PRIORITISATION OF CRITERIA IMPORTANT FOR ORE TRANSPORT SYSTEM SELECTION

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ABSTRACT. The selection of an optimal ore transport system represents a delicate task for mining engineers. The decision-making process should involve every criterion that could affect the final choice. The main objective of this paper is to emphasise the criteria important for ore transportation system selection and demonstrate their prioritisation by using the Multiple-Criteria Decision-Making (MCDM) method. The paper proposes the Stepwise Weight Assessment Ratio Analysis - SWARA for determining the ranking order of considered criteria. The possibilities of the proposed method are demonstrated by using a numerical example and the obtained results are reliable and real.

Keywords: MCDM, SWARA method, criteria, ore transport system

ПРИОРИТИЗИРАНЕ НА КРИТЕРИИ, ВАЖНИ ПРИ ИЗБОРА НА РУДНИЧЕН ТРАНСПОРТ

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РЕЗЮМЕ. Изборът на оптимална руднична транспортна система е деликатна задача за минните инженери. Процесът на вземане на решение трябва да включва всеки критерий, който може да повлияе върху окончателния избор. Основната цел на настоящия доклад е да се наблегне на критериите, които са важни за избора на система за рудничен транспорт и да се демонстрира тяхното приоритизиране чрез използване на многокритериалния метод за вземане на решения (ММВР). Докладът предлага поетапен анализ на коефициента на оценка на теглото (ПАКОТ) за определяне на реда за класиране на разглежданите критерии. Възможностите на предложения метод са демонстрирани с помощта на числов пример и получените резултати са надеждни и реални.

Ключови думи: ММВР, метод ПАКОТ, критерии, рудничен транспорт

Introduction

The selection of the system for ore transport from the mine to the processing plant represents a very important issue because the selected system affects the total costs of a mine. As Karande and Chakraborty (2013) stated in their paper, the material handling costs participate in the total operating costs of a mine with 30%-75%. Bearing that fact in mind, in the transport system selection the decision-maker (hereinafter referred to as DM) should take into account all influential criteria that impact the final decision.

Numerous criteria should be involved in the process of the transport system selection which points out the fact that the decision process should be based on the multiple-criteria approach (Kluge et al., 2017). Although DMs involve every criterion significant for obtaining the proper decision, it is very difficult to determine which of the criteria have the greatest impact on the final choice in the present conditions. Helpful in the resolving of that unknown could be the Multiple-Criteria Decision-Making method (MCDM).

MCDM represents a field of operational research and management science that has achieved great popularity in recent years. Until now, many different methods were proposed and a good overview could be found in the papers of Velasquez and Hester (2013), Zavadskas et al. (2014) and Mardani et al. (2015). Besides, a significant number of extensions of the proposed methods are introduced (e.g. Boran et al., 2009; Stanujkic et al., 2017; Stević et al., 2018). Various problems in many business fields could be resolved by using some of the MCDM techniques (e.g. Prasad et al., 2015; Luthra et al., 2017; Ghorabaee et al., 2018).

The MCDM approach is also used in the area of the selection of the appropriate transport system in the mining exploitation. Elevli and Demirci (2004) applied the PROMETHEE method in the selection of the transport system for an underground mine. Grujić et al. (2007) investigated the possibility of applying MCDM in the selection of the transport system in lead and zinc mine. Owusu-Mensah and Musingwini (2011) considered options for transportation from Kwesi Mensah Shaft (KMS) to the mill at Obuasi mine. Kun et al. (2013) performed a selection of the wheel loaders in open pit mine by using a combination of the AHP (Analytic Hierarchy Process) and the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) methods.

In this paper, the importance of the question connected to the determination of the criteria that have the greatest influence on the final transport system choice is emphasised. The list of the criteria that are submitted to the evaluation by using the Stepwise Weight Assessment Ratio Analysis - SWARA method (Keršiliene et al., 2010) are adopted from the paper of Owusu-Mensah (2010). Five DMs, experts in the field of mining exploitation were involved in the decision process. The rest of the paper is organised as follows: in the second part, the procedure of the SWARA method is presented; the third part of the paper includes the numerical example; the conclusion is given at the end.

