Multicriterial assessment of the raw material transport

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The interplant transport of mineral raw materials plays an important role in the mining process carried out in mining companies. An important part of this transport is a belt conveyor, utilised in underground mining as well as in open pits. The article is focused on suggestions regarding modifications of belt conveyor construction parameters which can contribute to optimization and innovation within the mineral raw materials transportation. Importance, or the effect, the strength of the impact of modifications of the selected parameters on the system optimization is assessed by the method of analytic hierarchy process. The article contains the complex knowledge obtained from the analysis of the belt conveyor system used in the limestone excavation and processing.

Key words: *belt conveyor, multicriterial decision, AHP method, criterion*

Introduction

Belt conveyor is the most economical and efficient material handling equipment. Belt conveyors have attained a dominant position in transporting bulk materials due to a number of inherent advantages like the economy and safety of operation, reliability, versatility and practically unlimited range of capacities [Gupta, 2013]. Belt conveyor is widely used in mine, coal, chemical industry, ports and power plants [Cun, 2012]. Lihua and Lin (2011) study the operation process of coal handling system in thermal power plant. Analyze technical characteristics of coal handling system and operating characteristics of the relevant machinery and equipment. The use of belt conveyors are many associated risks and negative impacts especially on the environment [Grujic et al, 2011]. Despite the existence of risk is a system of conveyors the most reliable and best performing.

Current experience from the operation of raw materials transport gives rise to the effort pursuing the improvement of the existing methods of bulk materials transport. Reduction of the total costs of the belt conveyor operation is solved by [Antoniak, 2003], whereas the main intention was to reduce the power consumption of the belt conveyor drive and increase the service life of the conveyor belt and other functional parts of the conveyor. Similar issues focused on power life of the transport equipment is collected [Bigos et al, 2010]. The issue of optimal conveyor belt lifetime by means of the renewal theory is solved by [Marasova and Pavliskova, 2004, Pavliskova, 2007]. Optimization of the continual transport parameters is dealt with by [Bindzar and Malindzak, 2008a]. During design belt conveyors can be applied logistic approach by Bindzar and Malindzak (2008b). Dynamic model of the belt conveyor is dealt by Harrison (2008). This dynamic model enables selection of dimensions and operating parameters of the belt conveyor in order to choose the size and the shape of the transport route.

Material and methods

Analytical Hierarchy Process (AHP) is a method that has been proposed by Professor Thomas L. Saaty in 1980. It is now one of the most famous and widely used methods of multicriteria decision making. Allows researcher to take into account all the elements that affect the analysis result, their mutual relations and the intensity of their mutual influence. Researcher can thus divide complex problems into smaller problems character, assign them to the criteria and to members of their hierarchy that contains several levels, each of which incorporates several elements. The highest level contains only one element – goal of evaluation and analysis. The AHP method makes it is possible to select the best method in a more scientific manner that preserves integrity and objectivity. The model is transparent and easy to comprehend and apply by the decision maker. For selecting a mining method, the AHP method is unique in its identification of multiple attributes, minimal data requirement and minimal time consumption [Ataei et al, 2008]. Duc (2006) states that in

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comparison with other methods used for determination of priorities, the AHP method is better, as it solves also making controversial decisions and determines measures in case of discrepancies between the decisions made by respondents.

Rohacova and Markova (2009) present the advantages and disadvantages of applying the AHP method and its possible use in the logistics. Andrejiova et al (2013) has used AHP method in the determination of the optimal selection criteria of conveyor belts and she has defined the weight of main criteria important for the selection of conveyor belts from the technical, energy, economic, ecological and ergonomic aspect [Andrejiova et al, 2012].

The AHP method uses the method of a pair comparison by which the preference relations of the pairs of single criteria are detected [Saaty, 1980]. Pair comparison is performed by a recommended basic rating scale (Tab. 1).

Tab. 1. The Saaty's scale for pairwise comparisons.

Intensity of importance	Characteristics
1	Criteria 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. Application of the AHP method begins with the creation of the so-called Saaty matrix S, where elements s_{ij} represent assumptions of the proportions of the weights of the criteria (how many times is one criterion more important than the other one). If the i and j criteria are equal, the value $s_{ij} = 1$. With slight preference of the i criterion to the j criterion, the value $s_{ij} = 3$. Saaty matrix is a square matrix and the elements outside the main diagonal valid $s_{ij} = 1/s_{ji}$. On the Saaty matrix diagonal the values always equal 1.

