin, the "Strategy of Mining - Technological Opening, Development, Optimization and Maintenance the Continuos Coal Production with Introduction the Process of Coal Enrichment of Dry Separation at the OP - GACKO" was made. The strategy has defined a number of ways of using the coal resources in order to maintain a continuity of coal production for the needs of the Thermal Power Plant Gacko with achieving the desired economic, social, environmental and other effects.

PRODUCTION STRATEGY OF COAL AT THE OP GACKO

The strategy is a detailed assessment the possible directions of development of the Open Pit Gacko with the required capacity of 2.3 million tons, and speciefied quality. There are three variant solutions. The variant solutions are analyzed in detail from optimization to developemtn of the open pit by the required time periods.

For the purposes of the Strategy of Mining - Technological Opening, Development, Optimization and Maintenance the Continuos Coal Production with Introduction the Process of Coal Enrichment of Dry Separation at the OP - GACKO, a 3D geological model of the coal deposit Gacko was made. Data from 680 drill holes were used in designing the 3D geological model.

[*] *Mining and Metallurgy Institute Bor – Department Coal Engineering Belgrade, e-mail: sasa.stepanovic@irmbor.co.rs, nikola.stanic@irmbor.co.rs, dejan.bugarin@irmbor.co.rs, miljan.gomilanovic@irmbor.co.rs*

Processing of the deposit began forming the database of exploration drill holes. Some files contain for each drill hole: the name of drill hole, data on elevation, coordinates, data on lithological members in geological pillars of drill holes (which are relevant to the assessment of position the seams in separated geological environments), as well as data on the results of chemical analyses of individual and composite tests.

The all required data were reached in the process of exploration drilling, as well as the carried out laboratory analyses (spatial location of each drill hole is defined by the X, Y, Z co-ordinates, the final depth of each drill hole, lithological members were determined in the process of mapping the drill hole core, and data on quality were obtained by laboratory analyses).

The coal deposit Gacko is presented by seamsof irregular shape. The deposit is constructed of four coal seams with seams and thin seams of barren rocks between and within it. Therefore, each of these seams and and thin seams, either coal or overburden was modeled as a separate seam (Table 1).

Table 1 *Vertical division of deposit on coal seams and thin seams in the 3D model of deposit*

Name of seam	Program seam name
A	B
Roof zone-upper level	U11
Roof zone-intermediate level	U12
Roof zone-lower level	U13
The main coal seam	GUS1
The main coal seam	GUS2
The main coal seam	GUS3
The first floor coal seam	PPUS1
The first floor coal seam	PPUS2
The first floor coal seam	PPUS3
The second floor coal seam	DPUS1
The second floor coal seam	DPUS2
The second floor coal seam	DPUS3

Data about the terrain topography are also entered. Digitization is performed by AutoCAD software package.

Optimization of the open pit was done using the software for long-term strategic planning of the mine - "Whittle Fx". In addition to the structural and qualitative characteristics, contained in a block model of the deposit, the techno - economic parameters, adopted on the basis of detailed analysis of mining and market conditions, were also used in optimization.

The complexity of conditions, in which the objects of mining the deposit Gacko are formed, is expressed through the spatial arrangement and structure of coal seams of the basin Gacko, the parameters of coal quality per individual coal sedries and, the administrative division of the deposit into two exploitation exploration fields, the Central and East, proximity of the town and infrastructure buildings on the northern edge of the deposit and urban planning purpose of the deposit area and immediate surroundings. The aforementioned limiting factors in terms of the future coal mining required a detailed analysis of a large number of variant solutions. One of the main goals of the Strategy development was also to be based on the results of comparative analysis and application the methods of optimization and strategic planning, to chose the most favorable open pit, both from the economic and technological aspects.

During the detailed consideration of operating conditions, optimal contours of structures and mining stsrem, three real variant solutions were distinguished that were analyzed in detail.

The analysis of these variant solutions included a detailed design of objects and parameters of mining systems, defined as the techno-economic indicators, social-societal impact of mining on the environment and degree of influence the mining activities on the environment.

