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APPLICATION OF MULTI-CRITERIA DECISION-MAKING METHODS FOR THE CONVEYOR BELT SELECTION IN PRACTICE

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Abstract:
Determination of the weights (preferences) of criteria is the first step in the process of multiple criteria decision-making and the assessment of several variants, i.e. solutions to the decision-making problems in practice. Belt conveyors are efficient conveyance systems that are used for the transportation of bulk materials across all industries. One of the basic components of these conveyors is a conveyor belt. The purpose of this article was to define the most important criteria (factors) and their preferences in the process of selecting a suitable type of conveyor belt or a suitable conveyor belt structure. The weights of selected criteria (technology, economy, energy, ecology and ergonomics) were determined by applying the multiple criteria decision-making methods (scoring method, best-worst method, pairwise comparison and Saaty's method). The results of the evaluation analysis showed that the Technology criterion had the highest preference (39.3%), followed by the Economy (22.1%) and Energy (21.7%) criteria.

Key words:
multi-criteria decision-making, scoring method, best-worst method, pairwise comparison, Saaty's method, conveyor belt.

1 INTRODUCTION

Nowadays, belt conveyors are used in a wide spectrum of applications. While in the past they were used primarily in the mining industry to transport raw materials, nowadays they may also be seen, for example, in automated operations, at airports or in manufacturing lines. Each type of the belt conveyor has its own special features, it is therefore very important to choose the transportation technology that is appropriate for a particular purpose (Marasova, 2006). In order to ensure that such a decision is correct, the multiple criteria decision-making methods may be applied. Authors Liu and Wang (Liu and Wang, 2013) and authors Jovcic et al. (Jovcic, Prusa and Nikolicic, 2018) applied the AHP method (Analytic Hierarchy Process – the Saaty's method) to evaluate the quality of belt conveyors. In paper (Parmar, James and Asjad, 2023), the authors used the AHP method to identify and analyse various challenges in the outsourcing of maintenance operations associated with the installation of belt conveyors. In their paper, Özfirat et al. (Özfirat, Özfirat and Malli, 2018) applied the aforementioned method to select the appropriate transportation technology for transporting excavated coal. Their decision was based on the costs and the technical parameters. A similar topic was discussed by Jankovic et al., in particular the selection of the suitable transportation technology to be used in the surface mining of coal (Jankovic, 2019). Belt conveyors are an important part of inter-facility transportation systems. In paper (Andrejiova, 2015), certain adjustments to the constructional parameters of belt conveyors that may contribute to the optimisation and innovation of the transport of raw materials were proposed. The importance, i.e. the impact or the power of the impact, of such adjustments to selected parameters on the system optimisation was evaluated by applying the AHP method. Transport services possess certain specific characteristics (picking up and delivery of goods, complaints, availability of the means of transport, transport duration, service reliability etc.). The identification and evaluation of those specifics facilitates an efficient improvement in the quality of those services. In papers (Marasova and Andrejiova, 2018), (Hruska, Kmetik and Chocholac, 2021), the application of the Saaty's method to the evaluation of quality of a transportation service was described.

A conveyor belt is an important component of a belt conveyor. It serves the carrying and the traction functions. However, during its utilisation, it is exposed to the effects of numerous loads that induce the wear and damage process. In the presented article, the general process of selecting a suitable conveyor belt on the basis of several criteria, by applying selected methods of multiple criteria decision-making, is described.

2 METHODS AND METHODOLOGY

2.1 Decision-making process

The decision-making process is a procedure of solving decision-making problems, in which it is important make a decision and select one of several potential solutions. In general, decision-making is perceived as choosing from more than one solution alternatives (variants). The output of the decision-making is a decision; it is an irreversible and the most difficult step on the way to the goal. It involves selecting the best, the optimal alternative out of all alternative solutions to the problem (Fotr and Švecová, 2010), (Šubrt, 2011).

Criteria are the key elements of the decision-making process. They are used to evaluate the individual alternatives and choose the optimal solution. If the decision-making process is carried out while considering several criteria at the same time (e.g. economic, social, technical, safety-related, ecological etc.), this process is referred to as the multiple criteria decision-making process.

