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# USING AHP METHOD AT THE DETERMINATION OF THE OPTIMAL SELECTION CRITERIA OF CONVEYOR BELTS

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*ABSTRACT: Multicriteria decision-making methods play nowadays an increasingly important role in many decision-making situations. Such a decision could be e.g. the selection of a supplier, the selection of an employer, the choice of a car brand, or a home computer. Apart from common decisions there are also such decisions, which have a key influence on the whole life of an individual or on the life of the society. Almost no our decision is influenced by one criterion only. Therefore an important step of the decision-making is the determination of the adequate criteria of the decision-making and consequently the determination of their preferences, degree of their importance, or importance. Multicriteria decision-making methods are applied in many areas, among which belong also transport and belt transport. The goal of this article is to define proper factors, criteria, which are important at the selection of optimal conveyor belts, and to set their importance by the use of the AHP method (the Saaty method).*
*KEYWORDS: multicriteria decision-making, AHP method, criteria, conveyor belt*

## INTRODUCTION

*Transport is an important logistic activity in the production systems influencing fluency of the production process. The optimization of transport systems enables the decrease of the total costs for a product by up to 70%. For the given reason the proper selection of the transport system and its design features for the existing operational conditions is very important. The belt transport system belongs to high-efficient and economical, as well as energy undemanding continual transport systems. The belt transport has a very wide use nowadays. Its advantage compared to other transport means is mainly in the performance and efficiency of its operation and maintenance, whereby the conveyor belt is its most important and most expensive part [6].*

*Figure 1. Conveyor belt with rubber-textile transport line*

*The conveyor belt is an enclosed element running around end pulleys and at the same time it is a carrying and drawing part of the conveyor line. The only exception is a cable belt conveyor, where the conveyor is only a carrying part and the function of a drawing part is overtaken by a cable. The conveyor belt transmits friction arising at its motion and it fulfills the function of the transport of material, loads or persons [6]. The typical use of the conveyor belts is for gravel sands, limestone quarries, cement factories, heat power plants, mining industry, raw material excavation and its treatment, stock-piles, docks, processing industry (Figure 1).*

## METHODS

*Multicriteria decision-making methods introduce decision-making problems, at which the decision-making effects are considered from the point of view of several criteria. At the decision-making problems it is necessary to take into consideration all elements, which influence the result of the analysis, the relation among them and the intensity by which they interact. One of the ways how* *to illustrate these facts is the creation of a certain hierarchical structure. By this notion we mean a linear structure, containing several levels, where each of them contains several elements [2, 4]. The highest level contains one element only and it is the goal of the evaluation and analysis (Figure 2, Table 1).*

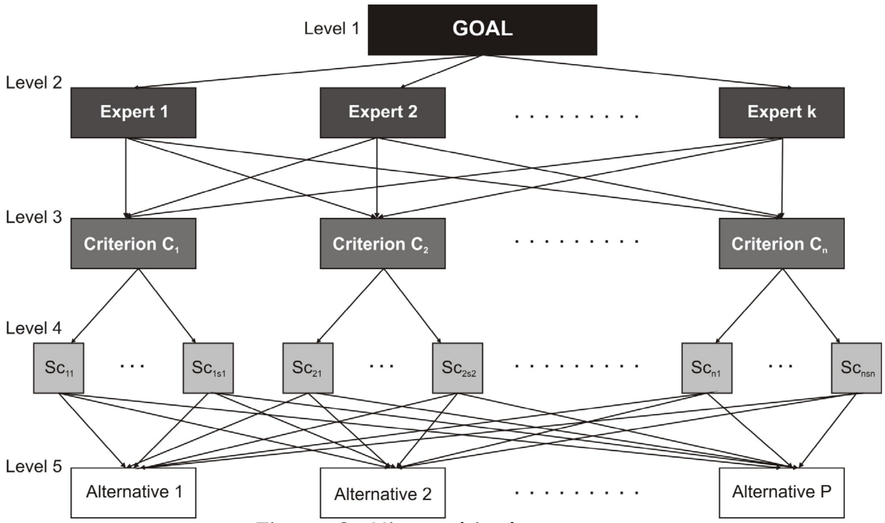


*Figure 2. Hierarchical structure*

*Table 1. Hierarchical structure of the decision-making task*

| Level | Characteristics |
|---|---|
| 1 | Defined goal of the evaluation and analysis |
| 2 | Experts who participate in the evaluation |
| 3 | Criteria of the evaluation |
| 4 | Division of the criteria into subcriteria |
| 5 | Review of the alternatives |