The overall variant solutions can be described as follows:

The first variant involves the formation of the open pit within the administrative space limitations-the regulation line, prospecting geological profile 55 and the existing works on excavation and disposal, with the annual capacity of $2.3 \cdot 10^6$ tons of run-of-mine coal;

Figure 1 *Contour of the open pit - Variant 1*

The second variant is represented by the open pit for excavation only the roof coal seams, with the annual capacity of $3.0 \cdot 10^6$ tons of run-of-mine coal, in order to create a significant accumulation of financial assets for further development of the mine

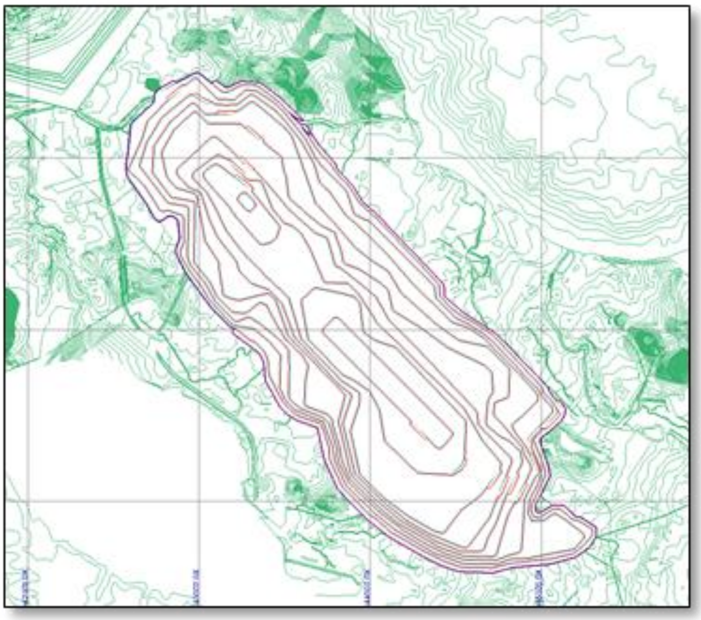

Figure 2 *Contour of the open pit - Variant 2*

The third variant is a continuation of the first, but not limited by the prospecting geological profile 55, with the annual capacity of $2.3 \cdot 10^6$ tons of run-of-mine coal.

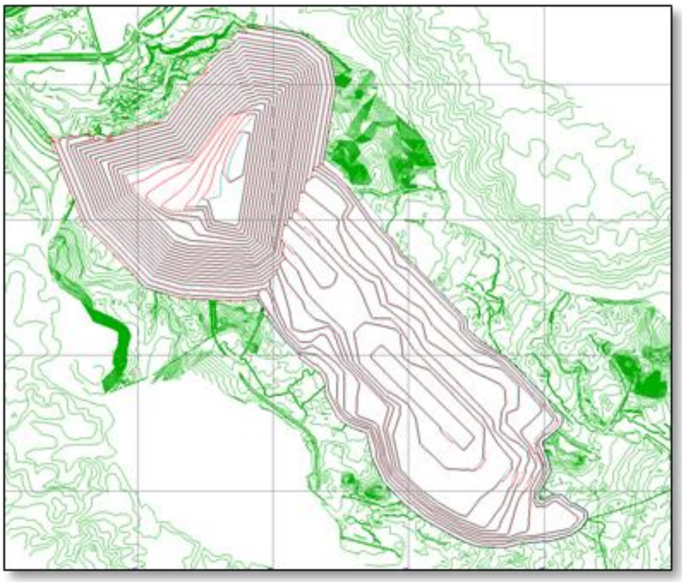

Figure 3 *Contoru of the open pit - Variant3*

As a suitable tool for selection the optimal variant of works development, the method of scoring model was used from the group of multi-criteria decision making.

METHOD OF MULTIU-CRITERIA DECISION MAKING

Making a choice is a study of identifying and selecting an alternative in order to find the best solution based on various factors and in accordance with the expectations of those who make the choice. Every decision is made in the appropriate environment, which is defined as a set of available information, alternatives, values and settings (preferences). A complex decision-making point is the number of criteria for evaluation of alternatives. The objectives are usually conflicting, and in the most cases different groups are present from those who should make a decision.

