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Mlađan Maksimović[*], Miodrag Brzaković[*], Miloš Grahovac[**], Ivana Jovanović[***]

AN APPROACH FOR EVALUATION THE SAFETY AND QUALITY OF TRANSPORT AT THE OPEN PIT MINES, BASED ON THE EDAS METHOD[****]

Abstract

Transport of ore and overburden at the open pit mines represents the most important and the most complex process in the open pit excavation technology. Transport organization significantly affects the capacity of machinery for excavation and disposal, excavation productivity, as well as the ore production costs.

This paper describes an attempt to select the most suitable transport system at the open pit mines from the safety and quality point of view. For that purpose, the EDAS method was used. Four types of transport systems were considered – truck transport, railway transport, belt conveyor and hydrotransport. It was found that, from the above mentioned aspect, the truck transport generally has the most favorable characteristics.

Keywords: *transport, open pit mine, safety, quality, EDAS method*

1 INTRODUCTION

Transport at the open pit mines takes place according to a determined cycle, the duration of which depends on the time of: loading, motion of the loaded and empty transport machine, unloading, maneuvering and stoppage in transport. All these operations can be performed with or without interruptions, and therefore, transport at the open pit mines can be divided into:

(1) Continuous (such as hydrotransport, belt conveyor)
(2) Discontinuous (with intermittent effect, such as trucks, trains, scrapers)
(3) Combined (for example truck transport with belt conveyor) [1].

Selection the type of transport for the specific conditions of an open pit mine is determined on the basis of different parameters, such as [1]:

- type as well as physicochemical and mechanical properties of material to be transported (looseness, brittleness, particle size, temperature, etc.);
- way of loading and unloading;
- working environment in which transport machinery will work (dustiness,

[*] *Faculty of Applied Management, Economics and Finance, Belgrade, University Business Academy Novi Sad, Jevrejska 24, 11000 Belgrade, Serbia, mladjan.maksimovic@mef.edu.rs*
[**] *Office of the War Crimes Prosecutor, Ustanicka 29, Belgrade, Serbia*
[***] *Mining and Metallurgy Institute Bor, Zeleni bulevar 35, 19210 Bor, Serbia*
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temperature changes, humidity, climate, etc.);
- dimensions of the facilities or machinery where the loading, passage and unloading is performed;
- capacity and operation mode of loading machinery, as well as technology of excavation and disposal;
- direction and transport distances, etc.

The selected type of transport at the open pit mine should ensure the safe transport of required quantities of materials, continuous operation, minimum operational difficulties, security, safety of employees, smooth operation of the basic and auxiliary machinery as well as the greatest possible cost - effectiveness. At the modern open pit mines, three types of transport are mainly applied: (1) railway transport, (2) trucks and (3) belt conveyors. In addition to the mentioned ones, less used are scrapers, cable cars, pipelines, etc. [1]

In this paper, according to the methodlogy of multi criteria decision making, the selection of the most suitable means of transportation at theopen pit mines is discussed. Basically, quality and safety of transport were accepted as the most important criteria in this discussion, but it should be emphasized that the quality of transport is considered through several parameters, that is: the length of the transport distance, the need for supply of power and water, the influence of working conditions and the impact of physical and mechanical properties of the transported material. The tests were carried out using the EDAS method.

2 THE EDAS METHOD

Before a short description of the EDAS method, given in the text, it is necessary to define a weighted average operator.

A *weighted average (WA) operator* of dimension n is a mapping $WA: R^n \to R$ that has an associated weighting vector $\omega = (\omega_1, \omega_2, \ldots, \omega_n)^T$ with $\omega_j \in [0,1]$ and $\sum_{j=1}^{n} \omega_j = 1$, is defined as [2]:

$$WA(a_1, a_2, \ldots, a_n) = \sum_{j=1}^{n} \omega_j a_j \qquad (1)$$

where a_j represents the argument variable.

The ***EDAS method,*** as a multi criteria decision making method, was introduced by Keshavarz Ghorabaee et al. (2015), and therefore it can be stated as a newly-proposed method. A fuzzy extension of this method was also developed by Keshavarz Ghorabaee et al. (2016), while a grey extension was proposed by Stanujkic et al. (2017) [3–5].

The basic ideas of the EDAS method are the use of two distance measures, namely the Positive Distance from Average (PDA) and the Negative Distance from Average (NDA); and that the evaluation of the alternatives is done according to higher values of the PDA and lower values of the NDA.

