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UNDERGROUND LOADING-HAULAGE EQUIPMENT SELECTION WITH APPLICATION OF TOPSIS METHOD WITH DIFFERENT WEIGHTING METHODS OF CRITERIA

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Abstract: The choice of adequate mining machines is one of the most complex problems in the underground exploitation of mineral raw materials. The weight of such a decision is reflected in the high prices of these machines and the occurrence of even greater costs during their use if their choice was wrongly conceived. There are numerous examples from practice in which such decisions were made solely on the basis of comparing the prices of machines, without considering any of the remaining important parameters that over time can bring significant benefits or harm to the investor. In this paper, by applying the TOPSIS method with different weighting methods of criteria the most suitable loader for work in the underground mine in question was selected. Based on 7 different criteria, a selection was made between 6 different loaders, which were produced by 3 different renowned manufacturers of mining equipment. The final benefit of this work, in addition to the selection of the optimal loader, is that with some corrections, it can also be applied to the selection of other mining equipment in underground mines such as: trucks, boomers or bolters.

Keywords: loading-haulage equipment; selection; TOPSIS; entropy; standard deviation; criterion weight

1 INTRODUCTION

The selection of underground loading-haulage equipment in the mining industry represents a vital task for mining engineers, especially in greenfield projects. Selection of adequate loading-haulage equipment is important because it directly affects the productivity of the underground mine. In greenfield projects, beside common parameters considered in alternative ranking such as capacity of the loading-haulage equipment, price and engine emission class other criteria such as delivery time of equipment, terms of payment (percentage of advance payment), possibility of remote control and the state of maintenance network should be evaluated. As with any decision-making process,

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these criteria have different weights. Often it is a common practice that the decision maker (expert), or a decision-making team defines these weights based on their expert opinion, making the alternatives ranking prone to subjectivism. For ranking to be more objective weights of criteria should be determined by some objective method.

In the mining industry many different methods are used for multi-criteria decision making. For example, when selecting the underground mining method methods such as VIKOR, TOPSIS, PROMETHEE, ELECTRA, AHP and others are often used (Mijalkovski et al., 2022; Saki et al., 2020; Ali et al., 2021; Mijalkovski et al., 2023). For selection maintenance strategy in mining industry Pourjavad et al. (2013) used ANP and TOPSIS method. Koçali (2023) used TOPSIS method for personal protective equipment selection. Fuzzy TOPSIS method was also used for human health and safety risk management in underground coal mines by Mahdevari et al. (2014). The same method was used for equipment selection by Yavuz (2016) and for selection of loading-haulage equipment in open pit mines by Bazzazi et al. (2008). TOPSIS was used for selection of a production drill rig by Chanda (2019) and for haulage system selection among TOPSIS, VIKOR and AHP were used by Ghasvereh et al. (2019).

Based on literature review it can be concluded that the TOPSIS method is scientifically verified for problem solving in the mining industry. In this paper a ranking of the best loading-haulage equipment will be conducted using TOPSIS method with expert given criteria weight (assigned weights) as well as objective criteria weight calculated by entropy and standard deviation method.

2 TOPSIS METHOD APPLICATION

TOPSIS method or The Technique for Order of Preference by Similarity to Ideal Solution is one of multi-criteria decision analysis method developed by Hwang and Yoon (1981). This technique focuses on determining the most desirable alternative by comparing its proximity to the positive ideal solution and distance from the negative ideal (anti-ideal) solution. The ideal solution is derived by amalgamating the best attributes from each criterion, while the anti-ideal solution comprises the worst attributes. It is important to note that this technique is applicable only to numerical datasets, where the criterion weights are known or defined based on expert opinions. By considering the assigned weights, the ranking results can be obtained (Tzeng & Huang, 2011; Uzun et al., 2021.; Amudha et al., 2021). As previously mentioned, weights defined by experts can be prone to subjectivism. To make ranking objective, the weights in this paper will be determined using entropy weight method and standard deviation method (Li et al., 2011; Wang & Luo, 2010) to rank the alternatives with TOPSIS method.

