Contents

The use of ANN in improving efficiency and ensuring the stability of the copper ore mining process

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The aim of the article is to propose a concept for controlling the loading and haulage process and copper ore in a mine with a pillar-chamber system. An appropriate method of control should ensure the production level assumed in the production plan at the lowest costs of the process. It is important to properly select the cost account showing the impact of cost factors (variable parameters) on the total costs of the process. In the presented concept, it is proposed to build an SSN model which will allow for such control of the rigs and haulage process, so that the process remains stable in the assumed period and the economic result is as large as possible. The process will remain stable if the extraction volume is consistent with the volume planned in the production plan. In addition, process control will be aimed at ensuring the lowest total costs of rigs and hauling off the output. The decision model proposed in the article will enable quick decisions to be made, allowing for the implementation of production plans while ensuring the criterion of production efficiency. Optimization of processes often leads to problems where there is a need to resolve the issues of process evaluation based on more than one objective function. The proposed solutions have been adapted to mining systems operating under the conditions of a given enterprise.

Key words: *ANN, process costs, process efficiency, controlling the loading and haulage process of the output*

Introduction

Currently, the costs of copper production in Poland in comparison to the competition are high and are constantly growing. In order to join the group of large global copper producers, one of the strategic pillars is the improvement of efficiency aimed at reversing the trend of rising costs by investing in new technologies, modernizing infrastructure, optimizing processes and organizing production (Gwiazda et al., 2017; Azadegan et al., 2011; Wirth et al., 2016). The high unit production costs of copper ore to a large extent result from organizational and process inefficiencies (Tworek et al., 2018). Cost savings can be found, in the proper management of mining processes, among others. The concept of controlling the loading process and copper ore presented in the article ensures, on the one hand, the stability of the process, and the lowest mining costs on the other.

The concept of stability is derived from the systems theory. Most definitions found in the literature refer to the concept of the state of balance and define the stability of a system as its ability to return to the state of balance after the disturbances that caused the instability has ceased. The stability of a control system is its most important feature that characterizes the ability to accomplish the tasks, for which it has been built (Bubnicki, 2005, Janson and Jurenoks, 2012).

If the value of the parameter $P(t_i)$, which characterizes the production system at the time t_i is within the predetermined interval $P1 \leq P(t_i) \leq P2$, this will indicate a correct course of the process. Otherwise, corrective measures should be taken. Corrective measures usually consist in changing the values of control variables (inputs to the system) in such a way, so that the values of the parameters characterizing the controlled variables (outputs from the system) return to the process course standards established at the planning stage (Bubnicki, 2005). Production plans and parameters characterizing them usually constitute the standards. A correct decision will cause the system to return to the steady state (Krenczyk et al., 2017).

It can be said that a production system is in the steady state if values of the parameters defining it are within the ranges specified in the planning function and recorded in a standard, that is, a production plan, as schematically shown in Fig. 1.

On the one hand, it is necessary to ensure the stability of production processes and, on the other hand, low production costs in order to ensure the company's competitiveness (Fusko et al., 2017). This statement seems particularly important in relation to mining processes characterized by high volatility and uncertainty due to variable and unpredictable environmental conditions (Dohn et al., 2014; Litwin et al., 2017; Tahir et al., 2015). These processes are unstable and cost-intensive, and controlling them is very difficult.

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The aim of this study is to comprehensively present the concept of controlling the loading and haulage process in the copper ore mining process ensuring the stability of this process while maintaining the appropriate level of costs, and as a result, striving to improve its efficiency.

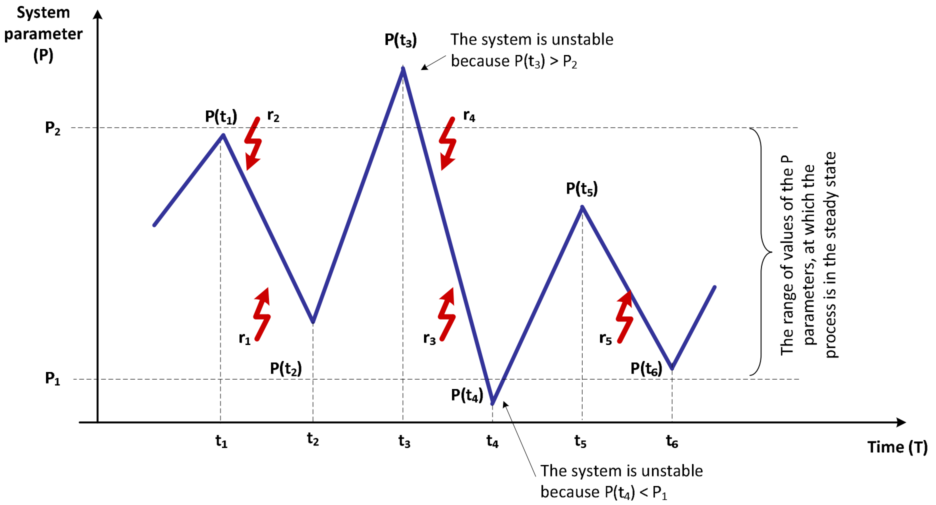

Fig. 1. The variability of the system parameter $P(t_i)$ is caused by the impact of disturbing factors (r_i) (Burduk, 2015).

