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THE RATIONAL TECHNOLOGY MODEL SELECTION OF THE UNDERGROUND DRIVAGE DEVELOPMENT FOR THE GIVEN CONDITIONS

MODEL IZBORA RACIONALNE TEHNOLOGIJE IZRADE PODZEMNIH PROSTORIJA ZA DATE USLOVE

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Abstract: The selection of the rational technology for the development of the underground drivages can be treated as a decision-making problem. The selection of one or more alternatives, which is at our disposal, depends on numerous factors. This paper presents a making of the general model of the selection, and for the purpose of better understanding, some examples will be used to illustrate the steps in the making of the model.

Key words: underground drivages, development, model, MADM

Apstrakt: Izbor racionalne tehnologije izrade podzemnih prostorija spada u domen teorije odlučivanja. Na raspolaganju nam stoji niz alternativa, a izbor jedne od njih ili više, zavisi od mnogo faktora. U ovom radu prikazano je formiranje opšteg modela za izbor, a radi boljeg razumevanja, pojedinim primerima biće ilustrovani koraci prilikom formiranja modela.

Ključne reči: podzemne prostorije, izrada, model, MADM

1. INTRODUCTION

The classification of the methods of underground drivage development can be caused by: the mining-geological conditions, by the spatial location of the drivages, by the way the rock mass disintegrates, purpose, drivages size, etc.

The most basic classification of the methods of underground drivage development (mining) is caused by the mining-geological conditions in which the drivages will be driven, therefore there are:

1. Methods of the drivage development in the normal mining-geological conditions;
2. Methods of the drivage development in the special mining-geological conditions.

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A very important classification of the methods of underground drivage development can be established according to the way the rock mass disintegrates and this would be the basic division:

I.   Underground drivage development by the use of explosives, and
II.   Underground drivage development without the use of explosives.

Based on the review of the underground drivage development, we realise that it is possible to create a set of alternatives – methods of driving. It is up to the decision maker to decide as objective as possible what suitable method to use (Antunović-Kobliška, 1973).

2. DECISION MAKING PROCESS

No matter what does the decision-maker decide, a certain mistake is made. The real problems the decision maker is faced with are:

-    A great number of criteria, i.e., the attributes that a decision-maker must create;
-    Conflict among the criteria, by far the most common case of real problems;
-    The incommensurable (incomparable) units of measurement, because as a rule, each criterion or attribute has a different unit of measurement;
-    Design or selection. Solutions of this kind of problems are either the designing of the best action (alternative) or the selection of the best alternative from a set of pre-defined finite actions.

Problems of this kind are solved in two ways:

A.   Multi-Attribute decision making (multi - criteria analysis), and
B.   Multi-Objective decision-making.

It is obvious that in this case we are to opt for the multi- criteria analysis i.e. the method that belongs to a group called Techniques of Multi-Attribute Decision Making i.e. in its original form A Multi Attribute Decision Making (MADM), (Gligorić, 2004).

3. DEFINING OF ALTERNATIVES

The method that we shall use here is based on defining the set of alternatives. In our case it is a set of the underground drivage development technologies. A set of alternatives is to be formed $A = (A_1, A_2, ..., A_m)$ to represent the set of production technologies. Due to the analysis of data of the driven underground drivages in our mines we see that about 98% of all drivages have been done by the drilling and blasting operations and only 2% in some other way (Tokalić et al. 2002). Based on these facts, as an example, we can form a set of two alternatives, that is:

I. A_1 - development of drivages with the use of explosives, and
II. A_2 - development of drivages without the use of explosives - driving with combined tunnel-boring machines.

4. DEFINING THE PARAMETERS (ATTRIBUTES) AND CRITERIA

Natural conditions, in which the underground drivage development is carried out, are classified as general and specific conditions and they represent parameters that are pre-defined and, as such, are crucial for the selection of the driving technology.

Another aspect is the level of technical equipment that allows us to carry out the driving in easier, safer and more economical way.

Natural factors are the result of action and occurrence of natural forces, while the technical factors are determined by man.