To facilitate this type of analysis, a set of tools known as the multi-criteria decision making methods is formed by the need to formalize the methods to aid in decision making in situations involving multiple criteria.

Methods of multiple-criteria decision making are a part of the overall field of operational research, and the models are suitable for solving the complex problems with a high degree of uncertainty, conflicting objectives, different types of data and information and aspects, and calculation in complex and development-level systems such as biophysical and socio-economic. This large class of methods is further divided into multi targeted decision-making and multi attribute decision making. These methodologies share the common features such as conflicting criteria, incommensurability units and complexity in the formation-choice of alternatives. The main difference between the two sets of methods is based on the number of alternatives that are evaluated. The multi attribute decision making methods were established for selection the clearly defined alternatives, and multi targeted methods of decision making are more suitable for solving the problems of planning the systems and processes that are characterized by a higher number of objects, when theoretically there are an infinite number of continuous. In the multi targeded decision making (also known as multi targeted programming or vector optimization / maximization / minimization of problems), the alternatives are not predetermined, but instead of a set of target functions optimize the variables in the set of constraints. The requirement is the optimal and most efficient solution. In a single solution, it is not possible to improve the performances of any target, and that at the same time the other targets are not reduced. In the multiple attribute decision making, an avaluation of a small number of alternatives is carried out on the basis of a set of parameters that is often difficult to quantify.

Using the multi-criteria decision making method is suitable for:

- Assessment and integration of multiple factors in the function of objective and transformation the quantitative and qualitative information in the criteria and weighting factors,
- View the complex and heterogeneous criteria in a simple and understandable way, and therefore the results are clear to multiple recipients, regardless of specialty.

The advantage of this method is reflected in these two important aspects:

1. The used criteria are evaluated and given values are constant and comparable with the initial data (as a measure of convenience)
2. The simple form of the output values makes the method clear and usable for various interested participants.

These methods can provide the solutions to increase the complex management problems. They provide a better understanding the specific characteristics in defining the problem, emphasize the role of participants in the decision making process, allow a compromise and collective decision and provide a good platform to understand the model and analyst in a realistic scenario. The methods help improvement the quality of decision making just making the decision clearer, more rational and efficient.

It should be noted that the methods and results are not necessarily comparable. Each of the methods has certain limitations which mainly arise from the initial assumptions. Inconsistency can occur because:

- Formulation the problem of choice does not imply the same structure of priorities,
- A way of information processing on priorities differ from method to method, and
- Methods take differently into account the weight criteria.

Multiple-criteria decision making can be considered as a complex and dynamic process, including the management and engineering level. Management level defines the objectives, selection of the final optimal alternative while engineering level defines the possible alternatives, points out the consequences of the selection anyone of the possible alternatives in terms of different criteria and performs the multiple-criteria ranking of alternatives. The optimization procedure is performed at the engineering level.

At the management level, the managers, decision makers can accept or reject the suggested solutions. The decision making process usually involves five main stages:

1. Defining the problem

2. Formation and establishment of alternative criteria,

3. Determination the weight factor criteria,

4. Evaluations,

5. Selection of appropriate multi-criteria method,

6. Ranking alternatives.

Basic phases višekritetijumskog method of decision-making are:

1. Define the problem, the formation of alternative and setting the criteria.

Problem-making should start by a clear definition of the problem, specifying the alternatives, identification of participants, objectives and possible conflicts with the limitations, degree of uncertainty and risk, and key issues. After this, the problem can be supplemented by defining the criteria for assessment.

2. Criteria for determining the weighting factors.

Other steps include determining the weighting factors of criteria. These weighting factors represent the set of relative measure of their importance in the method of multi-criteria decision making.

3. Formation of the evaluation matrix

At this stage, only the problem of multi-criteria decision making is defined by a way that enables the assessment of alternatives. The model can be represented in the matrix form as

Criteria: C1, C2, C3, ..., Cn

Weights: W1, W2, W3, ..., Wn

Alternatives

$$\begin{bmatrix} A1 \\ A2 \\ \\ Am \end{bmatrix}\begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}$$

where:

x_{ij} - assessment of given alternative(s) by the determined criterion,

w_j - weighting coefficients by the determined criterion,

n - number of criteria,

m - number of alternatives.