The solution to this problem requires:

- determination of operating costs for the exploitation process, taking into account the cost-generating factors of the so-called variable input parameters that will comprehensively manage these costs,
- building an SSN model that enables controlling the loading and haulage process, while maintaining stability in the assumed period,
- proposing a model for the optimization of this process according to extraction criteria as a function of many variables and the total cost of the process also as a function of the same variables with constraints on the stability and limit (acceptable) cost of this process,
- determining the optimal process efficiency, which will enable obtaining knowledge of the value of cost factors (input parameters) depending on the size of the output as a function of many variables set by the artificial neural network.

Application of artificial neural networks (ANN) in control of a production system

Neural networks are modern computational systems that process information based on phenomena occurring in the human brain. The neural network is a mathematical model, consisting of a network of computational nodes called neurons and their connections. In addition, it has the ability to learn. Artificial neurons, like their natural counterparts, are connected by means of connections whose parameters (weights) are modified in the so-called learning process. Input signals, being data from the production process, are processed by the network and outputted as a solution to the task. Most networks have a multi-layer structure, with the input and output layers and the so-called hidden layers stand out. This means that SN can be treated as so-called black boxes, capable of solving the problem under investigation with greater accuracy than classical methods, without the need to understand all relations between elements of the system. In the mathematical sense, the neural network is a universal approximator of the functions of several variables and performs non-linear functions on the form (Barron, 1994):

$$y = f(x), \quad (1)$$

where *x* is the input vector, and *y* is the performed vector function of many variables.
They can be used to map complex relationships between input signals and selected output signals with a high probability of success, without the need to build complex mathematical models.

The primary objective of modeling the dynamics of a production process is to identify the temporal variability of its physical quantities or states (Azadegan et al., 2011; Bozejko et al., 2012). To this end, a time series, that is, an ordered sequence of values of a certain variable over time should be determined. A time series may have a form of the vector $y(t_1), y(t_2), \dots, y(t_N)$. Due to the fact that process parameters may differ in individual phases of the process, the time series vector can take the form of a vector defined in N-dimensional space. Individual components of this vector will be the states of the production process stages in the past, which in turn can be regarded as points in multi-dimensional output space. Thus the task of analyzing the temporal variability of the production process can be reduced to searching N-dimensional space for a certain trajectory, on which the analyzed output variable of the process "moves". Thus, a given quantity in the form of a time series is determined in order to predict its value in future moments.

A unidirectional neural network can describe the regularities occurring in a time series and allows predicting its future values. Future value of the time series $t(t+1)$ is usually predicted on the basis of the current value and "k" past values y of the series, as well as the current value and "l" past values of input variables x according to the formula:

$$y(t+1) = f(y(t), y(t-1), \dots, y(t-k), x(t), x(t-1), \dots, x(t-l), w). \quad (2)$$

Unidirectional multilayer networks (without feedback) are used in over 80 % of all applications of neural networks (Barron, 1994). Fig. 2 shows a list of input and output data used in ANN models.

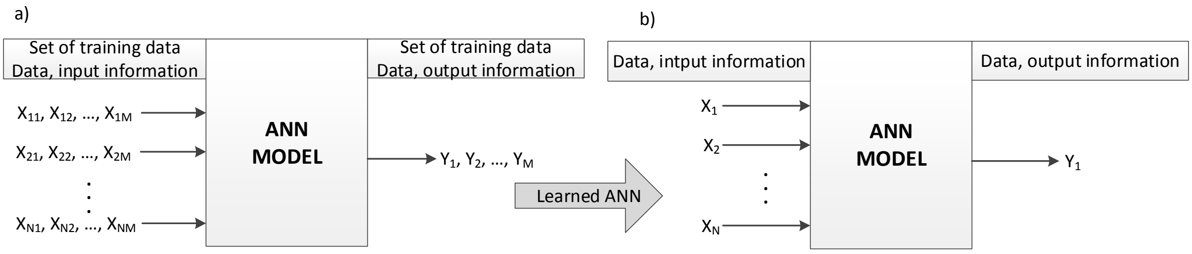

Fig. 2. List of input and output data in models of artificial neural networks a) network learning, b) conducting experiments.