Weights of individual criteria groups are determined also by applying the exact approach based on calculation of eigenvalues and eigenvectors of the Saaty matrix. Another possibility how to identify the criteria weights out of the given matrix is the calculation of the geometric average b_i of each line of the Saaty matrix

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

where s_{ij} means intensity of preferences, n number of criteria. The weight of the i criterion v_i is expressed by normalization of the value b_i according to the relation

$$v_i = \frac{b_i}{\sum_{i=1}^{n} b_i}, \; for \; i = 1,2,\cdots,n, \; while \; \sum_{i=1}^{n} v_i = 1. \tag{2}$$

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 are 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).

New approach for assigning criteria weighting has been described by Bitrafanand and Ataei (2004). They proposed two different methods of fuzzy multiple criteria decision making to solve the problem of mining method selection.

The research is carried out using all available knowledge obtained from the belt transport analysis, which was preceded by identification of the belt conveyor system. Generally possible changes of basic structural elements of belt conveyors, in terms of their optimization, are depicted in Figure 1. These fundamental structural elements (parameters) serve as the basis for deduction of the main criteria and additional subcriteria are deducted from their other components.

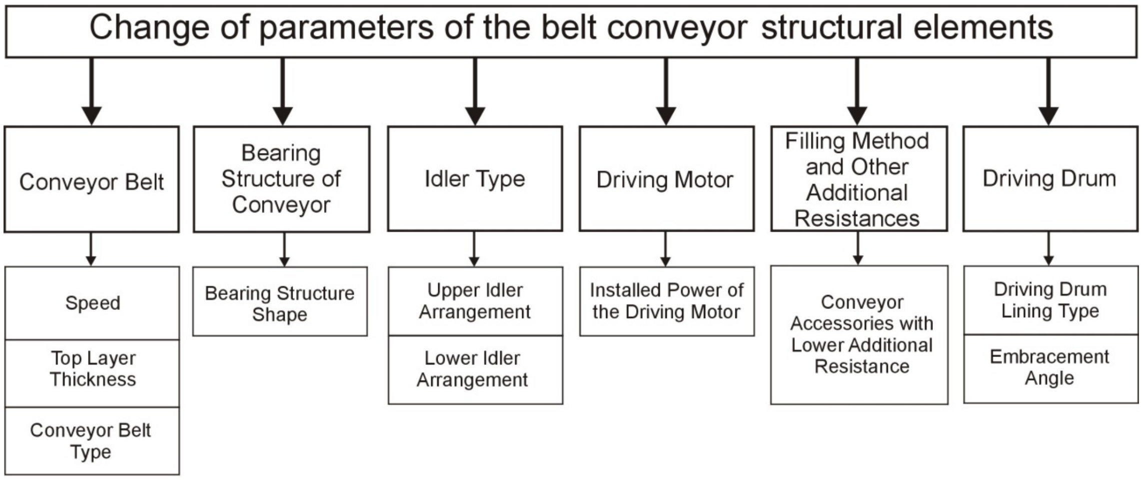

Fig. 1. Visualization of possible changes in belt conveyor parameters.

Increasing the efficiency by changing the logistic, structural, or specific parameters of the belt conveyors represents only one of the possible solutions [Bindzar, 2010]. Another solution is reached by simulation experiments which can simulate behaviour of the real system and thus obtain the relevant and more detailed information in order to make the transport system more efficient [Mantic et al, 2008; Saderova and Kacmary, 2012].

Results and discussion

The AHP method of weight determination was used as the decisive method to identify the importance of changes of the assessed belt transport. The selection of the relevant criteria is a very important step of the decision-making. The main criteria are shown in Table 2: Conveyor Belt (C1), Bearing Structure of the Conveyor (C2), Idler Type (C3), Driving Motor (C4), Filling Method and Other Additional Resistances (C5) and Driving Drum (C6).

Tab. 2. Main criteria and subcriteria.

Criteria		Subcriteria	
C1	**Conveyor Belt**	SC1 SC2 SC3	Speed Top Layers Thickness Conveyor Belt Type
C2	**Bearing Structure of the Conveyor**	SC4	Bearing Structure Shape
C3	**Idler Type**	SC5 SC6	Upper Idler Arrangement Lower Idler Arrangement
C4	**Driving Motor**	SC7	Installed Power of the Driving Motor
C5	**Filling Method and Other Additional Resistances**	SC8	Conveyor Accessories with Lower Additional Resistance
C6	**Driving Drum**	SC9 SC10	Driving Drum Lining Type Embracement Angle

The significance of the criteria is determined by assigning weights to the estimates of the individual criteria. The preferred solution is the one that will reduce the total resistance to motion, the necessary power input of drives of individual belt conveyors in connection with the complexity of their application while implementing the changes of the existing transport system.

Two 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.