At present, there is a wide spectrum of techniques and methods available for the multiple criteria decision-making process. They differ in the approach to seeking the optimal solution alternative, the level of their difficulty, and their applicability to different types of tasks.

Empirical methods are based on understanding the facts and on the experience of the decision-maker (for example, the “trial and error” method, adaptive management, brainstorming etc.). Heuristic methods are partially based on the subjective evaluation (judgement), while the evaluation results are further processed by applying the exact procedures (a decision-making analysis, a decision-making tree, decision-making tables, genetic algorithms, neural networks etc.). The exact methods that are based on a scientific analysis include, for example, statistical methods (e.g. a correlation analysis, the probability theory, and a time series analysis), mathematical analysis methods, algebra-based methods etc.

In a majority of the multiple criteria decision-making methods, it is necessary to differentiate the individual criteria based on their importance. One of the ways how to achieve that is to express their importance numerically, with the use of the so-called weights. The weights of criteria (i.e. the coefficients of importance, preferences and seriousness) represent a numerical expression of the importance of the analysed goals, which are transformed into selected criteria. Criteria that are more important are assigned higher weights. Conversely, less important criteria are assigned lower weights. In order to be able to compare the weights that were determined by applying different methods, the weights are normalised so that their sum equals 1.

2.2 Methods for the determination of the weights of criteria

There are a large number of available methods for the determination of weights. However, in every method there are negative effects of the subjective perception and decision-making, as well as the fact that different evaluators have different attitudes towards the problem that is being solved. If the decision-maker (evaluator) is not able, or cannot, for whatever reason, determine the preferences of the criteria, it is impossible to differentiate the importance of the individual criteria. In such a case, all of the criteria are assigned the same weight. If the evaluator possesses the information on the criteria, and hence is able to determine the order of importance of the individual criteria (referred to as the ordinal data), then the evaluator can apply two most frequently used methods: the best-worst method and the Fuller’s method. If the evaluator is able to determine not only the order of importance of the individual criteria, but also the ratio between the importance of the individual criteria (referred to as the cardinal data), then it is recommended to use the scoring method or the Saaty’s method (AHP method).

Scoring method

The procedure of identifying the weights involves assigning a certain number of points from a selected scale to each criterion. More important criteria are assigned more points. The scale may have five points or – for the purpose of better differentiation – ten points. In the case of a 10-point scale, the importance of the individual criteria is ranked by assigning 1 to 10 points, while 1 point is assigned to the lowest weight and 10 points are assigned to the highest weight.

Best-worst method

This method is based on arranging the criteria according to their mutual relative importance. The most important criterion is assigned the best position in the order, while the least important criterion is assigned the lowest position in the order. In the case the same position in the order is assigned to several criteria, the average position in the order s determined. The most important criterion is assigned *n* points (*n* is the number of criteria), the second most important criterion is assigned *n-1* points, and the least important criterion is assigned 1 point.

Pairwise comparison (Fuller's method)

When two criteria are compared, the one that is more important (more significant for the decision-making) is evaluated as "1", while the less important criterion is evaluated as "0". The resulting evaluation of the alternatives, or the weights of criteria, is obtained by "normalising" the evaluation. This means that the sum of all the evaluations, i.e. the weights, must equal 1. Each criterion is assigned the number of preferences fp which equals the number of units, while the weight of the j^{th} criterion $\mathbf{v_j}$ is calculated using the following equation:

$$\boldsymbol{v_j = \frac{n_j}{N}, N = \frac{n(n-1)}{2}} \tag{1}$$

wherein N is the number of comparisons and $\boldsymbol{n}$ is the number of criteria.

Analytic Hierarchy Process (Saaty's method)

The Analytic Hierarchy Process (AHP) is a method developed by Thomas L. Saaty in 1980. At present, it is one of the best-known and most frequently used methods of the multiple criteria decision-making (Saaty, 1991), (Vaidya, 2006).