Artificial neural networks are usually used to solve problems associated with the approximation, interpolation, prediction, classification, recognition, and control (Burduk, 2015; Rojek et al., 2012). Image recognition, which also includes classification, grouping, and processing, accounts for approx. 70 % of all industrial applications. In the management and operation of production systems, artificial neural networks are more and more often used for control of production processes, robots, analysis of manufacturing problems, diagnostics of electronic systems of machines, selection of personnel and input materials, optimization of the business activity, waste disposal, robot movements, planning overhauls of machines, forecasting of costs (Burduk and Jagodziński, 2015; Rojek et al., 2012).

Artificial neural network models can be used to control the production system, and thus to ensure its stability. The ease and speed of their construction make them a very useful tool. A large amount of data needed in the network learning process remains to be the only problem, which, however, in the era of the universality of information systems, parameterization and standardization of production processes cease to be a problem (Gola and Kłosowski, 2018; Furmann et al., 2017).

Application of the ANN model to ensure the stability of the copper ore mining process

The purpose of building the ANN model is to ensure such control of the copper ore (that is, an output) rigs and haulage process so that the process remains stable in the assumed period. The control will consist of an adequate selection of parameter values for process inputs in order to obtain an output value (that is, the production volume) consistent with the predetermined production plan. The process will remain stable if the production volume is consistent with the volume set in the production plan.

General characteristics of the production system

The study was conducted in one of the mining companies located in Lower Silesia, Poland. The mine, for which the neural network was built, covers an area of 158 km^2 underground, while mining operations take place at a depth from 610 to 850 m. One of the mining divisions of the mine (G-1 division) was selected for the analyses. The G-1 branch extracts copper ore from two mining fields XXIII/1 and XXIII/2. Machines operating in this branch are serviced by a heavy machinery chamber (KMC) C-2B. Fig. 3 shows a fragment of the mine map with the G-1 branch area marked out, roads followed by machinery from the heavy machinery chamber to mining fields and roads where copper ore is transported.

The operation process is the main process in the entire mining system, in the mine in question, it takes place in a pillar-chamber system, which means that the preparation of the field for operation consists in making pavements and excavation corridors. This is dictated by ventilation and transport considerations. The excavation corridor enables bringing large amounts of air into the operating fields, which is necessary due to the high primary temperature of the rocks and the combustion machines used in the operation process. The pavements enable organizing the movement for mining machines and the separation of the output route for haulage removal with conveyor belts.

The operation process consists of the following stages: encasing, drilling, blasting, rigs, and haulage, horizontal and vertical transport. The operation process consists of the stages described below, which run cyclically. The process itself takes place in many places simultaneously, in many fields of extraction in various parts (faces).

Key:

G1 mining area branch

C-2B heavy machinery chamber

The way of access of machines from the C-2B chamber to the mining fields of the G1 branch

Horizontal transport of output (belt conveyor)

G1 grates on the branch

Fig. 3. Diagram of the G1 mining branch.

Enclosing consists in securing the selected space with the ceiling securing the roof with anchors. The purpose of this process is to protect the selected space for further stages of the operation process involving people and machines. If the copper content in the deposit is too small, then further exploitation becomes unprofitable, and the selected space is liquidated.

The aim of the drilling process is to make blast holes, to which an explosive will be fired in the mining sub-process. Drilling is performed using the so-called self-propelled drilling rigs (SWW) and consists in making blast holes in the deposit to a depth of about 3 m. The number of holes varies and depends on the type of rock. Then in the blasted holes, with the help of self-propelled rigs (SWS), an explosive is fitted. Blasting is performed twice a day, that is firing the fitted explosives.

The purpose of the rigs and haulage process is to transport the blasted copper ore to the transfer point (so-called grid). A set of three machines is usually involved in the loading and haulage process: excavator/loader (ŁK) and two haulage rigs (WO). Due to the necessity of maneuvering, the rigs of the WO takes place in the chambers closest to the blasted face. Due to the conditions of work, machines are subject to frequent breakdowns and failure. Availability is the basic parameter that measures the use of machines in the process. Accessibility is calculated as the ratio of time in which the machine worked in the process to the time which it was in repair, service, or failure. The average availability for the WO in the analyzed period was 60 %, and for ŁK-2 it was 70%.

The next stages of the mining process consist in transporting the output, first with the help of belt conveyors, and then with the rail transport to the so-called skip, or mining shaft, in which the output is transported to the surface from where it will go to the ore processing plant. Between the consecutive stages in the transport process, there are so-called pouring points, output weights, and retention tanks. Storage reservoirs are buffers protecting the process of supplying ore to ZWR against disturbances and are equivalents of warehouses in typical production processes.