This methodology enables us to form a set of attributes that could be treated together or per groups (natural, technical, economic, security, etc.). These factors are defined as a set of attributes $X = (X_1, X_2, ..., X_n)$, (Tokalić, 2008). For the purpose of illustration the examples are given.

We shall single out from the set of natural factors influencing the selection of rational technology for the underground drivage development the most influential one, and define a set of attributes:

X_1 - uniaxial compressive strength [MPa];

X_2 - abrasiveness of the rock mass [mg];

X_3 - tectonics (the number of fractures, the distance in meters, per cent of block content in %/m),

X_4 - hydro-geological characteristics (l/min, bar, the general condition)

X_5 - stability of the drivage,

X_6 - the prevailing conditions in the rock massif, that relate to the presence of methane, the sudden gas and rock burst.

The most influential technical factors are the drivage length and the advance rate:

X_7 - the drivage length [m];

X_8 - the advance rate [m/day].

Economic impacts will be based on two criteria:

X_9 - cost of equipment [€]

X_{10} - the payback period (time horizon: month, year).

5. ANALYSIS OF THE RESTRICING INFLUENCES
   ## ON THE SELECTION

In order to avoid bipolarity, i.e. the existence of the scale of favourable and unfavourable attributes, it is advisable to assess the restrictive effect of each attribute on the final selection. Due to this reason, in the strategy of the decision making it has been resorted to the creation of unipolar scale, which instead of columns for "unfavourable" and "favourable" attributes has only one column called "degree of restricting effects" (Table 1).

From the point of view of the underground drivage development, the working conditions are going to be classified generally in five categories (for example):

Table 1 - Table of the restricting effects degree

The restricting effects degree	Category	Scale
very low	I	0.0 1.0
low	II	3.0
mean	III	5.0
high	IV	7.0
very high	V	9.0 10.0

- The first category (I) includes a favourable working conditions in which the underground drivage development can be performed in easy and safe manner;
- The second category (II) includes good working conditions in which the underground drivage development can be performed in a safe manner;
- The third category (III) includes moderate working conditions in which the underground drivage development can be performed with certain protection measures;
- The fourth category (IV) includes the hard working conditions, which significantly influence the selection of the development technology and where the special protection measures have to be applied;
- The fifth category (V) includes the very hard working conditions, which significantly influence the selection of the development technology (special methods) and where the special protection measures have to be applied.

An appropriate criterion is necessary to be allocated to each of the above-mentioned attributes. The natural outcome is that the attributes can be expressed numerically or descriptively. Therefore, there are two types of attributes: quantitative and qualitative (descriptive - fuzzy).

Based on these attributes, in a compliance with the decision to introduce the unipolar scale that takes into account the degree of restriction of each attribute for the proposed alternative, in the Table 2, are given guidelines prone to changes (only for one attribute because of the limited framework) as the example of the attribute-criterion relation. The following table shows the analysis of the technical factors - the drivage length and the suitable methods of the underground drivage development, i.e. X_7 - the drivage length [m], A_1 - underground drivage development with the use of explosives and A_2 - underground drivage development without the use of explosives – the drivage development with the tunnel boring machines (Tokalić, 2008).

Table 2 - The degree of restriction attributes for the selected alternative

Attribute Alternative	Category	Analysis	Scalar value
X₇, A₁	I	There is no restriction	0-2
	II	There is no restriction	2-4
	III	There are restrictions related to the delivery of materials, to the disposal of excavated materials, and to the distribution of energy	4-6
	IV	There are restrictions related to the delivery of materials, to the disposal of excavated materials, to the distribution of energy; to the ventilation, and to the drainage	6-8
	V	There are restrictions related to the delivery of materials, to the disposal of excavated materials, to the distribution of energy; to the ventilation, and to the drainage and the dynamic of performance	8-10
X₇, A₂	I	There are restrictions related to the great period of the organization in relation to the advance rate, to the huge initial investment, to the dimensions of the installed equipment, and to the high cost of dismantling. In this case the length of the equipment may be longer than the drivage length	8-10
	II	There are restrictions related to the great period of the organization in relation to the advance rate, to the huge initial investment, to the dimensions of the installed equipment, and to the high cost of dismantling	6-8
	III	There are restrictions for a long period of organization in relation to the advance rate, to the huge investment and dimensions of the installed equipment	4-6
	IV	There is no restriction	2-4
	V	There is no restriction	0-2

