Application of logistics principles when designing the process of transportation of raw materials

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The article focuses on the proposal of rationalization of the transportation of magnesite in a mining company. The inclusion of a transportation process in a company's logistics model provides a comprehensive view on the operation of a company as a whole. The application of generally applicable logistics principles may result in the increased efficiency of the transportation process. A part of this article deals with increasing the efficiency of the conveyor belt system operation by proper dimensioning in terms of their capacity and rigidity. The main input of the rationalisation proposal is the analysis of technical parameters of belt conveyors. The article points out possible ways how to improve the transportation process within exploitation and processing of raw materials by applying cost-efficient tools for designing the logistics systems. A general procedure of logistics system designing is divided into five fundamental steps, particularly the project identification, paradigm selection, logistics system analysis, project synthesis, and project evaluation. The contribution of this article consists in the practical area, in the form of applying the logistics approach when designing the logistics system of transportation of magnesite in a mining company.

***Key words**: designing, raw materials, logistics, conveying, belt conveyor*

Introduction

Transportation represents an integral part of the logistics system in each mining company. It accounts for approximately 20-30% of a company's overall production costs. Investments in new transportation systems are required only at the opening of new deposits or due to measures increasing the strictness of ecological limits. The investment environment connected with the mining industry is quite unique when compared to the environments of other typical production industries (Cehlár et al. 2009). The most frequently used mineral transportation system is the road transport. At present, other alternatives are being searched for, particularly for the road transport, as this transport mode requires high costs (Turnbull 2013). An appropriate solution is a continuous belt conveyor system with the crushing section directly in the quarry, using portable crushers (Drottboom 2013). A priority within the engagement of belt conveyors is to ensure smooth material flow with the lowest possible risk level (Šaderová 2012). Development trends in the field of belt conveyor systems are primarily focused on the energy consumption reduction (Bajda et al. 2007), belt conveyor structural component material savings (Mantič et al. 2013), (Grinčová et al. 2015), reduction of the negative environmental impact during the belt conveyor operation (Grujič et al. 2011), (Marasová et al. 2002), belt conveyor service life extension, (Andrejiová 2013), (Andrejiová et al. 2014). Assessment of transportation systems for minerals may be carried out while applying several methods [for example AHP (Andrejiová et al. 2015), DOE (Ambiško et al. 2014)] and procedures, especially the simulation and mathematical modelling (Grinčová 2014), (Marasová et al. 2001). Appropriate tools for identifying the processes of conveyor belt damage during the operation include also regression models (Grinčová et al. 2009), (Fedorko et al. 2014) and the logistic regression (Andrejiová et al. 2014).

Belt conveyor system technology is acquiring its specific place in the in-plant transportation system in every company and represents a stabile mainstay of the efficient in-plant transportation. On the other hand, however, this transportation mode must also be well dimensioned, so that the material flow is smooth, efficient, and cost-effective. A lot of companies do not use the potential of this technology to the maximum extent. They spend a large amount of money on the operation, maintenance or repairs thereof. However, it is frequently the case that individual conveyors are over-dimensioned, which finally impacts their overall efficiency. Over-dimensioning, especially of conveyor belts, results in significant increase in operating costs. The article

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is focused on the implementation of logistics designing tools with the aim to rationalise the process of continuous transportation of magnesite using belt conveyors.

Material and methods

The methodology of this article is based on the application of the general procedure of logistics system designing. Transportation system designing, in terms of its logistics parameters, was dealt with by (Bindzár 2010). Logistics system is perceived as the system consisting of subsystems and components conducting the assigned function while being mutually connected. The belt conveyor system is a transportation system providing for the transportation of materials using belt conveyors. Basic components of the belt conveyor system include the belt conveyor system technology, the technical base, and the legislation. To define a logistics system means to define its structure, functions, and objective.