The Saaty's method enables the decision-maker to take into account all the elements that affect the analysis result, as well as the relations between those elements and the intensity at which they affect each other. The decision-maker may thus break down a complex problem into less complex partial problems, subsequently apply relevant criteria to such partial problems, and arrange them in a hierarchy consisting of several levels, while each level contains several elements. The highest level contains only one element – the goal of the evaluation and analysis. This enables the decision-maker to better understand the problem that is being solved.

Fig. 1 shows a hierarchical structure of a complex task of a multiple criteria evaluation of several solution alternatives. In the task, *k* experts (Level 2) evaluate *n* criteria (Level 3), while each criterion consists of several sub-criteria (Level 4). The step of assessing and evaluating the individual alternatives is at Level 5.

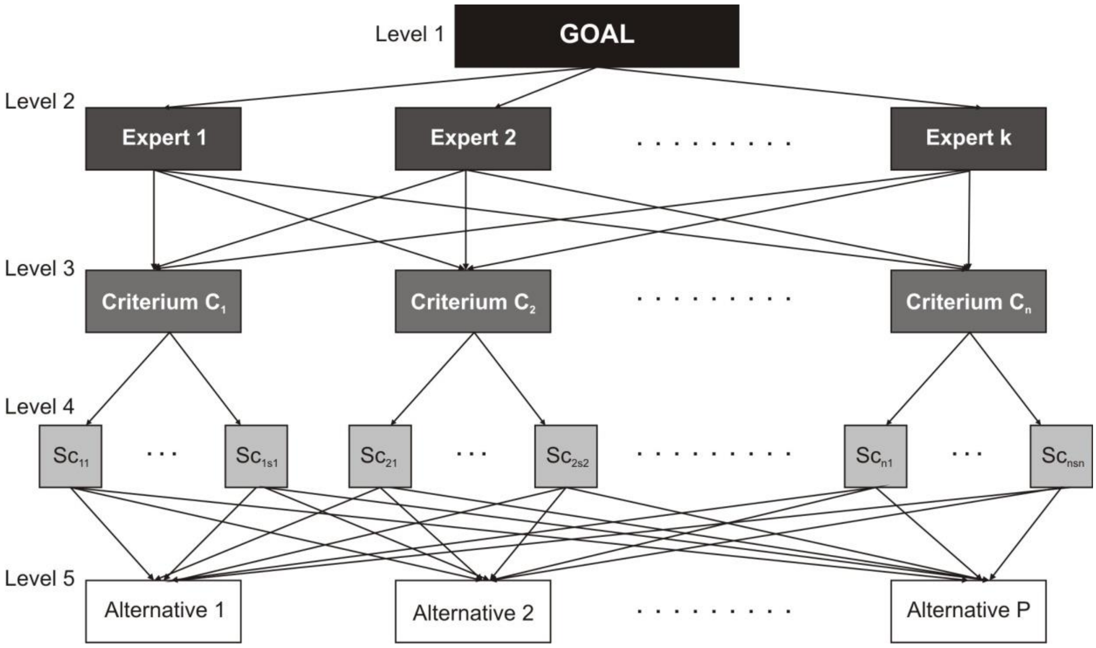

Fig.1 *Hierarchical structure – Saaty's method*
Source: (Authors)

The AHP method uses a pairwise comparison, in which the preference relations between the criteria are evaluated by comparing criteria against each other in pairs (Table 1). The pairwise comparison is carried out using the recommended underlying scale. Values 2, 4, 6 and 8 may be used for better differentiation of the degrees of preference of the criteria pairs.

Table 1 *Saaty's scale*

Number of points	Description
1	Criteria are of the same importance.
3	The first criterion is slightly more important than the second criterion.
5	The first criterion is fairly more important than the second criterion.
7	The first criterion is provably more important than the second criterion.
9	The first criterion is absolutely more important than the second criterion.