6. THE TOPSIS MODEL ALGORITHM FOR THE DECISION MAKING

Having gathered all relevant information, the decision-making can be done. The method used in this paper is from the group of Multi-Attribute Decision Making Methods, (MADM). Yoon and Hwang developed a method called Technique For Order Preference By Similarity To Ideal Solution (TOPSIS), (Hwang and Yoon, 1981) (the technique for determining the order of the values according to the similarity to the ideal solution, based on the concept that the selected alternative should have the shortest distance from the ideal solution and the furthest from the negative-ideal solution (Figure 1).
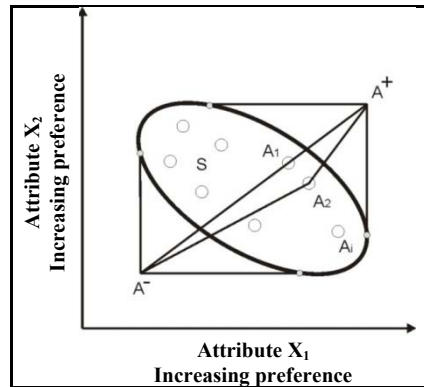
Figure 1 - Euclidean distance to the "ideal" and "negative-ideal solution"
in two-dimensional space

The initial step in the TOPSIS method application is the assessment of the decision matrix, which contains *m* alternatives associated with *n* attributes (or criteria):

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{1n} & A_1 \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{2n} & A_2 \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{in} & A_i \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mj} & \cdots & x_{mn} & A_m \\ X_1 & X_2 & \cdots & X_j & \cdots & X_n & \end{bmatrix} \quad (1)$$

Where is:
A_i - i[th] alternative is taken into account,
x_{ij} - numerical outcome of the ith alternative with respect to the jth criterion.

This method assumes that each attribute in the decision matrix takes either uniform increasing or uniform decreasing preference. In other words, the greater the outcomes of the attributes the more preferences for the "benefit" criteria and the fewer preferences for the "cost" criteria. Furthermore, any outcome that is expressed in non-numerical manner should be quantified through a suitable technique of proportions.

Step 1. Construction of the normalised decision matrix: This procedure attempts to transform the different dimensions of attributes into non-dimensional attributes. One of the methods that can be applied is the normalisation of attribute values. Now, decision matrix *D* takes the form of a normalized matrix *R* whose elements are calculated based on the expression (2):

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1j} & \cdots & r_{1n} & A_1 \\ r_{21} & r_{22} & \cdots & r_{2j} & \cdots & r_{2n} & A_2 \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ r_{i1} & r_{i2} & \cdots & r_{ij} & \cdots & r_{in} & A_i \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mj} & \cdots & r_{mn} & A_m \\ X_1 & X_2 & \cdots & X_j & \cdots & X_n \end{bmatrix} \tag{2}$$

Step 2. **Construction of weighted normalized decision matrix:** A set of weights $w = (w_1, w_2, \cdots, w_j, \cdots, w_n)$, $\sum_{j=1}^{n} w_j = 1$ is adjusted to the decision matrix in this step by the decision maker. Relative importance of the criterion is an essential part of the multi-criteria task setting because in this way, the relation between the criteria, which as a rule, are not of the same importance. Most of the methods used in decision making require information about the relative importance of each attribute. It is usually given by the set of weights (preferences) that is normalised with the sum to one, i.e. 100%.

The decision maker, himself/herself, can assign the appropriate weight to attributes based either on his/her own particular assessment or he/she can use one of the methods of assessment (as the primary or as an aid to decision-making).