*In Figure 2 there is a hierarchical structure of a more complex task of a multicriteria evaluation of p alternatives (Level 5), which contains five levels [2]. In this task k experts participate in the evaluation (Level 2), who evaluate n criteria (Level 3). Each criterion can consist of several subcriteria (Level 4).*

*One of the methods for the analysis of the decision-making problems by means of a hierarchical structure is an Analytic Hierarchy Process (AHP), designed by prof. Saaty in 1980. The AHP method (so called Saaty method) uses the method of a pair comparison by which the preference relations of the pairs of single criteria are detected [2, 3, 4, 7, 8]. Pair comparison is performed by a recommended basic rating scale (Table 2).*

*Table 2. The Saaty's scale for pairwise comparisons*

| Intensity of importance | Characteristics |
|---|---|
| 1 | Criterions are equally important. |
| 3 | First criterion slightly more important than the other one. |
| 5 | First criterion is rather more important than the other one. |
| 7 | First criterion is demonstrably more important than the other one. |
| 9 | First criterion is absolutely more important than the other one. |

*Values 2, 4, 6, 8 can be used for a finer distinction of the size of pair criteria preferences.*

*The starting point for the application of the Saaty method is the construction of the so called Saaty matrix S, which elements $s_{ij}$ represent the estimates of the share of importance of criteria (how many times one criterion is more important than the other one). If an i-th and a j-th criterion are equal, then $s_{ij} = 1$. If the j-th criterion is slightly preferred to j-th criterion, then $s_{ij} = 3$. On the diagonal of the Saaty matrix the values always equal 1:*

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

*To define the significance of the criteria under consideration we need to know the eigenvector w corresponding to the maximum eigenvalues $\lambda_{\max}$ of the Saaty matrix S, which we find by the solving of a system of equations [3,4,5]*

$$(S - \lambda_{max} I) w = 0 \ . \qquad (2)$$

*We define the criteria significance by the relation*

$$v_i = \frac{w_i}{\|w\|}, \quad i = 1,2,\ldots,n, \quad \|w\| = \sum_{i=1}^{n} w_i \ . \qquad (3)$$

*Further simple and undemanding way of the criteria significance defining from the set matrix S lies in the calculation of the geometrical mean of each line of the Saaty matrix S [2, 3,4].*

*The requirement for the right decision is to observe the consistency rule at the allocation of the importance to single criteria. In case of non-fulfillment of the condition of consistency it is appropriate that the evaluating subject reviewed his/her criteria evaluation and modified the matrix of significance, so that its consistency has increased.*

*The criteria consistency analysis is done by means of the consistency index CI:*

$$CI = \frac{\lambda_{max} - n}{n - 1}, \qquad (4)$$

*where n is a number of criteria. The more consistency index approaches zero, the bigger consistency between the criteria is [3, 4, 8]. The matrix is sufficiently consistent if CI < 0.1. In that case the result is sufficiently accurate and it does not show any need for corrections in comparisons.*

*At the large number of criteria it is recommended to use the method of a gradual setup of importance, which is based on the idea of grouping the criteria into groups by their affinity.*

*The final importance is always influenced not only by the selection of the method, but also by the subject, which sets the importance by means of the selected method. The reliability of the gained results increases if a larger number of methods is used (resultant importance can be determined as an arithmetical mean of importance gained by single methods) or by a use of a larger number of evaluators (experts), who can work independently or in a team (resultant importance can be set as an arithmetical mean of importance determined by single evaluators).*

## MATERIAL AND METHODS

*The properties of conveyor belts influence the fluency of the transport process mainly at the continuous transport. It is an enclosed element running around end pulleys, which during its rotation / cycle fulfills the function of carrying of material or persons on the transport length and at the same time it fulfills the function of the drawing part and it transmits all friction arising at its motion [6].*