Belt conveyor system designing may be divided into 3 levels, particularly designing of logistics parameters, structural parameters and specific parameters (Bindzár 2008). The efforts within the belt conveyor system designing are aimed at adjusting five fundamental steps of a general procedure of logistics system designing in an appropriate manner to individual basic components of the transportation system. The first step of the designing is the *project identification,* i.e. the determination of characteristic parameters and factors of passive and active logistics components. A passive component in the belt conveyor system is the transported material. The identification also includes the definition of geometric signs, mechanical, physical and chemical properties of the material. An active logistics component is a belt conveyor and within the identification stage it is important to know its technical and economic parameters. Within a comprehensive identification, it is also appropriate to know the transportation system control method. The second step is the *paradigm selection*. When selecting a paradigm, it is possible to apply the flash analysis with the aim to obtain the largest possible amount of information about the examined company and propose the elimination of initially observed deficiencies, which is the content of brainstorming. The flash analysis is concluded with a workshop of ideas; task solutions are put in the sequence depending on their significance, including a determination of deadlines for the execution thereof. The knowledge obtained so far facilitates the selection of a final strategy of further procedure (case study, reengineering, systems analysis). A common feature of all strategies is to optimise the transport costs and increase the ability to adjust to changes in economic, technological and production conditions. The output is the adoption of evaluation criteria for a particular transportation mode and the method of control thereof. In the third step of the designing process, *the logistics system analysis*, an analysis selection and execution are followed by the collection of detailed and accurate information on the transportation technology. Without the analysis, further designing procedure would not be efficient. Understanding of relevant mutual connections and properties of basic components of the belt conveyor logistics system facilitates obtaining the required knowledge of the examined logistics system. Complexity and extent of the transportation system affect the decision making about basic analysis types: SWOT analysis, multiple-criteria analysis, analytic hierarchy process, heuristic or systems analysis. The fourth step of the designing is the *project synthesis*. On the basis of the obtained knowledge and information, especially from the analysis, we design a more efficient transportation system. This step includes submission of the final technical and economic solution, including execution of changes and the verification thereof. The fifth and the final step of the designing is the *project evaluation*, including evaluation of the fulfilment of the determined objective.

Result and discussion

The article applies the tools of logistics system designing to the assessment of the system for the transportation of magnesite using belt conveyors in the largest magnesite mining and processing plant in Slovakia. The quantity of final products intended for sale is approximately 350,000 tons every year. The highest annual increase in the sale is monitored in case of the sale of monolithic materials, which are becoming, together with dead burnt magnesite, a primary for-sale commodity in the company. The plant production is intended for metallurgical and ceramic industries, particularly brick magnesite, slag additive – the slagmag, alkaline monolithic refractory materials. Products for chemical industry include raw magnesite and brick dust, and products for the building industry include magnesite gravel and sand of various fractions. Material flow in the overall production process is organised by the motion of raw ore from the underground transported on rails or in mining conveyors to the surface towards the 1st and 2nd degree crushing and then to the rotary press.

The objective of designing the project of logistics system for the transport of magnesite using belt conveyors is to increase the efficiency of the belt conveyor system operation in a mining company, while applying the logistics system designing principles in the form of a case study. A logistics system of transportation of magnesite (hereinafter referred to as LSTM) was based on general logistics system designing principles (Malindžák 2010). The LSTM designing procedure is as follows:

Step 1: **Identification of parameters and factors of the logistics system for the transportation of magnesite**

A passive component in the examined logistics system is magnesite with the powder density $\rho = 1.7\ t.m^{-3}$. Magnesite properties do not change after passing through the transportation system. *An active component* of the examined transportation system is the set of selected 7 belt conveyors (Fig. 1).

Fig. 1. Transportation of magnesite in the 1st degree crushing section.

Input technical parameters of the examined belt conveyors are listed in Table 1. Each belt conveyor (BC) is filled through a feeding hopper and via chutes. The speed of conveyor belts is $1.31 m.s^{-1}$. *The transportation time factor* is not decisive for a real transportation system.

Tab. 1. Technical parameters of selected belt conveyor types.