Figure 1. shows the steps in TOPSIS MCDM process.

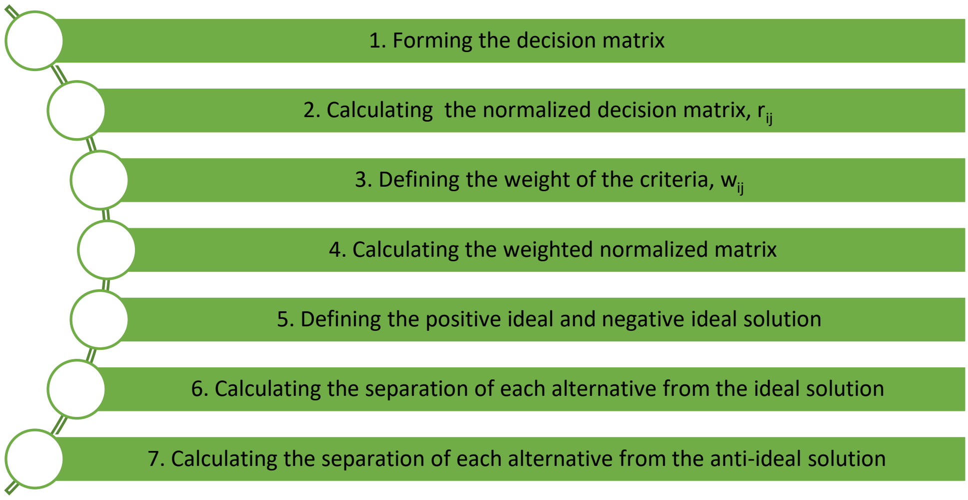

Figure 1 Steps in TOPSIS MCDM process

2.1 Forming the decision matrix

Decision matrix in its basic form is presented in following equation:

$$X = \begin{matrix} & \begin{matrix} C_1 & \cdots & C_n \end{matrix} \\ \begin{matrix} A_1 \\ \vdots \\ A_m \end{matrix} & \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \end{matrix} \tag{1}$$

Decision matrix for underground loading-haulage equipment selection will have 6 alternatives and 7 criteria as shown in figure 2. In these six alternatives, there are two loaders from each of the renowned manufacturers of mining equipment Sandvik, Epiroc and GHH, but due to the confidentiality of business data, it was not possible to show them with the names of manufacturers and models in this paper. Given that this choice of equipment was conceived for the needs of participating in the tender announced by the mine owner, it was necessary to take several criteria for choosing the optimal solution. For the investor, the most important criteria were the delivery date of the machine and the engine class, while for the contractor as a buyer and user of this machine, the other criteria were also very important. In addition to the price and method of payment for the machine, it is very important for the buyer how he will be able to maintain the machine, and the possibility of remote control will allow him to use the machine in unsupported underground facilities.

	C1: Price (€)	C2: Bucket capacitiy (t)	C3:Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of payment (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
A1:OPTION 1	733.000	10	52	III	35	Does not exist	Yes
A2:OPTION 2	865.000	14	48	III	40	Does not exist	No
A3:OPTION 3	965.000	14	24	V	20	Good	Yes
A4:OPTION 4	876.000	14	36	IV	30	Good	No
A5:OPTION 5	1.330.000	17	32	IV	20	Very good	No
A6:OPTION 6	1.120.000	21	32	IV	25	Very good	No

Figure 2 Decision matrix

As seen from Figure 2, some criteria are quantitative (C1, C2, C3, C4, C5) and some are qualitative (C6 and C7). To be able to proceed to step 2 of the TOPSIS algorithm, qualitative scale needs to be defined for C6 and C7. For criteria C6: State of maintenance network qualitative scale is transformed to quantitative values according to table 1.

Table 1 Qualitative and quantitative values of criteria C6

Qualitative values	Quantitative values
Does not exist	1
Poor	2
Average	3
Good	4
Very good	5

For criteria C7: Possibility of remote control is transformed from qualitative to quantitative values according to table 2.