Now, the weighted decision matrix can be calculated by multiplying each column of the matrix R with its associated weight w_i^o. Thus, the weighted normalized decision matrix V is equal to:

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1j} & \cdots & v_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ v_{i1} & v_{i2} & \cdots & v_{ij} & \cdots & v_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mj} & \cdots & v_{mn} \end{bmatrix} = \begin{bmatrix} w_1^o r_{11} & w_2^o r_{12} & \cdots & w_j^o r_{1j} & \cdots & w_n^o r_{1n} \\ \vdots & \vdots & & \vdots & & \vdots \\ w_1^o r_{i1} & w_2^o r_{i2} & \cdots & w_j^o r_{ij} & \cdots & w_n^o r_{in} \\ \vdots & \vdots & & \vdots & & \vdots \\ w_1^o r_{m1} & w_2^o r_{m2} & \cdots & w_j^o r_{mj} & \cdots & w_n^o r_{mn} \end{bmatrix} \tag{3}$$

Step 3. **Define of the ideal and the negative ideal solution:** Let's assume that that alternatives A^+ and A^- are defined as:

$$A^+ = \left\{ \left(\max_i v_{ij} \,\middle|\, j \in J \right), \left(\min_i v_{ij} \,\middle|\, j \in J' \right) \middle| i = 1,2,...,m \right\} = \left\{ v_1^*, v_2^*, ..., v_j^*, v_n^* \right\}$$

$$A^- = \left\{ \left(\min_i v_{ij} \,\middle|\, j \in J \right), \left(\max_i v_{ij} \,\middle|\, j \in J' \right) \middle| i = 1,2,...,m \right\} \tag{4}$$

Where is:

$J = \left\{ j = 1,2,...,n \,\middle|\, j \right\}$ - is associated with the "benefit" criteria;

$J' = \left\{ j = 1,2,...,n \,\middle|\, j \right\}$ - is associated with the "cost" criteria.

It is obvious than, that the two created alternatives A^+ and A^- indicate the most appreciated alternative (ideal solution) and the least appreciated alternative (negative-ideal solution) solution for each individually.

Step 4. **Calculation of the separation distance:** The separation between each alternative can be calculated by using the n-dimensional Euclidean distance. Thus, the distance of each alternative from the "ideal" is given by the following equation:

$$S_{i^*} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^* \right)^2}, \qquad i = 1, 2, ..., m \tag{5}$$

In addition, the distance of the "negative-ideal" solution is given by the equation:

$$S_{i^-} = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2}, \qquad i = 1, 2, ..., m \tag{6}$$

Step 5. **Calculation of the relative closeness to the ideal solution:** The relative closeness of A_i with the respect to A^+ is defined as:

$$C_{i^*} = \frac{S_{i^-}}{\left(S_{i^*} - S_{i^-} \right)}, \qquad 0 < C_{i^*} < 1, \qquad i = 1, 2, ..., n \tag{7}$$

It is clear that $C_{i^*} = 1$ if $A_i = A^+$ and that $C_{i^*} = 0$ if $A_i = A^-$. Alternative A_i is closer to the A^+ as C_{i^*} approaches 1.

Step 6. Final ranking: now the set of alternatives with the respect to preference can be ranked according to descending order C_{i^*} (Hwang and Yoon, 1981).

6.1. Testing of the model

The proposed model can be evaluated on the hypothetical or actual data. The flexibility of the model can be tested on different, first of all, very extreme values, with or without the influence of the decision-maker on the rank (weight) of attributes. Tests can determine the breakpoints, or places, where according to the evaluation is going to be the change of alternatives. If the testing of the given parameters provides satisfying results, then all the cases in between and all the values of attribute, occurring in practice, will be in the range between minimum and maximum, and the obtained results will be very reliable. In the following text, an example is given to illustrate it.
Input data for the testing are:
-    Moderate conditions;
-    Drivage Length for the alternative A_1 is taken with a restriction degree of one;
-    Drivage Length of the alternative A_2 is taken with a restriction degree of ten;
-    Equipment costs for the alternative A_1 is taken with a restriction degree of one;
-    Equipment cost for the alternative A_2 is taken with a restriction degree of ten;
-    The advance rate for the alternative A_1 is taken with the restriction degree of ten, and for the alternative A_2 is taken with the restriction degree of one;

- The payback period of the investment for the alternative A_1 is taken with a restriction degree one;
- The payback of the investment for the alternative A_2 is taken with a restriction degree of ten.