4. Selection of appropriate methods

Multi-criteria methods can be selected and applied to the problem in accordance with the order of alternatives. Data and de gree of uncertainity is a key factor for the decision makers when choosing between the multi-criterion methods.

5. Ranking alternatives

Finally, the alternatives are ranked, and the best ranked one represents a solution to the problem.

METHODS OF EVALUATION AND RANKING THE VARIANT SOLUTIONS

As a recommendation for future work of development the open pit, a selection of scoring method was done. This widely accepted expert method allows relatively quick and easy way to identify the best alternative decisions.

It is assumed that it is necessary to decide on one or more variants, in the specific case of the three present variants of development the mining activities.

There are the following phases that are necessary to set up the scoring models:

Phase I

Set a list of criteria that should be considered. The criteria are important factors for evaluation of every decision.

Phase II

Determine the weight of each criterion that indicates its relative importance:

w_i = weighting criteria *i*

Phase III

Determine each criterion measure that shows how well each alternative meets each criterion:

r_{ij} = criteria and measures *i* for decision *j*

Phase IV

Calculate the value for each alternative decision:

S_j = value for alternative decision *j*

The equation for calculating the value S_j as follows:

$$S_j = \sum_i w_i \cdot r_{ij}$$

Phase V

The order of selected alternatives from the highest to the lowest value is at the same time ranking by the scoring model for alternative decisions. The decision is made for an alternative with the highest number of scores, and it is recommended for implementation.

According to this method, the choice of development variants was carried out in five steps, wherein the first defines a list of criteria, the second defines the weighting criterion, the third defines the measure of satisfaction level, the fourth defines a calculation alternative value for decision-making, and the fifth is ranking of variants.

Phase I: List of criteria

- Degree of utilization the available reserves,
- Service life,
- Quality of supplied coal,
- Investments,
- Net present value of the project.

Phase II

A scale is used for determining the weight, depending on the criterion validity, and in the specific case, since the five-point scale is used for selected list of criteria.

Importance	**Weight (w_i)**
Very important	5
Somewhat important	4
Moderate important	3
Somewhat unimportant	2
Very unimportant	1

Thus, for the selection of variants defined in Table 2.

Table 2 *Criterion of decision making, importance and weight of criteria*

Order No.	Criterion	Importance of	Weight
1	Degree of utilization the available reserves	Somewhat unimportant	2
2	Service life	Somewhat important	4
3	Quality of supplied coal	Medium important	3
4	Investments	Somewhat important	4
5	Net present value of the project	Very important	5

Phase III:

Each alternative of decision is evaluated in terms of satisfaction of each criterion. For selection the possible variants, thefollowing levels of satisfaction have been selected:

Level of satisfaction	Measure (r_{ij})
Extremely high	9
Very high	8
High	7
Almost a high	6
Medium	5
Almost low	4
Low	3
Very low	2
Extremely low	1

The calculation process must be completed for each combination of decisions for alternative for each criterion. Since there are five criteria and three alterna tives for decision making (5 x 3 = 15), the measure 15 is obtained for alternative decisions that are given in the following Table 3.

Table 3 *Measures for making the alternative decisions*

Criterion	Variant 1	Variant 2	Variant 3
Degree of utilization the available reserves	4	5	7
Service life	4	3	6
Quality of supplied coal	8	5	6
Investments	2	4	2
Net present value of the project	5	8	8

Phase IV

It is necessary, according to the given weight, to calculate the value of each alternative for decision - making. Thus, for example, for alternative 1, its value is:

$$S_j = \sum_i w_i \cdot r_{ij} = 2{\cdot}4{+}4{\cdot}4{+}3{\cdot}8{+}4{\cdot}2{+}5{\cdot}3 = 75$$

Based on the determined values, the values of alternatives for decision-making are obtained, which are given in Table 4.