Table 2 Qualitative and quantitative values of criteria C7

Qualitative values	Quantitative values
No	0.0001*
Yes	1

*Value 0.0001 instead of 0 is used so entropy method for criteria weight can be calculated

Now our decision matrix has quantitative values for all criteria, as shown in Figure 3.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
A1:OPTION 1	733.000,00	10	52	3	35	1	1
A2:OPTION 2	865.000,00	14	48	3	40	1	0,0001
A3:OPTION 3	965.000,00	14	24	5	20	3	1
A4:OPTION 4	876.000,00	14	36	4	30	3	0,0001
A5:OPTION 5	1.330.000,00	17	32	4	20	5	0,0001
A6:OPTION 6	1.120.000,00	21	32	4	25	5	0,0001

Figure 3 Decision matrix with all quantitative values

2.2 Calculation of normalized decision matrix

Normalization is technique that is used to standardize the values, making them to a common scale with values ranging from 0 to 1. There are several normalization techniques that are used for multi-criteria decision making (Çelen, 2014). In this paper vector normalization is performed. Transformation from decision matrix to normalized decision matrix is done by following equation:

$$\|X\| \rightarrow \|R\| \tag{2}$$

Where:

$$\|R\| = \left\|r_{ij}\right\|_{m\times n} \tag{3}$$

Where:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{4}$$

Following previous equations, we get the normalized decision matrix as shown on figure 4.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
OPTION 1	0,30	0,27	0,55	0,31	0,49	0,12	0,71
OPTION 2	0,35	0,37	0,51	0,31	0,56	0,12	0,00
OPTION 3	0,39	0,37	0,25	0,52	0,28	0,36	0,71
OPTION 4	0,36	0,37	0,38	0,42	0,42	0,36	0,00
OPTION 5	0,54	0,45	0,34	0,42	0,28	0,60	0,00
OPTION 6	0,46	0,56	0,34	0,42	0,35	0,60	0,00

Figure 4 Normalized decision matrix (vector normalization)

2.3 Defining weight of criteria

Weight of criteria has very high influence on the final ranking of the alternatives. In this paper weight will be assigned by a team of decision makers, relying on their expertise. Weights of criteria assigned like this can be subjective and sometimes may lead us to wrong conclusion. For this reason, two commonly used methods for objective criteria weight calculation (entropy and standard deviation) will be used to compare the rankings of the alternatives. In all cases the sum of all criteria weights must be 1.

2.3.1 Subjective criteria weight

The criteria weight assigned by the expert team for decision making is presented in figure 5.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
Weight	0,2	0,25	0,13	0,09	0,12	0,11	0,1

Figure 5 Subjective criteria weight

2.3.2 Entropy method

The entropy weight function is based on the discrete probability distribution:

$$e_j = \frac{-1}{\ln(m)} \sum_{i=1}^{m} r_{ij} \ln(r_{ij}) \tag{5}$$

The degree of diversity (d) possessed by each criteria is evaluated as:

$$d_j = 1 - e_j, j = 1, 2, 3 \tag{6}$$

The weight objective for each criteria is given by:

$$W_j = \frac{d_i}{\sum_{i=1}^{m} d_i} \tag{7}$$

For entropy method calculation a vector normalized matrix cannot be used, so another normalized matrix, a linear one was calculated using the equations 2, 3 and the following equation:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{8}$$

Linear normalized matrix is presented in figure 6.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenanc e network	C7: Possibility of remote control
OPTION 1	0,12	0,11	0,23	0,13	0,21	0,06	0,50
OPTION 2	0,15	0,16	0,21	0,13	0,24	0,06	0,00
OPTION 3	0,16	0,16	0,11	0,22	0,12	0,17	0,50
OPTION 4	0,15	0,16	0,16	0,17	0,18	0,17	0,00
OPTION 5	0,23	0,19	0,14	0,17	0,12	0,28	0,00
OPTION 6	0,19	0,23	0,14	0,17	0,15	0,28	0,00

Figure 6 Normalized decision matrix (linear normalization)