This example was used to evaluate simultaneously unguided (I) and guided (II) flow of the calculation and the comparison of the results was made. The guided flow represents giving of the weight (preference) to certain attributes by the decision maker.

Due to the limited framework only the initial normalized matrix as well as unguided and guided determination of the attribute weight w_j, and the final result at Figure 2 - parallel display of the alternative flow (Tokalić, 2008) has been presented.

$$
D = \begin{array}{c} \\ A_1 \\ A_2 \end{array} \begin{array}{cccccccccc} X_1 & X_2 & X_3 & X_4 & X_5 & X_6 & X_7 & X_8 & X_9 & X_{10} \\ 6 & 5.5 & 5 & 5.5 & 5.5 & 5.5 & 1 & 1 & 10 & 1 \\ 4.5 & 4 & 4.5 & 4 & 4.5 & 5 & 10 & 10 & 1 & 10 \end{array}
$$

I case - unguided flow:

$$w_j = |0.0064 \quad 0.0078 \quad 0.0009 \quad 0.0078 \quad 0.0031 \quad 0.0007 \quad 0.2433 \quad 0.2433 \quad 0.2433 \quad 0.2433|$$

II case - guided flow:

$$w_j = \begin{vmatrix} 0.0064 & 0.0078 & 0.0009 & 0.0078 & 0.0031 & 0.0007 & 0.2433 & 0.2433 & 0.2433 & 0.2433 \\ 5.0\% & 5.0\% & 5.0\% & 5.0\% & 5.0\% & 5.0\% & 10.0\% & 20.0\% & 25.0\% & 15.0\% \end{vmatrix}$$
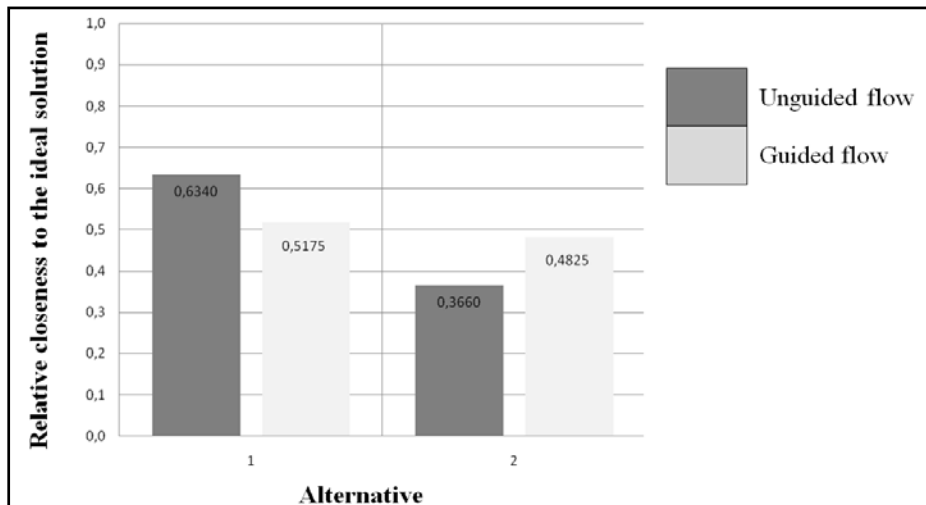

Figure 2 - Parallel display of the alternative rank

Having analyzed the diagram in Figure 2 we can see how the relative closeness to the ideal solution is changing in the favour of alternative A_2 by giving priority to the certain attributes, whereas in the case of unguided flow the alternative A_1 has the clear preference, for the same input parameters.

7. CONCLUSION

TOPSIS method represents a swift and effective way in helping to make the right decision about the selection of the underground drivage development technology for the given exploiting conditions.

It may be concluded that the flow of the algorithm can be successfully steered by giving the significant weight to certain attributes. This option, in author's opinion, should not be avoided, but first of all everything ought to be left to the automatism, and then on the grounds of the gained results and in the consultation with the experts make the corrections.

Once again it should be emphasized that the success of this method depends on the quality and quantity of inputs and impartiality of the decision-maker towards the offered alternatives.

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