BC parameters and designation	M4	M6	M7	M8	M44	M45	M48
L[m]	270.55	75.55	16.8	155.55	36.8	111.55	98.25
δ [^{0}]	30	10	45	30	0	20	30
n_h [ks]	405	120	27	180	66	138	90
n_d [ks]	29	13	3	18	8	12	10
λ [^{0}]	30	30	40	45	30	30	40
B [mm]	1,200	1,200	1,200	1,200	800	800	1,200

Legend: L - conveyor length, δ - conveyor inclination angle, n_h - number of rollers in the upper idler, n_d - number of rollers in the lower idler, λ - rollers inclination angle, B - belt width

Step 2: **Paradigm selection**

Project designing was carried out using the simplest paradigm, particularly a case study of designing a logistics system for the transportation of magnesite. In the applied form, this step contains the formulation of tasks and the selection of evaluation criteria. When designing a logistics system for the transportation of magnesite (LSTM), we can formulate the research purpose as the rationalization of selected basic parameters of belt conveyors with the aim to ensure the efficient use thereof while minimising the operating costs. Proposal of changes for 7 selected conveyors (M4, M6, M7, M8, M44, M45, M48) will be primarily focused on the reduction of costs necessary to purchase conveyor belts and the transportation of 1 ton of magnesite. The basic evaluation criterion was determined as the costs of 1 ton of transported mineral.

Step 3: **Analysis of magnesite transportation system**

The analysis objective is to verify technical parameters of belt conveyors on the basis of identified parameters and factors in the examined system of magnesite transportation with the aim to increase the efficiency of the mineral transportation process based on calculations made pursuant to the STN EN 263102 standard. The analysis inputs are technical parameters of 7 belt conveyors listed in Table 1. The analysis subject includes belt conveyors of a single technological node, particularly from the crushing section to the magnesite processing section. For each belt conveyor, calculations were made with regard to their capacities and rigidity, driving engines powers, relations between forces affecting the actuating drum, and the inspection of the conveyor belt rigidity. When assessing conveyors within a case study, each examined conveyor belt must meet the following requirement:

$$T_{max\ kontr} > T_{1max} \quad [N] \qquad (1)$$

whereas

$$T_{max\ kontr} = T_{dov}.\ B \quad [N] \qquad (2)$$

where: T_{dov} – allowable strain of a conveyor belt [N.mm^{-1}] ,
B – conveyor belt width [mm].

Results of the conveyor belt (CB) rigidity inspection (Table 2) indicated over-dimensioning of four out of seven conveyor belts. This situation may be solved by the replacement of original conveyor belts with conveyor belts with lower rigidity, which will facilitate the reduction of energy consumption and reduction of costs of purchase of conveyor belts. This proposal for the reduction of conveyor belt rigidity degree in M6, M8, M45, M48 conveyors meets the requirements specified by the relation (1).

Tab. 2. Results of rigidity calculation and the proposed changes in CB rigidity and weight.

BC No.	**Current CB rigidity** [N.mm^{-1}]	**Inspection of current CB rigidity** [N]	**Proposed CB rigidity** [N.mm^{-1}]	**Current CB weight** [kg.m^{-1}]	**Proposed CB weight** [kg.m^{-1}]	**CB weight savings** [%]
M6	1,000	96,000 >12,865	400	16.56	8.92	46.14
M8	1,000	120,000 >72,354	800	16.56	13.80	16.67
M45	800	64,000 >30,026.97	400	11.04	8.92	19.20
M48	1,000	96,000 > 40,196.24	400	16.56	8.92	46.14

The analysis of conveyor belt rigidity indicated possible rationalization, in terms of reduction of conveyor belt rigidity and weight, which will facilitate the reduction of overall dynamic resistance and thus also the required power of conveyor driving engines. As a result, the costs of electricity will be reduced as well.