The calculated values for weight criteria by entropy method is presented in figure 7.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
Weight	0,01	0,02	0,02	0,01	0,02	0,12	0,79

Figure 7 Criteria weight by Entropy method

2.3.3 Standard deviation method

The standard deviation method determines the weights of the criteria in two steps, by the following equations (Odu, 2019):

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}\left[r_{ij} - \overline{r_j}\right]^2}{m}}, i = 1, \dots, m; j = 1, \dots, n \tag{9}$$

Therefore

$$W_j = \frac{\sigma_j}{\sum_{j=1}^{n} \sigma_j} \tag{10}$$

Where σ_j is the standard deviation for criteria j.

The calculated values for weight criteria by standard deviation is presented in figure 8.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
Weight	0,06	0,07	0,08	0,06	0,09	0,18	0,46

Figure 8 Criteria weight by standard deviation

Figure 9. presents the comparative preview of weight of criteria by different approaches (subjective, entropy and standard deviation).

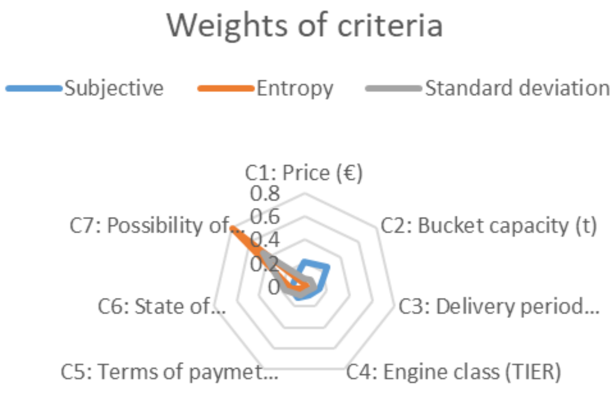

Figure 9 Comparative preview of weight of criteria by different approaches

2.4 Calculation of the weighted normalized matrix

Now we can form weighted decision matrix following next equation:

$$V_{ij} = W_j \cdot r_{ij} \tag{11}$$

Where W_j is the weight of the j-th criteria, $\sum_{j=1}^{n} w_j = 1$.

Now we get weighted decision matrixed for all our three cases (with subjective weights, with entropy calculated weights and with standard deviation calculated weights). On figures 10-12. weighted matrixes are presented.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
OPTION 1	0,06	0,07	0,07	0,03	0,06	0,01	0,07
OPTION 2	0,07	0,09	0,07	0,03	0,07	0,01	0,00
OPTION 3	0,08	0,09	0,03	0,05	0,03	0,04	0,07
OPTION 4	0,07	0,09	0,05	0,04	0,05	0,04	0,00
OPTION 5	0,11	0,11	0,04	0,04	0,03	0,07	0,00
OPTION 6	0,09	0,14	0,04	0,04	0,04	0,07	0,00

Figure 10 Subjective weighted matrix

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
OPTION 1	0,00	0,00	0,01	0,00	0,01	0,01	0,56
OPTION 2	0,00	0,01	0,01	0,00	0,01	0,01	0,00
OPTION 3	0,01	0,01	0,01	0,01	0,01	0,04	0,56
OPTION 4	0,00	0,01	0,01	0,00	0,01	0,04	0,00
OPTION 5	0,01	0,01	0,01	0,00	0,01	0,07	0,00
OPTION 6	0,01	0,01	0,01	0,00	0,01	0,07	0,00

Figure 11 Entropy weighted matrix

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
OPTION 1	0,02	0,02	0,05	0,02	0,04	0,02	0,32
OPTION 2	0,02	0,03	0,04	0,02	0,05	0,02	0,00
OPTION 3	0,03	0,03	0,02	0,03	0,02	0,06	0,32
OPTION 4	0,02	0,03	0,03	0,02	0,04	0,06	0,00
OPTION 5	0,03	0,03	0,03	0,02	0,02	0,11	0,00
OPTION 6	0,03	0,04	0,03	0,02	0,03	0,11	0,00

Figure 12 Standard deviation weighted matrix

2.5 Defining the ideal and anti-ideal solution

For each criteria the ideal and anti-ideal solution are calculated according to the type of the criteria (MIN or MAX). In the table 3. are listed types of the criteria.