The Saaty's method is based on constructing the Saaty's matrix S. The matrix contains elements s_{ij} , i.e. the estimates of the ratios between the weights of criteria (how many times one criterion is more important than the other). If the i^{th} and j^{th} criteria are equally important, then $s_{ij} = 1$. If the i^{th} criterion is slightly preferred over the j^{th} criterion, then $s_{ij} = 3$. The diagonal of the Saaty's matrix always contains the values that equal 1:

$$\boldsymbol{S} = \begin{pmatrix} 1 & s_{12} \cdots & s_{1n} \\ 1/s_{12} & 1 \quad \cdots & s_{2n} \\ \vdots & & \\ 1/s_{1n} & 1/s_{2n} & 1 \end{pmatrix}. \tag{2}$$

In order to determine the weights of the applied criteria, it is necessary to know the eigenvector $\boldsymbol{w}$ that corresponds to the maximum eigenvalue $\lambda_{\max}$ of the Saaty's matrix, which may be calculated using the following set of equations:

$$(\boldsymbol{S} - \lambda_{max}\boldsymbol{I})\boldsymbol{w} = 0. \tag{3}$$

The weights of criteria are then calculated as follows:

$$v_i = \frac{w_i}{\|\boldsymbol{w}\|}, \ \ i = 1,2,\dots,n, \quad \|\boldsymbol{w}\| = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} w_i \tag{4}$$

Another simple and easy method how to calculate the weights of criteria from the known matrix S is to calculate the geometric mean of each line of the Saaty's matrix:

$$b_i = \sqrt[n]{\prod_{j=1}^{n} s_{ij}}\,; i,j = 1,2,\dots,n, \tag{5}$$

wherein s_{ij} is the degree of preference. The weight of the i^{th} criterion v_i is calculated by normalising value b_i using the following equation:

$$v_i = \frac{b_i}{\sum_{i=1}^{n} b_i}; \ i = 1,2,\dots,n, \tag{6}$$

so that the following condition is met:

$$\sum_{i=1}^{n} v_i = 1; \ v_i \geq 0. \tag{7}$$

In order to make the correct decision, it is necessary to respect the consistency requirement when assigning importance to the individual criteria. If the consistency requirement is not met, the evaluator should reconsider the ranking of the criteria and adjust the matrix of importance in order to increase its consistency. The analysis of the consistency of criteria is carried out using the consistency index CI:

$$CI = \frac{\lambda_{max} - n}{n-1}, \tag{8}$$

wherein λ_{max} is the highest eigenvalue of the Saaty's matrix and n is the number of criteria. According to (Šubrt, 2011, Fiala, 1997), as the consistency index approaches 0, the consistency between the criteria increases. The matrix is sufficiently consistent if $CI < 0.1$. Another method how to verify consistency is to identify the consistency ratio CR using the following equation:

$$CR = \frac{CI}{RI}, \tag{9}$$

wherein RI (random index) is the average consistency index. A matrix is regarded sufficiently consistent if the following condition is met: $\text{CR} < 0.1$

In the case of a large number of criteria, it is recommended that the method of gradual allocation of weights is applied. This method is based on grouping the criteria depending on the relationships between them.

3 RESULTS

There are many types of conveyor belts. When selecting the optimal conveyor belt, multiple factors should be taken into account; for example, the conveyor type, the working environment, the impact of the belt utilisation on the working environment, and the ecological impact. According to Cvekla and Dražan (Cvekla, Dražan, 1976), choosing the correct type of conveyor belt and understanding its properties has a decisive impact not only on its service life, but also on its construction and overall performance.

3.1 Data characteristics

Two evaluators (experts) from the Institute of Logistics and Transport of the Faculty of Mining, Ecology, Process Control and Geotechnologies, the Technical University of Košice, created the group of main criteria that are important in the process of selecting a conveyor belt.

Out of all the relevant factors, 5 main criteria (factors) were selected: Technology (C1); Economy (C2); Energy (C3); Ecology (C4); and Ergonomics (C5).