*In case of a malfunction resulting from a failure of transport belts due to their bad utility qualities or underrating of machinery or rubber maintenance the enterprises have big financial losses due to stoppages. It results from the given facts that the right selection of the proper type of the conveyor belt from different aspects before its installation into operation is important.*

*The selection of the relevant criteria is a very important step of the decision-making. Of a large number of criteria five main group criteria (Table 3) and 11 subcriteria of optimum selection of conveyor belts (Table 4) were chosen.*

*Table 3. Main criteria of the optimum selection of conveyor belts*

| Criterion | Characteristics |
|---|---|
| Technology | represents weight of the conveyor belt and the capacity of the material transport |
| Economy | includes capital costs (prize of 1m$^2$ of the conveyor belt) and maintenance costs |
| Energy | represents electrical energy consumption during the operation of the conveyor belt |
| Ecology | represents the influence of the conveyor belt on the environment pollution (air, soil, water), soil occupation caused by the conveyor belt construction and the recycling of the used-up conveyor belts |
| Ergonomy | regards the influence on the working environment from the point of view of pollution of environment and noise as well as transport safety |

*Table 4. Main criteria and subcriteria of the selection of an optimum conveyor belt*

| Criterion | | Subcriterion | |
|---|---|---|---|
| C1 | Technology | SC1 | Weight of the conveyor belt |
| | | SC2 | Transport capacity |
| C2 | Economy | SC3 | Price of the belt |
| | | SC4 | Maintenance costs |
| C3 | Energy | SC5 | Electric energy consumption |
| C4 | Ecology | SC6 | Environment pollution |
| | | SC7 | Soil occupation |
| | | SC8 | Recycling of used up conveyor belts |
| C5 | Ergonomy | SC9 | Working environment pollution |
| | | SC10 | Noise |
| | | SC11 | Transport safety |

*The hierarchical structure of a multicriteria analysis for the optimum selection of a conveyor belt in case of the evaluation of three experts is in Figure 3.*

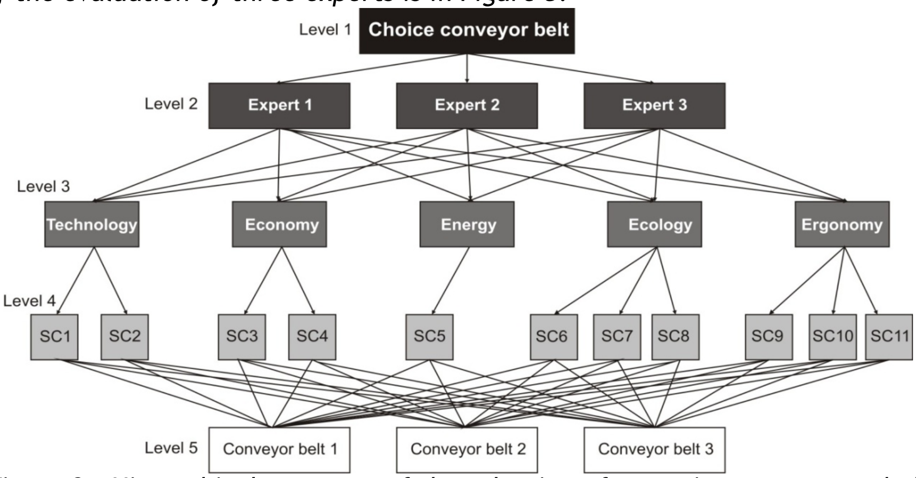


*Figure 3. Hierarchical structure of the selection of an optimum conveyor belt*

*Three experts from the Logistics Institute of Industry and Transport of the Faculty of Mining, Ecology, Process Control and Geotechnologies of the Technical University of Košice participated in the evaluation of the criteria preferences [1]. The importance of single groups of criteria was calculated by an exact approach, based on the calculation of the eigenvalues and eigenvectors of the Saaty matrix. The resultant matrix of the evaluation of the group of criteria by the first expert is stated in Table 5.*