The SWARA method

Various methods have proved to be very useful for determination of the criteria significance and some of them are: Analytic Hierarchy Process – AHP method (Saaty, 1980), the Kemeny Median Indicator Ranks Accordance – KEMIRA method (Krylovas et al., 2014) and the Pivot Pairwise Relative Criteria Importance Assessment - PIPRECIA method (Stanujkic et al., 2017). In this paper, for the prioritisation of the criteria important for the transportation system selection, the SWARA method (Keršuliene et al., 2010) is proposed and presented through the following series of steps.

Step 1. Select the evaluation criteria and sort them in descending order, in lieu of the expected significance.

Step 2. DM should express the relative significance of the criterion *j* relative to the previous criterion (*j-1*) for each criterion, starting from the second.

Step 3. Determine the coefficient k_j in the following manner:

$$k_j = \begin{Bmatrix} 1 & j=1 \\ s_j+1 & j>1 \end{Bmatrix}, \quad (1)$$

where s_j denotes the ratio of the comparative importance of the average value.

Step 4. Determine the recalculated weight q_j is as follows:

$$q_j = \begin{Bmatrix} 1 & j=1 \\ \dfrac{k_j-1}{k_j} & j>1 \end{Bmatrix}. \quad (2)$$

Step 5. Calculate the relative weights of the criteria by using the following equation:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k}, \quad (3)$$

where w_j is the relative weights of the criterion *j*.

A numerical example

In this section, a numerical example is presented which points to the prioritisation of the considered criteria. The criteria that impact the final decision relative to the transport system could roughly be divided into three categories and they are: technical, economic and environmental. Some authors, such as Kun et al. (2013) proposed introducing one more category – commercial criteria. All of the mentioned criteria categories contain a greater number of sub-criteria.

For this paper, the list of the criteria proposed by Owusu-Mensah (2010) has been adopted. Each criterion from the given list belongs to one of the previously mentioned criteria categories. The proposed list of criteria, as well as appropriate explanations, are shown in Table 1.

Table 1. *The criteria list (Owusu-Mensah, 2010)*

	Criteria	Explanation
C_1	System productivity	A working output of the system
C_2	System flexibility	A system possibility to adapt to changes in tonnage
C_3	Safety in operation	A possibility of the emergence of potentially dangerous and harmful situations
C_4	Easiness of set up	The system requires minimal technical effort and time in preparing for use
C_5	Topography	Easiness of manoeuvre in different terrains
C_6	System availability	High work efficiency and rarely breaking down of the system
C_7	Spare parts supply	Availability of spare parts
C_8	Repair easiness	A difficulty of system repairing
C_9	Durability	Long lasting of the system
C_{10}	Capital cost	Capital for the purchase of the system
C_{11}	Energy cost	Costs for fuel and electricity
C_{12}	Maintenance cost	Cost for system repairing and maintenance
C_{13}	Operating unit cost	Cost per tonne of ore moved
C_{14}	Jobs/Labour	Cost of labour
C_{15}	Emissions levels	Harmful emissions and gases that could damage the environment
C_{16}	Noise levels	Loud and unpleasant sounds emitted into the surroundings
C_{17}	Aesthetic/Visuals	Visual impact on the environment

Five DMs were involved in the evaluation process. By using the equations (1)-(3) the ranking according to the DM_1 is performed and the results are presented in Figure 1.