Table 3 Types of criteria

Criteria	Criteria type
C1: Price (€)	MIN
C2: Bucket capacity (t)	MAX
C3: Delivery period (weeks)	MIN
C4: Engine class (TIER)	MAX
C5: Terms of payment (advance payment %)	MIN
C6: State of maintenance network	MAX
C7: Possibility of remote control	MAX

The ideal solution is the solution that maximizes the benefit criteria (MAX type) and minimizes the cost criteria (MIN type) whereas the anti-ideal solution maximizes the cost criteria (MIN type) and minimizes the benefit criteria (MAX type) (Roszkowska, 2011).

Ideal solution A^+ has the form:

$$A^+ = \left\{\left(\left(MAX_i v_{ij} \middle| j \in K'\right)\right), \left(MIN_i v_{ij} \middle| j \in K''\right)\right\} = \{v_1^+, v_2^+, \dots, v_n^+\}, (i = 1,2, \dots m) \quad (12)$$

Anti-ideal solution A^- has the form:

$$A^- = \left\{\left(\left(MIN_i v_{ij} \middle| j \in K'\right)\right), \left(MAX_i v_{ij} \middle| j \in K''\right)\right\} = \{v_1^-, v_2^-, \dots, v_n^-\}, (i = 1,2, \dots m) \quad (13)$$

Where:

$K' \subseteq K \rightarrow K'$ is a subset of set K who makes the MAX type criteria,

$K'' \subseteq K \rightarrow K''$ is a subset of set K who makes the MIN type criteria.

According to equations 12 and 13 we can now calculate the ideal and anti-ideal solutions for subjective assigned weights of criteria, entropy calculated weights of criteria and standard deviation calculated weights of criteria (Figure 13).

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control
Subjective							
Ideal	0,060	0,139	0,033	0,047	0,033	0,066	0,071
Anti-ideal	0,109	0,066	0,072	0,028	0,067	0,013	0,000
Entropy							
Ideal	0,004	0,010	0,006	0,006	0,007	0,070	0,559
Anti-ideal	0,007	0,005	0,013	0,004	0,014	0,014	0,000
Standard deviation							
Ideal	0,019	0,041	0,021	0,030	0,024	0,106	0,324
Anti-ideal	0,035	0,019	0,046	0,018	0,048	0,021	0,000

Figure 13 Ideal and anti-ideal solutions for each criteria regarding the different weight approach

2.6 Calculation of each alternative distance from ideal solution

The separation distance of each alternative from the ideal solution is calculated according to equation:

$$S_i^+ = \sqrt{\sum_{j=1}^{k} (v_{ij} - v_j^+)^2}, (i = 1,2, \dots m) \quad (14)$$