- Technology (C1) – it represents the weight of the conveyor belt and its capacity of transported materials;
- Economy (C2) – it includes the investment costs (price of 1m^2 of the conveyor belt) and the maintenance costs;
- Energy (C3) – it represents the electrical energy consumption during the conveyor belt utilisation;
- Ecology (C4) – it represents the impact of the conveyor belt on the pollution of the environment (air, soil, water); the area of the land used in the production of the conveyor belt and the recycling of the used conveyor belts;
- Ergonomics (C5) – the impact on the working environment is taken into account in terms of the pollution and noise, as well as the transport safety.

We want to emphasize that the considered criteria represent only basic (general) criteria. For a more detailed analysis, we recommend supplementing the main group of criteria with several sub-criteria, which are closely related to specific types of conveyor belts (more detailed information on technical parameters, operating costs, etc.). These sub-criteria will then represent specifics for individual conveyor belt in praxis.

3.2 Evaluation of the weights of criteria

The individual criteria were assigned weights, i.e. preferences, by applying the selected multiple criteria decision-making methods.

Scoring method (Method 1)
The weights were determined using the scale of 1 to 10 points, while the evaluation was based on the evaluator's preferences.

***Tab. 1** Determination of the weights of criteria using the scoring method*

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**Sum**
Expert 1						
Number of points	10	8	9	7	7	41
Normalised weight	0.24	0.20	0.22	0.17	0.17	1
Expert 2						
Position in the order	10	8	8	7	6	39
Normalised weight	0.26	0.21	0.21	0.18	0.14	1
Average normalised weight	0.250	0.205	0.215	0.175	0.155	

The overall evaluation presented by the two experts revealed that the weight of C1 criterion was 0.250; the weight of C2 criterion was 0.205; and the weight of C3 criterion was 0.215. The weight of C4 criterion was 0.175, while the weight of C5 criterion was the lowest – 0.155.

Best-to-worst method (Method 2)

The weights were determined based on the order of preference, i.e. the order of importance of the individual criteria – from the most important criterion to the least important criterion. The least important criterion was assigned weight 1, while the most important one was assigned the number of points that was identical to the number of criteria.

***Tab. 2** Determination of the weights of criteria using the best-to-worst method*

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**Sum**
Expert 1						
Position in the order	5	3	4	2	1	
Points	5	3	4	2	1	15
Normalised weight	0.333	0.200	0.267	0.133	0.067	1
Expert 2						
Position in the order	5	4	4	2	1	
Points	5	4	4	2	1	16
Normalised weight	0.313	0.250	0.250	0.125	0.062	1
Average normalised weight	0.322	0.225	0.259	0.129	0.065	1

The overall evaluation presented by the two experts revealed that the weight of C1 criterion was 0.332; the weight of C2 criterion was 0.225; and the weight of C3 criterion was 0.259. The weight of C4 criterion was 0.129, while the weight of C5 criterion was the lowest – 0.065.

Pairwise comparison of criteria (Method 3)

The experts were gradually comparing the pairs of criteria. If C1 criterion was more important than C2 criterion, then value 1 was entered in the table of preferences, otherwise value 0 was assigned. The weights of criteria were calculated on the basis of the number of preferences of the given criterion and the number of the pairwise comparisons.

***Tab. 3** Determination of the weights of criteria using the pairwise comparison – Expert 1*
Note: Weights were calculated using equation (10)*

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**Number of preferences**	**Weight**	**Weight***
C1	-	1	1	1	1	4	0.40	0.333
C2	0	-	1	1	1	3	0.30	0.267
C3	0	0	-	1	1	2	0.20	0.200
C4	0	0	0	-	1	1	0.10	0.133
C5	0	0	0	0	-	0	0	0.067
Sum						10	1	1

If the number of preferences of a certain criterion is zero, it is recommended that the weight is calculated using the adjusted equation:

$$\boldsymbol{v_j} = \frac{\boldsymbol{n_j+1}}{\boldsymbol{N+n}}. \tag{10}$$

An analogical procedure was applied by Expert 2 to determine the weights of criteria (Table 4).