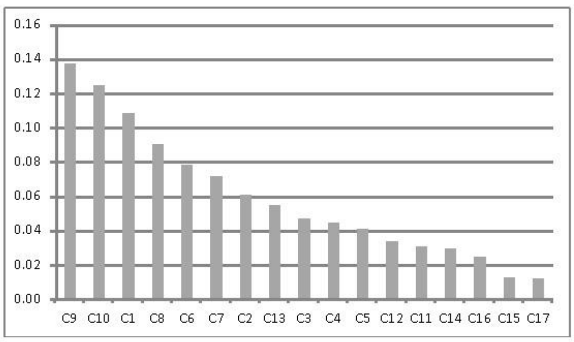

Fig. 1. The ranking order of the criteria according to the DM_1

As can be seen, the most important criterion for DM_1 is criterion C_9 – *Durability*. So, for this DM the lasting of the system represents one of the crucial aspects that impact on the final selection of the adequate transport system. Second-ranked is criterion C_{10} – *Capital cost* and third is criterion C_1 – *System productivity*. According to the DM_1, the least significant is criterion C_{17} – *Aesthetic/Visuals*.

In the previously explained way, the final rank of the criteria for the DM_2 is determined and the obtained results are presented in Figure 2.

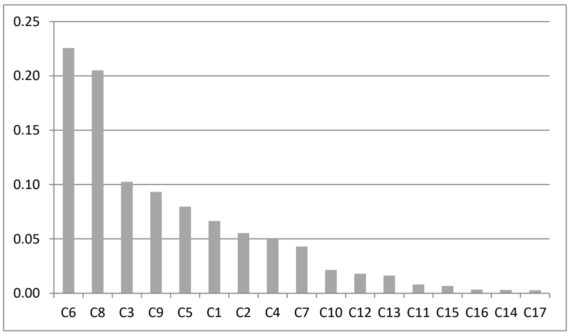

Fig. 2. The ranking order of the criteria according to the DM_2

Two extremely important criteria for DM_2 are C_6 – *System availability* and C_8 – *Repair easiness*. The criteria: C_{16} – *Noise levels*, C_{14} - *Jobs/Labour* and C_{17} – *Aesthetic/Visuals* are not so important according to the DM_2.

The results for the DM_3 are presented in Figure 3.

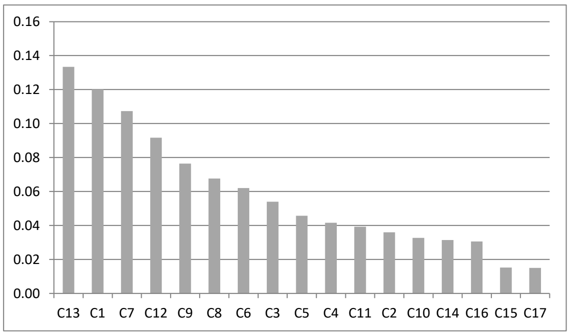

Fig. 3. The ranking order of the criteria according to the DM_3

Figure 3 shows that the criterion C_{13} – *Operating unit cost* is the most influential. The mentioned criterion is followed by the criterion C_1 – *System productivity*, while the least significant are criteria C_{15} – *Emissions levels* and C_{17} – *Aesthetic/Visuals*.

Assessment results for the DM_4 are as Figure 4 shows.

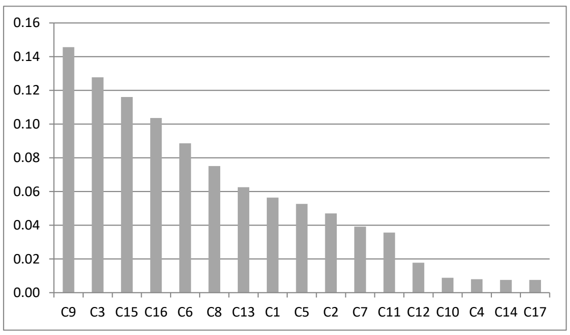

Fig. 4. The ranking order of the criteria according to the DM_4

DM_4 gives the priority to the criterion C_9 – *Durability*, which is the same case as with DM_1. In addition, the last three positions are occupied by the following three criteria: C_4 – *Easiness of set up*, C_{14} – *Jobs/Labour* and C_{17} – Aesthetic/Visuals. It seems that the way in which the transport system influences the visual conditions of the surroundings is not so important for the DM_4.