Now we can calculate the separation distance for every alternative for our case. On Figure 13. Alternative distance from ideal solution is presented for all three cases.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control	S+
Subjective								
A1: OPTION 1	0,00000	0,00533	0,00148	0,00036	0,00063	0,00277	0,00000	**0,10280**
A2: OPTION 2	0,00012	0,00216	0,00109	0,00036	0,00112	0,00277	0,00500	**0,11227**
A3: OPTION 3	0,00036	0,00216	0,00000	0,00000	0,00000	0,00069	0,00000	**0,05665**
A4: OPTION 4	0,00014	0,00216	0,00027	0,00009	0,00028	0,00069	0,00500	**0,09288**
A5: OPTION 5	0,00237	0,00071	0,00012	0,00009	0,00000	0,00000	0,00500	**0,09104**
A6: OPTION 6	0,00100	0,00000	0,00012	0,00009	0,00007	0,00000	0,00500	**0,07922**
Entropy								
A1: OPTION 1	0,00000	0,00003	0,00005	0,00001	0,00003	0,00311	0,00000	**0,05677**
A2: OPTION 2	0,00000	0,00001	0,00004	0,00001	0,00005	0,00311	0,31279	**0,56214**
A3: OPTION 3	0,00000	0,00001	0,00000	0,00000	0,00000	0,00078	0,00000	**0,02812**
A4: OPTION 4	0,00000	0,00001	0,00001	0,00000	0,00001	0,00078	0,31279	**0,56000**
A5: OPTION 5	0,00001	0,00000	0,00000	0,00000	0,00000	0,00000	0,31279	**0,55930**
A6: OPTION 6	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	0,31279	**0,55929**
Standard deviation								
A1: OPTION 1	0,00000	0,00045	0,00062	0,00015	0,00032	0,00712	0,00000	**0,09310**
A2: OPTION 2	0,00001	0,00018	0,00046	0,00015	0,00057	0,00712	0,10511	**0,33705**
A3: OPTION 3	0,00004	0,00018	0,00000	0,00000	0,00000	0,00178	0,00000	**0,04474**
A4: OPTION 4	0,00001	0,00018	0,00011	0,00004	0,00014	0,00178	0,10511	**0,32769**
A5: OPTION 5	0,00025	0,00006	0,00005	0,00004	0,00000	0,00000	0,10511	**0,32481**
A6: OPTION 6	0,00010	0,00000	0,00005	0,00004	0,00004	0,00000	0,10511	**0,32456**

Figure 14 Separation distance from ideal solution for every alternative regarding the different weight approach

2.7 Calculation of each alternative distance from anti-ideal solution

The separation distance of each alternative from the anti-ideal solution is calculated according to equation:

$$S_i^- = \sqrt{\sum_{j=1}^{k} (v_{ij} - v_j^-)^2}, (i = 1,2, \dots m) \quad (15)$$

Now we can calculate the separation distance for every alternative for our case. On Figure 15. Alternative distance from anti-ideal solution is presented for all three cases.

	C1: Price (€)	C2: Bucket capacity (t)	C3: Delivery period (weeks)	C4: Engine class (TIER)	C5: Terms of paymet (advance payment %)	C6: State of maintenance network	C7: Possibility of remote control	S-
Subjective								
A1: OPTION 1	0,00237	0,00000	0,00000	0,00000	0,00007	0,00000	0,00500	**0,08627**
A2: OPTION 2	0,00144	0,00071	0,00003	0,00000	0,00000	0,00000	0,00000	**0,04664**
A3: OPTION 3	0,00089	0,00071	0,00148	0,00036	0,00112	0,00069	0,00500	**0,10120**
A4: OPTION 4	0,00137	0,00071	0,00048	0,00009	0,00028	0,00069	0,00000	**0,06019**
A5: OPTION 5	0,00000	0,00216	0,00076	0,00009	0,00112	0,00277	0,00000	**0,08301**
A6: OPTION 6	0,00029	0,00533	0,00076	0,00009	0,00063	0,00277	0,00000	**0,09934**
Entropy								
A1: OPTION 1	0,00001	0,00000	0,00000	0,00000	0,00000	0,00000	0,31279	**0,55929**
A2: OPTION 2	0,00001	0,00000	0,00000	0,00000	0,00000	0,00000	0,00000	**0,00340**
A3: OPTION 3	0,00000	0,00000	0,00005	0,00001	0,00005	0,00078	0,31279	**0,56007**
A4: OPTION 4	0,00001	0,00000	0,00002	0,00000	0,00001	0,00078	0,00000	**0,02860**
A5: OPTION 5	0,00000	0,00001	0,00003	0,00000	0,00005	0,00311	0,00000	**0,05655**
A6: OPTION 6	0,00000	0,00003	0,00003	0,00000	0,00003	0,00311	0,00000	**0,05652**
Standard deviation								
A1: OPTION 1	0,00025	0,00000	0,00000	0,00000	0,00004	0,00000	0,10511	**0,32464**
A2: OPTION 2	0,00015	0,00006	0,00001	0,00000	0,00000	0,00000	0,00000	**0,01488**
A3: OPTION 3	0,00009	0,00006	0,00062	0,00015	0,00057	0,00178	0,10511	**0,32921**
A4: OPTION 4	0,00014	0,00006	0,00020	0,00004	0,00014	0,00178	0,00000	**0,04863**
A5: OPTION 5	0,00000	0,00018	0,00032	0,00004	0,00057	0,00712	0,00000	**0,09071**
A6: OPTION 6	0,00003	0,00045	0,00032	0,00004	0,00032	0,00712	0,00000	**0,09100**