***Tab. 4** Determination of the weights of criteria using the pairwise comparison – Expert 2*
Note: Weights were calculated using equation (10)*

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**Number of preferences**	**Weight**	**Weight***
C1	-	1	1	1	1	4	0.40	0.333
C2	0	-	0	1	1	2	0.20	0.200
C3	0	1	-	1	1	3	0.30	0.267
C4	0	0	0	-	1	1	0.10	0.133
C5	0	0	0	0	-	0	0	0.067
Sum						10	1	1

The overall evaluation presented by the two experts revealed that the weight of C1 criterion was 0.333; the weight of C2 criterion was 0.234; and the weight of C3 criterion was 0.234. The weight of C4 criterion was 0.133, while the weight of C5 criterion was the lowest – 0.067.

Saaty's method (Method 4)

The resulting matrix for the evaluation of the group of criteria by Expert 1 is presented in Table 5.

***Tab. 5** Determination of the weights of criteria using the Saaty's method (Saaty's matrix) – Expert 1*

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**
C1	1	5	5	9	7
C2	1/5	1	3	7	5
C3	1/5	1/3	1	5	3
C4	1/9	1/7	1/5	1	1/3
C5	1/7	1/5	1/3	3	1

The weights of the individual criteria were calculated by applying the exact approach, which is based on the calculation of eigenvalues and eigenvectors of the Saaty's matrix in the Matlab environment. The maximum eigenvalue of the criteria that corresponded to the Saaty's matrix was $\lambda_{\max} = 5{,}3672$. The eigenvector of the group criteria that corresponded to the maximum value was

$$\boldsymbol{w_1} = (0.9030, 0.3673, 0.1943, 0.0512, 0.0964\,)^T.$$

The eigenvector whose components determined the weights of the individual criteria was identified by transforming the eigenvector of the matrix into a normalised eigenvector, as follows

$$\boldsymbol{v_1} = (0.5601, 0.2278, 0.1205, 0.0318, 0.0598)^T.$$

An analogical procedure was applied to calculate the values of the weights of the group of criteria by both Experts (Table 6).

Tab. 6 *Determination of the weights of criteria using the scoring method*

Criterion	**C1**	**C2**	**C3**	**C4**	**C5**	**Sum**
Expert 1						
Normalised weight	0.560	0.228	0.121	0.032	0.060	1
Expert 2						
Normalised weight	0.489	0.209	0.194	0.070	0.038	1
Average normalised weight	0.525	0.219	0.158	0.051	0.048	1

The consistency of all Saaty's matrices was verified and eventually found sufficient. The results indicated that *C1* criterion had the highest average weight of 0.525, while the weight of *C2* criterion was 0.219 and the weight of C3 criterion was 0.158. The weight of C4 criterion was assigned the weight of 0.051, while C5 criterion had the lowest weight – 0.048.

Table 7 contains the resulting weights of criteria, which were determined as an arithmetic mean of the weights identified by applying the individual methods.

Tab. 7 *Determination of the resulting average weights of criteria*

Criterion	**Method 1**	**Method 2**	**Method 3**	**Method 4**	**Average weight**
C1	0.250	0.322	0.333	0.525	0.393
C2	0.205	0.225	0.234	0.219	0.221
C3	0.215	0.259	0.234	0.158	0.217
C4	0.175	0.129	0.133	0.051	0.122
C5	0.155	0.065	0.067	0.148	0.109

4 CONCLUSIONS

The article deals with the use of multi-criteria decision-making methods in defining the weights of the main criteria important for the selection of transport belts from a technical, energy, economic, ecological and ergonomic aspect. The results of the evaluation analysis showed that the Technology (39.3%) criterion had the highest preference, followed by the Economy (22.1%) and Energy (21.7%) criteria, while both these criteria had comparable average weights. The resulting weights of the criteria are always affected not only by a selected method, but also by the person who determines the weights by applying the selected method. The reliability of the obtained results is higher when more methods are applied (the resulting weights may be determined as an arithmetic mean of the weights obtained through the individual methods) or when more evaluators (experts) are engaged. They may work independently or as a team (the resulting weights may be determined as an arithmetic mean of the weights determined by the individual evaluators).

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