Another objective of the analysis was to evaluate the impact of the conveyor belt rigidity reduction on the costs related to the purchase of conveyor belts. Within the monitored section of the belt conveyor system, two types of CB were used, particularly the conveyor belt type EP 1000/3, 4+2 AA and type EP 800/4W, 4+2 AA. Table 3 presents the proposal of changes in conveyor belt types and Table 4 presents the cost savings after the execution of these changes.

Tab. 3. Proposed changes in conveyor belt type in selected BCs.

CB type description	Conveyor belt status							
	M6		M8		M45		M48	
	Current	Proposal	Current	Proposal	Current	Proposal	Current	Proposal
CB frame type	EP	EP	EP	EP	EP	EP	EP	EP
Tensile strength *[N.mm^{-1}]*	1,000	400	1,000	800	1,000	400	1,000	400
Number of plies *[pc]*	3	3	3	3	3	3	3	3
Thickness of upper cover layer *[mm]*	4	5	4	5	4	5	4	5
Thickness of lower cover layer *[mm]*	2	2	2	2	2	2	2	2
Cover layer category	AA	AA	AA	AA	AA	AA	AA	AA

Step 4: Synthesis of the logistics system

Proper selection of appropriate conveyor belt types (Table 3) may ensure high operational safety and cost-effectiveness of belt conveyors. Operational safety is guaranteed by the required allowable strain of conveyor belts, i.e. by meeting the requirement specified by the relation (1), and the cost-effectiveness by saving the costs of purchase of conveyor belts (Table 4). Analysis results, following the subsequent interpretation and substitution in the selected evaluation criteria, are assessed in Table 5.

The proposed change for conveyor belts of M6, M8, M45 and M48 conveyors, due to over-dimensioning in terms of tensile strength (Table 2), suggests for current textile conveyor belt with polyester textile frame (EP) and with 3 textile plies to be replaced with conveyor belts with lower rigidity and higher cover layer (CL) thickness (Table 3), as magnesite is abrasive material and causes intensive wear of a conveyor belt and thus also reduction of the upper cover layer thickness.

Another advantage of lower tensile strength of conveyor belts used in M6, M8, M45, M48 conveyors is also the reduction of conveyor belt weight, as documented in Table 2, where in 2 cases the reduction in weight of 1 meter of conveyor belt represents as much as 46.14 %. In case of the total length, for example of the conveyor belt M48, the overall reduction represents 1,577.66 kg, which is significantly manifested by the reduction of energy consumption for the belt conveyor driving.

Tab. 4. Savings in costs of purchase of CB after changing conveyor belt rigidity.

Conveyor belt status		Total CB length (2x L+10m) [m]	CB rigidity [N.mm^{-1}]	CB price [€.m^{-2}]	Total CB price [€]	Costs savings [€]
M4	Current	551.1	1,000	61.08	40,393.43	-
	Proposal	-	-	-	-	
M6	Current	161.1	1,000	61.08	11,807.99	1,989.27
	Proposal	161.1	400	50.79	9,818.72	
M7	Current	43.6	1,000	61.08	3,195.71	538.38
	Proposal	43.6	400	50.79	2,657.33	
M8	Current	321.1	1,000	61.08	23,535.35	512.48
	Proposal	321.1	800	59.75	23,022.87	
M44	Current	83.6	800	59.75	3,996.08	666.12
	Proposal	83.6	315	49.79	3,329.96	
M45	Current	233.1	800	59.75	11,142.18	1,670.86
	Proposal	233.1	400	50.79	9,471.32	
M48	Current	206.5	1,000	61.08	15,135.62	2,549.86
	Proposal	206.5	400/3	50.79	9,471.32	

To enable the comparison of the achieved savings within the solution of magnesite transportation, the costs of 1 ton of transported mineral were identified. With the price of electricity of 0.0766 € for 1 kWh for the calculation of costs of transportation of 1 ton of magnesite, the following relation applies:

$$\text{Price of transportation of 1ton of magnesite} = \frac{\mathrm{P} \times c_1}{\mathrm{Q}}, \tag{3}$$

where P is the power of driving engine [kW], c_1 is the price for 1 kWh [€] and Q is the actually transported quantity [t.h^{-1}].