The results connected with the standpoint of the DM_5 are shown in Figure 5.

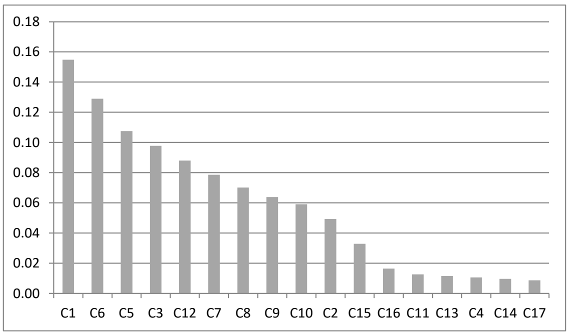

Fig. 5. The ranking order of the criteria according to the DM_5

DM_5 puts the criterion C_1 – *System productivity* in the first place. As well as in the previous cases, the last position occupies the criterion C_{17} – *Aesthetic/Visuals*.

The overall result is obtained by applying the following equation:

$$w_j = \left(\prod_{r=1}^{R} w_j^{nr} \right)^{1/R}, \tag{4}$$

where w_j^{nr} denotes the weight of the criterion *j* obtained from the respondent *r*, *R* represents the number of the respondents, w_j is the group weight of the criterion *j*.

The obtained final results are as follows (Fig. 6).

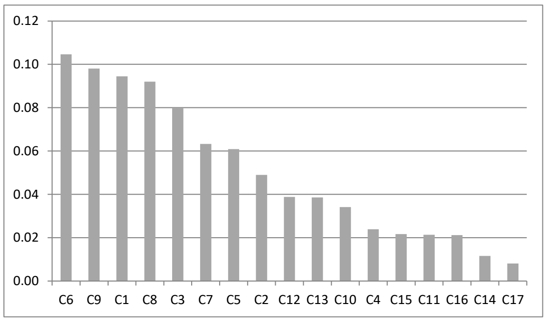

Fig. 6. The overall ranking order of the considered criteria

The overall results show that criterion C_6 – *System availability* has the greatest influence on the selection of the optimal transport system in the mining industry. As it was expected, the criterion C_{17} – *Aesthetic/Visuals* is at the last position.

The obtained results show that a group of criteria connected to environmental issues is not so important for the selection of the optimal transport system. The crucial criteria are mainly of technical nature which is confirmed by the first ranked criterion. The proper functionality and reliability of the selected transport system are of the greatest importance for the DMs i.e. mining engineers.

Conclusion

The selection of the suitable transport system that enables the transportation of ore from the mine to a certain processing plant requires detailed and methodical analysis. Although the costs are the first issue when business planning is in question, the basing of a decision only on the economic type of criteria would not lead to justified and appropriate decisions. The decision, such as the selection and purchasing of the system for ore transportation should involve different types of influential criteria. In this case, it is very difficult to determine which criterion has the greatest influence on the final choice.

In this paper, for the prioritising the criteria for transport system selection the SWARA method is proposed. The evaluation process was performed in a group decision-making environment that involved 5 DMs which assessed 17 criteria (Owusu-Mensah, 2010). The final results, obtained by applying geometric mean, are completely reliable and justified.

The SWARA method proved to be useful and to successfully facilitate the decision process. Besides the prioritisation of the considered criteria, this method could be used in the process of the transport system selection, as well. Also, the SWARA method could be applied in other fields of mining exploitation as a tool that could increase the reliability and validity of decisions. The main shortage of the used method is that it is not quite suitable for group decision-making, because the process of obtaining the overall results is somewhat complicated. In that sense, the possibilities of the newly introduced PIPRECIA method (Stanujkic et al., 2017) should be used and it will be very interesting to perform the comparison of these two methods on the same example.

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