Identification of the resulting normalized weights of the main criteria

In this work, the weights of individual criteria groups were identified using the normalized geometric average of the Saaty matrix lines. The resulting Saaty matrix S_1 evaluation criteria of the first expert, together with the calculated weights are shown in Table 3.

Tab. 3. Weights Identification -Expert 1.

	C1	C2	C3	C4	C5	C6	b_i	v_i	Order
C1	1	4	4	1/5	1/5	3	1.115	**0.125**	3.
C2	1/4	1	1	1/7	1/5	1/3	0.365	**0.041**	5.
C3	1/4	1	1	1/7	1/5	1/3	0.365	**0.041**	5.
C4	5	7	7	1	5	5	4.277	**0.478**	1.
C5	5	5	5	1/5	1	3	2.054	**0.230**	2.
C6	1/3	3	3	1/5	1/3	1	0.765	**0.086**	4.

The results show that the Driving Motor (C4) has the strongest weight of 0.478 and the second one is the Filling Method and Other Additional Resistances (C5) with the weight of 0.230. The lowest importance is in Idler Type (C3) and Bearing Structure of the Conveyor (C2) with the weight of 0.041.

The requirement for the right decision is to observe the consistency rule at the allocation of the importance of single criteria. In case of non-fulfillment of the condition of consistency, it is appropriate that the evaluating subject reviewed the criteria evaluation and modified the matrix of significance, so that its consistency has increased. Consistence will be assessed by calculating its consistence index CI and using the so-called consistence ratio CR, for which it applies that

$$CI = \frac{\lambda_{\max} - n}{n-1}, CR = \frac{CI}{RI}, \tag{3}$$

where $\lambda_{\max}$ is the highest own figure of the Saaty matrix, n is the number of criteria and RI (Random Index) is the average consistence index, whose values depend on the number of criteria. The matrix is sufficiently consistent, if $CI \le 0.1$ or $CR \le 0.1$. In that case the result is sufficiently accurate and it does not show any need for corrections in comparisons.

The maximum eigenvalue is obtained by solving the equation

$$(S - \lambda_{\max} I)w = 0, \tag{4}$$

where w eigenvector corresponding to the maximum eigenvalues $\lambda_{\max}$ of the Saaty matrix S_1. The maximum eigenvalue is $\lambda_{\max} = 6.597$. The values of consistency index and consistency ratio are $CI = 0.119$ and $CR = 0.096$. On the basis of consistence index values we can regard the Saaty matrix S_1 as sufficiently consistent and evaluations of individual criteria are not in mutual contradiction.

Applying the analogical method, we calculated the weights in case of Expert 2. The criteria weights calculation is shown in Table 4.

Tab. 4. Weights Identification-Expert 2.

	C1	C2	C3	C4	C5	C6	b_i	v_i	Order
C1	1	5	5	1/5	1/5	2	1.123	**0.130**	3.
C2	1/5	1	1	1/7	1/9	1/3	0.319	**0.037**	6.
C3	1/5	1	1	1/5	1/5	1/5	0.342	**0.040**	5.
C4	5	7	5	1	3	3	3.411	**0.395**	1.
C5	5	9	5	1/3	1	3	2.466	**0.286**	2.
C6	1/2	3	5	1/3	1/3	1	0.970	**0.112**	4.

The results show that the Driving Motor (C4) has the strongest weight of 0.395 and the second one is the Filling Method and Other Additional Resistances (C5) with the weight of 0.256. The lowest weight is in case of Bearing Structure of the Conveyor (C2) with the weight of 0.037.

The maximum eigenvalue of the Saaty matrix S_2 is $\lambda_{\max} = 6.580$. For the consistence index values it applies $CI = 0.116$ and $CR = 0.094$. The results of the consistence indexes show that the Saaty matrix S_2

can also in this case be regarded as sufficiently consistent-assessment of individual criteria are not in mutual contradiction.

Average weight values obtained from both experts are shown in Table 5.

Tab. 5. Average Weight Results.

Criterion		Weight	Order
Conveyor Belt	C1	0.127	3.
Bearing Structure of the Conveyor	C2	0.039	6.
Idler Type	C3	0.040	5.
Driving Motor	C4	0.437	1.
Filling Method and Other Additional Resistances	C5	0.258	2.
Driving Drum	C6	0.099	4.

It followed from the order of average weights of the main criteria with regard to the decision making on the used method of belt conveyor innovation that the most important criterion is the Driving Motor (C4) The second most important criterion is the Filling Method and Additional Resistances (C5) that include also resistance from overcoming the transport altitude. Its change will cause the remarkable change of the total resistance to motion. The third place belongs to the Conveyor Belt (C1) criterion, as its weight, depending on the type and strength, changes the value of total resistances and necessary power output of drives. The fourth criterion is the Driving Drum (C6) which is in the calculation, carried out in compliance with the standard, represented by the values of friction coefficient μ and the embracement angle α. The next to the last criterion is the Idler Type (C3) which changes the value of the transversal cross-section and subsequently the actual transported quantity. The last criterion is the Bearing Structure of the Conveyor (C2).