Table 5 presents the price of consumed electric energy recalculated for 1 ton of magnesite and the total price of a belt conveyor. Moreover, the table contains savings in these prices after proposed innovations. The price of conveyor belt replacement was determined according to the quotation provided by the conveyor belt manufacturer.

Tab. 5. Savings in costs of transportation of 1 ton of magnesite and purchase of CB.

BC designation	CB status	Driving unit input power [kW]	Costs of magnesite transportation [€.t^{-1}]	Savings in costs of magnesite transportation [%]	Costs of CB purchase [€]	Savings in costs of CB purchase [%]
M_6	current	19.08	0.00438	21.23	11,807.99	16.85
	after change	15.02	0.00345		9,818.72	
M_8	current	91.19	0.02095	19.52	23,535.35	2.18
	after change	73.39	0.01686		23,022.87	
M_{45}	current	46.28	0.01063	0.237	11,142.18	15.00
	after change	46.09	0.01059		9,471.32	
M_{48}	current	58.51	0.01344	0.892	15,135.62	16.85
	after change	57.97	0.01332		12,585.76	

Step 5: Magnesite transportation project evaluation

Solutions proposed in the case study do not incur any investment costs to the operator. Replacement of conveyor belts after expiry of the service lives of current conveyor belts shall represent current operating costs, and from the time point of view, the belt replacement may be planned within the scheduled repairs in the company.

The following solutions resulted from individual steps of LSTM designing:

For the M6 belt conveyor, after the inspection of the conveyor belt in terms of tensile strength, it is advisable to replace the current conveyor belt type with the strength of *1,000 N.mm* $^{-1}$, due to over-dimensioning in *83.135 kN,* with the conveyor belt with the strength of *400 N.mm*$^{-1}$. CB replacement will result in 16.85% savings in costs of CB purchase, as is the case of M48 belt conveyor (Tab. 5). Costs of transportation of magnesite by the M6 belt conveyor will be reduced by 21.23 %. The second most significant savings in costs of magnesite transportation apply to the M8 belt conveyor and they represent approximately 19.52 %. Replacement of currently used conveyor belt with the strength of *1,000* N.mm $^{-1}$ with the conveyor belt with the strength of *800 N.mm* $^{-1}$ in this case is only 2.18 %; however, the difference in costs of magnesite transportation represents almost one-fifth, compared to current costs (especially of belt conveyor drive). All the proposed solutions meet the requirements regarding allowable strains of conveyor belts while ensuring the transportation of the required quantity of magnesite, i.e. 333.3 tons per hour.

Conclusions

The article was dealing with the evaluation of magnesite transportation while applying the generally applicable procedure of logistics systems designing with the application for designing the belt conveyor system. The process of magnesite transportation logistics system designing included the designing of basic parameters of belt conveyors in the real operation in a magnesite mining and processing company. Evaluation criteria were derived from the principle of belt conveyor system operation based on the transfer of frictional force between the drum and the conveyor belt while overcoming the main, auxiliary, and additional resistances. Chosen evaluation criteria included capacity and strength calculations, drive design, and inspection of conveyor belt rigidity. The main decisive criterion was the reduction of costs required for the transportation of 1 ton of material. On the basis of obtained results, the economic evaluation of changes in belt conveyors was carried out. Calculations made pursuant to the STN EN 263102 standard for individual belt conveyors and the financial analysis confirmed substantiation of proposed changes in their selected parameters in compliance with the operating conditions and with the nature of transported material. The method of evaluation of the process of transportation of magnesite in the form of a case study, while applying the general principles of logistics system designing and verification of selected parameters of belt conveyors, can serve as a suitable tool for the operator when making decisions about possible changes in the examined belt conveyor system. Results presented in the synthesis confirmed the fact that by proper selection of appropriate conveyor belt types it is possible to ensure high operational safety, high transportation capacity, and efficiency of the transportation process using belt conveyors.

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