*Table 5. Resultant Saaty matrix of the criteria evaluation – Expert 1*

| | C 1 | C 2 | C 3 | C 4 | C 5 |
|---|---|---|---|---|---|
| **C 1** | 1 | 5 | 5 | 9 | 7 |
| **C 2** | 1/5 | 1 | 3 | 5 | 5 |
| **C 3** | 1/5 | 1/3 | 1 | 3 | 3 |
| **C 4** | 1/9 | 1/5 | 1/3 | 1 | 3 |
| **C 5** | 1/7 | 1/5 | 1/3 | 1/3 | 1 |

*We have gained eigenvalues of the Saaty matrix by solving the equation*

$$\begin{vmatrix} 1-\lambda & 5 & 5 & 9 & 7 \\ 1/5 & 1-\lambda & 3 & 5 & 5 \\ 1/5 & 1/3 & 1-\lambda & 3 & 3 \\ 1/9 & 1/5 & 1/3 & 1-\lambda & 3 \\ 1/7 & 1/5 & 1/3 & 1/3 & 1-\lambda \end{vmatrix} = 0 \cdot$$

*The maximum eigenvalues corresponding the Saaty matrix is $\lambda_{max} = 5.351$. It results from the results of the first expert evaluation that the criterion Technology has the biggest importance 0.5646, the criterion Economy 0.2207 and Energy 0.1130. To the criterion Ergonomy belongs the importance of 0.0636 and the lowest importance of 0.0381 is allocated to the criterion Ecology. The results of the importance of criteria of the Expert 1 are in Table 6.*

*Table 6. Resultant importance of main criteria – Expert 1*

| Criterion | | Importance | Importance[%] | Rank |
|---|---|---|---|---|
| C1 | Technology | 0.5646 | 56.46% | **1.** |
| C2 | Economy | 0.2207 | 22.07% | **2.** |
| C3 | Energy | 0.1130 | 11.30% | **3.** |
| C4 | Ecology | 0.0381 | 3.81% | **5.** |
| C5 | Ergonomy | 0.0636 | 6.36% | **4.** |

*Table 7. Resultant values of criteria importance*

| Criterion | Expert 1 | Expert 2 | Expert 3 | Average Importance | Importance [%] | Rank |
|---|---|---|---|---|---|---|
| C1 | 0.5646 | 0.5601 | 0.5054 | 0.5434 | 54.34% | **1.** |
| C2 | 0.2207 | 0.2278 | 0.2694 | 0.2393 | 23.93% | **2.** |
| C3 | 0.1130 | 0.1205 | 0.1190 | 0.1175 | 11.75% | **3.** |
| C4 | 0.0381 | 0.0318 | 0.0576 | 0.0425 | 4.25% | **5.** |
| C5 | 0.0636 | 0.0598 | 0.0486 | 0.0573 | 5.73% | **4.** |

*We have done the analysis of the consistency of criteria by means of a consistency index CI. It results from the final value of the index CI = 0.0878, that the conditions of consistency of the Saaty matrix are fulfilled (CI < 0.1), and so the Expert 1 has a clear idea of the criteria and the criteria do not contradict each other. The analogical way was used to calculate the value of importance of the group of criteria from further two experts (Table 7).*

*The consistency of all Saaty matrixes was certified and we can assume that the consistency of the matrixes is adequate. It results from the total evaluation of all experts, that the criterion Technology has a importance of 0.5434, the criterion Economy 0.2393 and Energy 0.1175. The criterion Ecology has been allocated the importance of 0.0425 and the criterion Ergonomy has importance of 0.0573.*

*The consistency of the statements of the evaluating experts was certified by means of Kendall's index of rank concordance, for which the relation*

$$w = \frac{12\sum_{j=1}^{m}\left[\sum_{k=1}^{p}\alpha_{kj} - \frac{p(m+1)}{2}\right]^2}{p^2\left(m^3 - m\right)}, \quad (5)$$

*is valid, where m is a number of criteria, p is a number of experts and $\alpha_{kj}$ is a number allocated by j-th expert to a j-th criterion. If a low index of consistency is reached (less than 0.5), it is recommended that the experts mutually share their views of the evaluation of the significance of single criteria and perform a new evaluation. In our case $w = 0.965$, this attests to an excellent consistency of the expert statements.*