Table 4 *Values of alternatives for decision-making*

Criterion	Weight	Variant 1		Variant 2		Variant 3	
		Measure	**Value**	**Measure**	**Value**	**Measure**	**Value**
	(w_i)	(r_{i1})	$(w_i{*}r_{i1})$	(r_{i2})	(r_{i3})	$(w_i{*}r_{i3})$	$(w_i{*}r_{i2})$
Degree of utilization of available reserves	3	4	12	5	15	7	21
Service life	4	4	16	3	12	6	24
Quality of supplied coal	3	8	24	5	15	6	18
Investments	4	2	8	4	16	2	8
Net present value of the project	5	5	25	8	40	8	40
Total value o			**85**		**98**		**111**

Phase V: Ranking

1. Variant 3 = 111
2. Variant 2 = 98
3. Variant 1 = 85

Based on the scoring method and obtained ranking of variants, it is necessary, as optimal, to adopt the Variant 3, that satisfies the all production and economic criteria according to all techno-economic parameters in the best way.

When considering the variants, the statutory-legal conditions were not used as a criterion which will be used for future mining. This was done in order that the considered variants could be compared on the basis of objective technical-economic parameters, without taking into account the formal-legal framework of mining on the relevant area.

From this aspect, it is important to note that mining by the preferred variants 2 and 3 would be developed in the area both of the Central and Eastern exploration-exploitation field. This includes the provision of appropriate legal permits to perform the exploitation of the entire area of the basin.

However, bearing in mind:

- the current state of coal mining in the area of the Gacko coal basin,
- the necessary amounts and quality of coal supplies for thermal power plant,
- the available time necessary for the provision of legal conditions for continuation of exploitation for the purpose of stable supply of the thermal power plant with fuel (period of validity of the existing Supplementary and Simplified Mining Project), and
- readiness of the study, design and other necessary technical documentation,

it is certain that in the future, and in a very short period of time, an appropriate legal framework for coal exploitation can be provided exclusively for the area of the

Central exploration-exploitation field. In this way, the current development of mining activities in the area of the Gacko coal basin is limited to Variant 1.

Based on the possibility of providing the legal requirements for development of exploitation, it is clear that in the immediately upcoming period, development of mining activities must be carried out within the framework of the Central field, and according to Variant 1. Considering the techno - economical parameters, and evaluation the rank of the considered variants, it is necessary to focus the following activities to provide the conditions for implementation Variant 3, which realizes the most favorable economic, but also social and other effects.

CONCLUSION

Application the method of multi-criteria decision making in selection the optimal alternative, in the cases of complex techno-economic projects (or system), provides a number of advantages which are reflected primarily in the following:

- substantially avoids the subjectivity when deciding on selection the best alternative,
- the results of evaluation and ranking the alternatives are clear decision-maker regardless of whether they have the specific knowledge related to the technical, technological and other solutions which are solved within the engineering part of considering the problems,
- ranking of alternatives presented by numerical value provides better understanding the results,
- a number of methods enable combining the preferences of many experts and the qualitative and quantitative types of criteria are applicable.

The necessary condition for successful application of these methods is to provide the accurate and complete information about the nature of project, and values of parameters by individual alternatives and criteria.

REFERENCES

[1] Strategy – Mining - Technological Opening, Development, Optimization and Maintenance the Continuity of Coal Production with Introduction the Process of Coal Enrichment of Dry Separation OP - GACKO, Book 1, MMI Bor, Bor, 2015 (in Serbian)

[2] Introduction to Decision Making Methods. Working Paper 05-6, Fülöp Janos, Laboratory of Operations Research and Decision Systems, Computer and Automation Institute, Hungarian Academy of Sciences, Budapest, November 2005.

[3] Multi Criteria Analysis in the Renewable Energy Industry, San Cristobal Mateo, Jose Ramon, University of Cantabria, Springer, London, 2012.

[4] Strategic Decision Making, Kathleen M. Eisenhardt, Mark J. Ybaracki, Strategic Management Journal, Vol. 13, Special Issue: Fundamental Themes in Strategy Process Research, pg. 17-37, John Wiley & Sons, New York, 1992.

[5] Multi-Criteria Analysis: A Manual, Department for Communities and Local Government, London, 2009.