Figure 15 Separation distance from anti-ideal solution for every alternative regarding the different weight approach

2.8 Calculation of the relative closeness of alternative to the ideal solution

Calculation of the relative closeness of alternative to the ideal solution can be done by following equation:

$$C_i = \frac{S_i^-}{S_i^- + S_i^+}, 0 \leq C_i \leq 1 \tag{16}$$

Regarding that $C_i = 0$ represents anti-ideal solution and $C_i = 1$ represents the ideal solution. Figure 16. represents the relative closeness of alternatives to the ideal solution according to the previous equation.

	Subjective	Entropy	Standard deviation
OPTION 1	0,456	0,908	0,777
OPTION 2	0,293	0,006	0,042
OPTION 3	0,641	0,952	0,880
OPTION 4	0,393	0,049	0,129
OPTION 5	0,477	0,092	0,218
OPTION 6	0,556	0,092	0,219

Figure 16 Relative closeness of the alternatives to the ideal solution with respect to the weighting method

Figures 17-19. Represent relative closeness of every alternative to ideal solution for three different weighting methods.

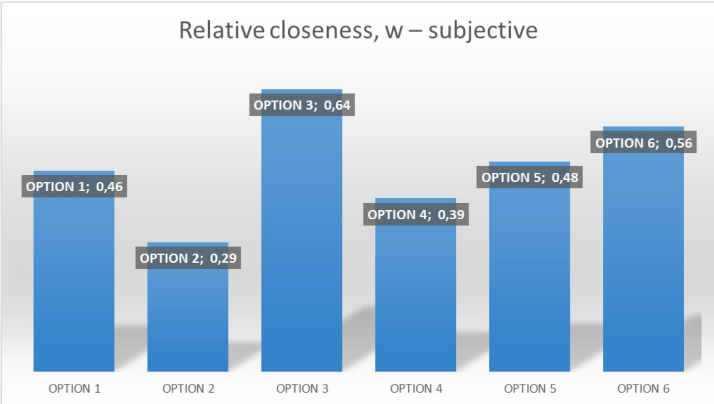

Figure 17 Relative closeness of the alternatives to the ideal solution, subjective weighting

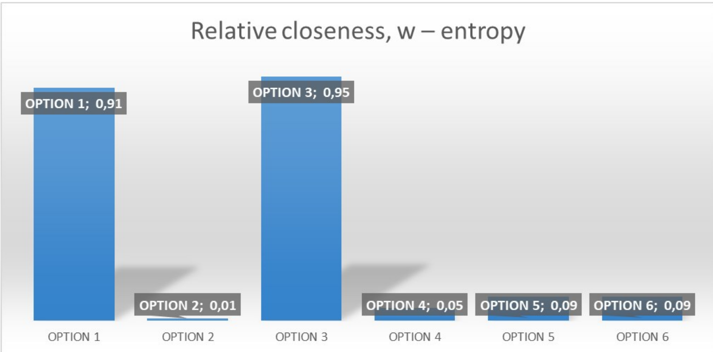

Figure 18 Relative closeness of the alternatives to the ideal solution, entropy weighting