*In the following step the importance of subcriteria in single groups were calculated (Table 8 and Table 9).*

*Table 8.Resultant matrix of the evaluation of subcriteria SC1-SC4*

| Criterion C1 | | Importance | Criterion C2 | | Importance |
|---|---|---|---|---|---|
| SC1 | Weight of conveyor belt | 0.1250 | SC3 | Belt price | 0.6667 |
| SC2 | Transport capacity | 0.8750 | SC4 | Maintenance costs | 0.3333 |

*Table 9. Resultant matrix of the evaluation of subcriteria SC6-SC11*

| Criterion C4 | | Importance | Criterion C5 | | Importance |
|---|---|---|---|---|---|
| SC6 | Environment pollution | 0.6491 | SC9 | Working environment pollution | 0.0546 |
| SC7 | Land occupation | 0.0719 | SC10 | Noise | 0.1734 |
| SC8 | Recycling | 0.2790 | SC11 | Safety | 0.7720 |

*The third group criterion Energy contains one criterion only, which is the electric Energy consumption SC5, whose importance is 0.119. The consistency of all Saaty matrixes was verified again and also in this case the consistency of the matrixes was sufficient. The resultant values of importance of all considered subcriteria were gained by multiplying their importance by the relevant group criteria (Table 10).*

*Table 10. Resultant values of criteria and subcriteria importance*

| Criterion | Subcriteria | | Normed importance | Normed importance[%] | Rank |
|---|---|---|---|---|---|
| C1 | SC1 | Weight of conveyor belt | 0.0679 | 6.79% | 5. |
| | SC2 | Transport capacity | 0.4755 | 47.55% | 1. |
| C2 | SC3 | Belt price | 0.1595 | 15.95% | 2. |
| | SC4 | Maintenance costs | 0.0798 | 7.98% | 4. |
| C3 | SC5 | Energy consumption | 0.1175 | 11.75% | 3. |
| C4 | SC6 | Environment pollution | 0.0276 | 2.76% | 7. |
| | SC7 | Land occupation | 0.0030 | 0.30% | 11. |
| | SC8 | Recycling | 0.0119 | 1.19% | 8. |
| C5 | SC9 | Working environment pollution | 0.0031 | 0.31% | 10. |
| | SC10 | Noise | 0.0099 | 0.99% | 9. |
| | SC11 | Safety | 0.0442 | 4.42% | 6. |

*It results from the analysis and the evaluation of the criteria and subcriteria that the biggest preferences go to the criterion Transport capacity (0.4755), the Price of the conveyor belt (0.1595) and Energy consumption (0.1175). Further important group of criteria consists of Maintenance costs (0.0798), Weight of conveyor belt (0.0679), Safety of transport and handling with transport belts (0.0442). The lowest importance at the selection of the conveyor belt is put to the Working environment pollution (0.0031) and Land occupation (0.0030).*

## CONCLUSIONS

*The main goal of the application of multicriteria decision-making methods is that all obstacles the decision-maker has at the solving of the decision-making problem were consistently managed. In practice the emphasis is often put on the selection of the best alternative, the best solution at the large number of information. Analytical hierarchical process belongs to frequently used multicriterial methods, which are used in more complex decision-making tasks. The method can be used not only for the setting of preferences among criteria, but also among variants.*

*The methods of multicriteria decision-making play at present an increasingly important role also at the selection of the proper transport technology or engineering transport parts. The important step within the decision-making process at the selection of the proper design was the setting of five basic criteria (Technology, Economy, Energy, Ecology, Ergonomy) and consequently 11 subcriteria.*

*It results from the analysis and evaluation of the selected criteria and subcriteria, that the criterion transport capacity, belt price and electric energy consumption have the biggest preferences. Further important group of criteria at the selection of conveyor belt is made of the costs of its maintenance, weight of conveyor belt and the safety of transport and handling with transport belts. It results from the evaluation that the lowest importance at the selection of the optimum conveyor belt is put to the environment pollution and land occupation.*

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