Based on Stanujkic et al. (2017), the computational procedure of the EDAS method, for a decision - making problem with m criteria and n alternatives, can be presented as follows:

***Step* 1.** Select the available alternatives, the most important criteria that describe the alternatives, and construct the decision-making matrix X, shown as follows:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{12} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{1n} & x_{2n} & \cdots & x_{mn} \end{bmatrix}, \qquad (2)$$

where x_{ij} denotes the performance rating of the alternative i on the criterion j.

***Step* 2.** Determine the average solution according to all criteria, shown as follows:

$$x_j^* = (x_1, x_2, \cdots, x_n), \quad (3)$$

where

$$x_j^* = \frac{\sum_{i=1}^{m} x_{ij}}{m}. \quad (4)$$

***Step* 3.** Calculate the positive distance from average d_{ij}^+ and the negative distance from average d_{ij}^-, according to the type of criteria (benefit and cost), shown as follows:

$$d_{ij}^+ = \begin{cases} \frac{\max(0, (x_{ij} - x_j^*))}{x_j^*}; & j \in \Omega_{\max} \\ \frac{\max(0, (x_j^* - x_{ij}))}{x_j^*}; & j \in \Omega_{\min} \end{cases}, \quad (5)$$

$$d_{ij}^- = \begin{cases} \frac{\max(0, (x_j^* - x_{ij}))}{x_j^*}; & j \in \Omega_{\max} \\ \frac{\max(0, (x_{ij} - x_j^*))}{x_j^*}; & j \in \Omega_{\min} \end{cases}, \quad (6)$$

where $\Omega_{\max}$ and $\Omega_{\min}$ denotes the set of the benefit criteria and the cost criteria, respectively.

***Step* 4.** Determine the weighted sum of PDA, Q_i^+, and the weighted sum of NDS, Q_i^-, for all alternatives, as follows:

$$Q_i^+ = \sum_{j=1}^{n} w_j d_{ij}^+, \quad (7)$$

$$Q_i^- = \sum_{j=1}^{n} w_j d_{ij}^-. \quad (8)$$

***Step* 5.** Normalize the values of the weighted sum of the PDA and the weighted sum of the NDA for all alternatives, shown as follows:

$$S_i^+ = \frac{Q_i^+}{\max_i Q_i^+}, \quad (9)$$

$$S_i^- = 1 - \frac{Q_i^-}{\max_i Q_i^-}, \quad (10)$$

where S_i^+ and S_i^- denote the normalized weighted sum of the PDA and the NDA, respectively.

***Step* 6.** Calculate the appraisal score S_i for all alternatives, as follows:

$$S_i = \frac{1}{2}(S_i^+ + S_i^-). \quad (11)$$

***Step* 7.** Rank the alternatives according to the decreasing values of appraisal score. The alternative with the highest S_i is the best choice among the candidate alternatives.

a. Application of EDAS method in a group of decision making

One of the simplest approaches for application of the EDAS method in a group environment can be provided forming a group matrix of decision-making based on the individual matrices obtained from the participants of a group, using the WA operator, i.e. applying Eq. (1).

3 NUMERICAL EXAMPLE OF THE EDAS METHOD APPLICATION

a. Basic postulates of multi criteria decision making for selection of mode of transport

In this case, the evaluation of four potential modes of transport is considered, as follows:

A_1 – Truck transport
A_2 – Railway transport
A_3 – Belt conveyors
A_4 – Hydrotransport

in relation to the following criteria:

C_1 – Transport safety

C_2 – Transport distance
C_3 – Supply of power and water
C_4 – Working environment conditions (temperature changes, humidity, terrain configuration)
C_5 – Physical and mechanical properties of materials

In order to evaluate the alternatives, a team of three experts was formed. At the very beginning of the evaluation, the experts assigned a significance to the selected criteria using the estimates (*E*) in the interval [0,1), as it is shown in Table 1.

Table 1 *Significance of criteria obtained from three experts*

Criteria	E_1	E_2	E_3
C_1	1	1	1
C_2	1	0.9	1
C_3	0.7	0.8	0.8
C_4	0.5	0.6	0.6
C_5	0.9	0.9	0.9

Weights of the criteria were subsequently determined using the following formula:

$$w_i = \frac{\sum_{j=1}^{3} x_{ij}}{\sum_{i=1}^{5}\sum_{j=1}^{3} x_{ij}} \tag{12}$$

Group weights is shown in Table 2.