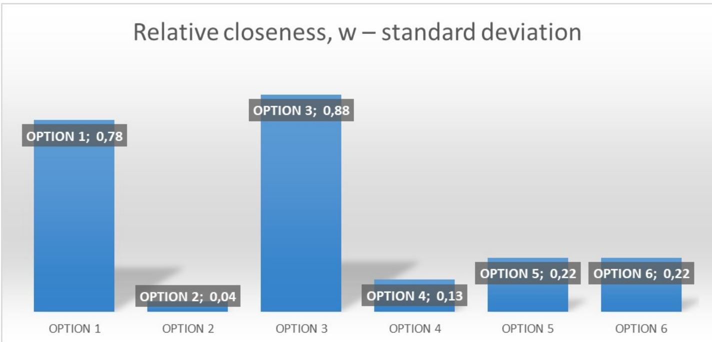

Figure 19 Relative closeness of the alternatives to the ideal solution, standard deviation weighting

2.9 Ranking the preference order

Ranking of the alternatives is done according to the descending order of the C_i. Now with known values of relative closeness of each alternative to the ideal solution ranking of the alternatives can be done. Figure 20. shows the ranking of the alternatives regarding the weighting method.

Alternative	Ci	Rank
A3: OPTION 3	0,64	1
A6: OPTION 6	0,56	2
A5: OPTION 5	0,48	3
A1: OPTION 1	0,46	4
A4: OPTION 4	0,39	5
A2: OPTION 2	0,29	6

Subjective weighted

Alternative	Ci	Rank
A3: OPTION 3	0,95	1
A1: OPTION 1	0,91	2
A5: OPTION 5	0,09	3
A6: OPTION 6	0,09	4
A4: OPTION 4	0,05	5
A2: OPTION 2	0,01	6

Entropy weighted

Alternative	Ci	Rank
A3: OPTION 3	0,88	1
A1: OPTION 1	0,78	2
A6: OPTION 6	0,22	3
A5: OPTION 5	0,22	4
A4: OPTION 4	0,13	5
A2: OPTION 2	0,04	6

Standard deviation weighted

Figure 20 Ranking the preference order

3 DISCUSION

The initial assumption of this paper was that all six alternatives of analyzed loaders do not exceed the limit values given in the mining design with their external dimensions. The choice is further narrowed by the condition that the maximum deadline for the delivery of a new machine must not exceed one year. Three renowned manufacturers of mining equipment submitted their offers, which are shown in Figure 2. Seven different criteria were selected for the evaluation of these offers. The application of the TOPSIS method of multi-criteria decision-making resulted in the recommendation that the optimal solution should be the loader, which is designated as Option 3 in this paper.

It is interesting to point out that in all three cases of ranking the alternatives using the weight method, alternative 3 was chosen as the optimal, while alternative 2 was chosen as the least desirable. The loader marked as alternative 3 had an 11.6% higher price than the loader marked as alternative 2 and it was fourth in terms of price. If the choice of the machine were to be carried out, as is the practice in a large number of cases, based on the price alone, an alternative 3 would certainly not be considered as an acceptable option.

It is clear that some other criteria were decisive for alternative 3 to be chosen as the optimal. The facts that this alternative had the shortest delivery time, was the only one with a TIER V engine class and shared the best values with one of other alternatives in three other criteria were crucial for it to be chosen as the optimal.

By choosing alternative 3, the investor will receive a new machine in the shortest possible time and will be able to activate it immediately and realize benefits in the form of increased production in his mine. The bidding company has good after-sales support in the mine region, which will greatly reduce machine downtime in the future. However, as the most significant value of the selected alternative, the possibility of remote control of this loader should be singled out, which gives more opportunities for its use in various operations in the mine and drastically affects the operator's safety when performing risky loading and transport operations in underground mines.

4 CONCLUSION

The choice of mining machinery should be “protected” from the subjective decisions of investors or managers and be based on the application of mathematical methods in order to find the optimal solution that will enable safer work and a healthier environment for operators and finally to the improvement of productivity in the operation of the mine in terms of the reliability of the selected equipment during its lifetime. The application of TOPSIS or some other method of multi-criteria decision-making should become a standard “tool” when selecting mining machinery. It is certain that if decision-makers were presented with the possibilities of this way of applying mathematical methods and were shown the real and long-term benefits for their business, the vast majority would correct their previous principles when choosing equipment for their mines.

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