Generally determined order of priority of individual structural elements of the belt conveyor should be individually applied to innovation of each belt conveyor. The ratio of resistances affecting along the entire conveyor length, resistances affecting at certain locations and in certain version is different.

Determination of the resulting standardized weights of subcriteria

In the following year, we will apply a similar procedure when calculating the criteria weights in individual groups. The order will include the resulting assessment of subcriteria Conveyor Belt (Tab. 6) the resulting assessment of subcriteria Idler Type (Table 7) and the resulting assessment of subcriteria Driving Drum (Tab. 8).

Tab. 6. Resulting Assessment of Subcriteria Conveyor Belt.

Conveyor Belt	C1	Weights of Factors		
		Expert 1	Expert 2	Average
Speed	**SC1**	0.313	0.311	0.312
Top Layers Thickness	**SC2**	0.068	0.080	0.074
Conveyor Belt Type	**SC3**	0.619	0.609	0.614

Tab. 7. Resulting Assessment of Subcriteria Idler Type.

Idler Type	C3	Weights of Factors		
		Expert 1	Expert 2	Average
Upper Idler Arrangement	**SC5**	0.833	0.875	0.854
Lower Idler Arrangement	**SC6**	0.167	0.125	0.146

Tab. 8. Resulting Assessment of Subcriteria Driving Drum.

Driving Drum Type	C6	Weights of Factors		
		Expert 1	Expert 2	Average
Driving Drum Lining Type	**SC9**	0.200	0.250	0.225
Embracement Angle	**SC10**	0.800	0.750	0.775

All cases meet the consistence requirement. If we multiply the obtained weights of subcriteria with the weights of the respective group criteria, we will obtain the weights of all the considered criteria (Table 9).

Tab. 9. Resulting Average Values of Criteria Weights.

Criteria	Weight	Subcriteria		Weights	Order
C1	0.127	**SC1**	**Speed**	0.040	5.
		SC2	**Top Layers Thickness**	0.008	9.
		SC3	**Conveyor Belt Type**	0.079	3.
C2	0.039	**SC4**	**Bearing Structure Shape**	0.039	6.
C3	0.040	**SC5**	**Upper Idler Arrangement**	0.035	7.
		SC6	**Lower Idler Arrangement**	0.005	10.
C4	0.437	**SC7**	**Installed Power of the Driving Motor**	0.437	1.
C5	0.258	**SC8**	**Conveyor Accessories with Lower Additional Resistance**	0.258	2.
C6	0.099	**SC9**	**Driving Drum Lining Type**	0.022	8.
		SC10	**Embracement Angle**	0.077	4.

On the basis of the resulting assessment of subcriteria weights (Tab. 9) that specify in more details the fundamental criteria, the importance of specific parameters of changes in belt conveyors structural elements were identified. On the first three places are the subcriteria that are related to Installed Power of the Driving Motor (drive regulation, SC7), Conveyor Accessories with Lower Additional Resistance (SC8) and Conveyor Belt Type (SC3), which are identical with the fundamental criteria Driving Motor, Filling Method and Other Additional Resistances and Conveyor Belt. As for the order of fundamental criteria, the fourth criterion Driving Drum was preceded by subcriteria Embracement Angle (SC10). In the basic assessment of the subcriteria, the last place belonged to subcriterion Lower Idler Arrangement (SC6).

Conclusion

Belt conveyance plays an important role in the complex chain of operations performed in the process of mineral raw materials excavation and processing. An important step in its optimization and efficiency enhancement is the selection of suitable and feasible modifications of belt conveyor construction parameters. Based on the general knowledge of the belt conveyor´s operation, six primary parameters (criteria) were determined: Conveyor Belt, Bearing Structure of the Conveyor, Idler Type, Driving Motor, Filling Method and Other Additional Resistances, Driving Drum, as well as 10 subsequent criteria. The importance and significance of modifications of the suggested parameters were assesses applying the AHP method.

The results of the belt conveyor basic parameters analysis and assessment show that the most important modification is the modification of the Driving Motor. The following one is the Filling Method and Other Additional Resistances and Conveyor Belt. On the basis of subcriteria assessment, three most important parameters of belt conveyor modification were determined: Installed Power of the Driving Motor, Conveyor Accessories with Lower Additional Resistance and the Conveyor Belt Type.

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