Table 2 *Group weights*

Criteria	w_i
C_1	1
C_2	1
C_3	0.7
C_4	0.5
C_5	0.9

After that, the experts evaluated the alternatives in relation to the selected criteria. The results, obtained from three experts, are shown in Tables 3, 4 and 5.

Table 3 *Results of the alternatives evaluation, obtained from the first of three experts*

Alternatives	***Criteria***				
	C_1	C_2	C_3	C_4	C_5
A_1	3	4	4	3	4
A_2	1	1	3	1	3
A_3	2	3	2	2	2
A_4	4	2	1	4	1

Table 4 *Results of the alternatives evaluation, obtained from the second of three experts*

Alternatives	***Criteria***				
	C_1	C_2	C_3	C_4	C_5
A_1	3	4	3	3	4
A_2	1	2	3	3	3
A_3	2	3	2	2	2
A_4	4	2	1	4	2

Table 5 *Results of the alternatives evaluation, obtained from the third of three experts*

Alternatives	Criteria				
	C_1	C_2	C_3	C_4	C_5
A_1	3	3	3	3	4
A_2	1	2	3	1	3
A_3	2	3	2	2	2
A_4	4	2	1	3	1

b. The results of a group of multi criteria decision making

Group performances of alternatives in relation to the selected criteria – i.e. the transformation of individuals into the group decision matrix, was carried out using the WA operator. The first expert was assigned with significance of 0.4, while the second and third expert were assigned with significance of 0.3 (Table 6).

Table 6 *Group performances of alternatives obtained from three experts*

Alternatives	*Criteria*				
	C_1	C_2	C_3	C_4	C_5
A_1	0.24	0.23	0.18	0.13	0.21
A_2	3.00	3.70	3.40	3.00	4.00
A_3	1.00	1.60	3.00	1.60	3.00
A_4	2.00	3.00	2.00	2.00	2.00

After that, the average solution is determined for each criterion using Eq. (4). The obtained results are shown in Table 7.

Table 7 *Average solution according to all criteria*

Criteria	C_1	C_2	C_3	C_4	C_5
x_j^*	2.50	2.58	2.35	2.58	2.58

In the next steep the positive distance from average d_{ij}^+ and the negative distance from average d_{ij}^- are determined using Eq. (5) and Eq. (6), respectively. The obtained results are shown in Tables 8 and 9.

Table 8 *The positive distance from average*

Alternatives	Criteria				
	C_1	C_2	C_3	C_4	C_5
A_1	0.50	1.13	1.05	0.43	1.43
A_2	0.00	0.00	0.65	0.00	0.43
A_3	0.00	0.43	0.00	0.00	0.00
A_4	1.50	0.00	0.00	1.13	0.00

Table 9 *The negative distance from average*

Alternatives	Criteria				
	C_1	C_2	C_3	C_4	C_5
A_1	0.00	0.00	0.00	0.00	0.00
A_2	1.50	0.98	0.00	0.98	0.00
A_3	0.50	0.00	0.35	0.58	0.58
A_4	0.00	0.58	1.35	0.00	1.28

The weighted sum of positive distance from average, Q_i^+, and the weighted sum of negative distance from average, Q_i^-, are calculated using Eq. (7) and Eq. (8), respectively; after which the their normalized values, S_i^+ and S_i^-, are determined using Eq. (9) and Eq. (10). Finally, the appraisal score S_i of considered alternatives is calculated using Eq. (11).The mentioned values are shown in Table 10.

Table 10 *Appraisal score and ranking order of the considered alternatives*

Alternatives	Q_i^+	Q_i^-	S_i^+	S_i^-	S_i	*Rank*
A_1	0.93	0.00	1.00	1.00	1.00	1
A_2	0.21	0.71	0.22	0.00	0.11	4
A_3	0.10	0.38	0.10	0.46	0.28	3
A_4	0.51	0.65	0.55	0.09	0.32	2

As it can be seen from Table 9, the best ranked alternative is the alternative denoted as A_1. In other words, the truck transport is chosen as the most suitable type of transport at the open pit mines, taking into account several criteria.

CONCLUSIONS

A group of multi criteria decision making procedure for selecting the most suitable type of transport at the open pit mines is proposed in this paper. This procedure is based on the use of the EDAS method. The usability and efficiency of the proposed procedure is confirmed by the obtained results. According to these results, in terms of safety and quality, the truck transport was proved to be the most adequate.

It should be noted that the proposed criteria can be replaced by other criteria, which is indicative of the fact that the proposed procedure is flexible and conve-nient for solving the similar problems.

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