In the operation process, the added value is generated, and a product is created (properly fragmented copper ore) for the external customer, which is an ore processing plant. The process of loading and haulage the output was selected in order to present the concept of control of the mining process, allowing to ensure the stability and economics of extraction.

Characteristics and cost analysis of the loading and haulage process

The rigs and haulage process is one of the most important processes in the mining process. Its purpose is to move the ore from the mine face to the grate, where the ore is crushed and discharged onto a belt conveyor. Main stages of this process are shown in Fig. 4.

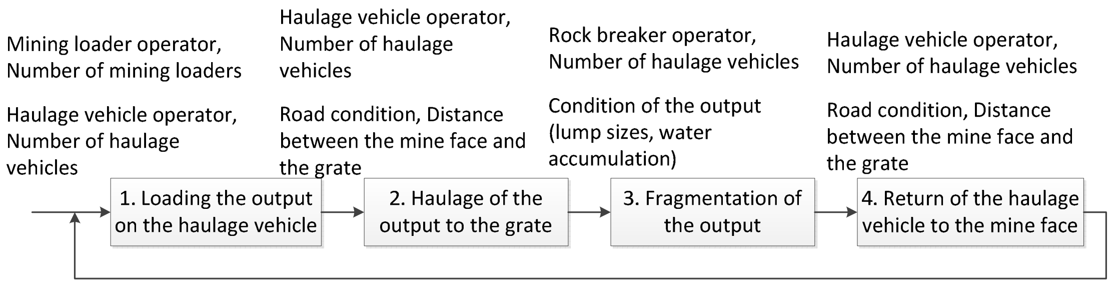

Fig. 4. Main stages of the rigs and haulage process.

1. Rigs the output onto a haulage vehicle. This operation is performed with the use of a mining loader in the mine face and consists in rigs a haulage vehicle with copper ore. Fig. 5 shows the model of rigs the output onto a haulage vehicle saved in BPMN notation.

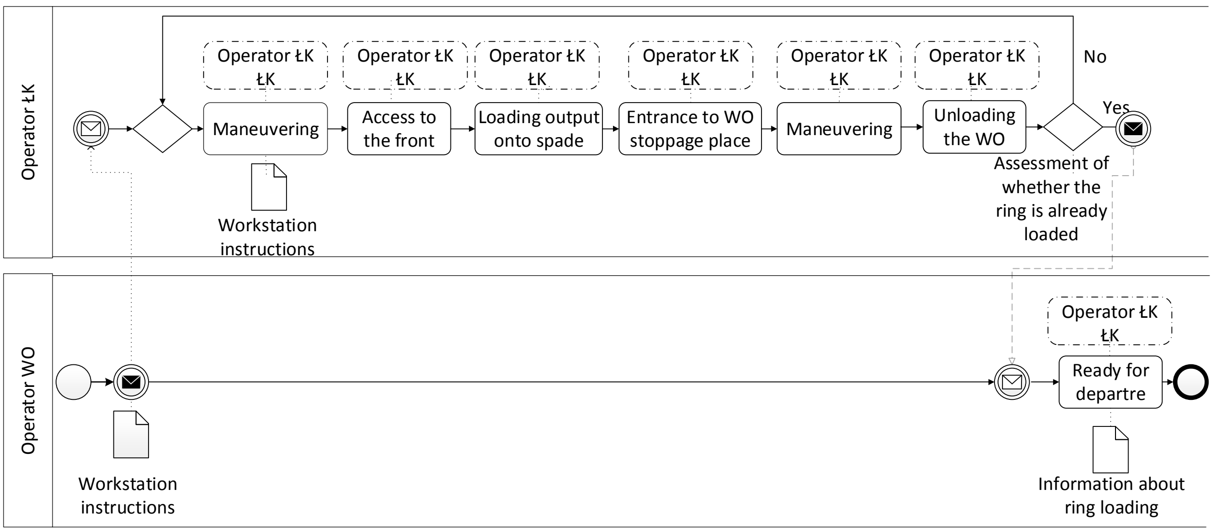

Fig. 5. Model of rigs the output onto a haulage vehicle saved in BPMN notation.

2. Haulage of ore to the grate. The haulage vehicle, after having been loaded, goes to the discharge point (grate). Haulage roads may have a different inclination angle, while their condition may vary depending on the type of rocks forming the road. If the rocks are fairly soft, the road becomes muddy over time and ruts are formed in it. As time goes on, the transport on such a road becomes more and more difficult and therefore longer.
3. Unrigs the output on the grate. The grate is located over the belt conveyor and is a discharge point, where the transport of the copper ore to the ore enrichment plant is started. Its role consists in adequate fragmentation of the output and retaining all impurities, such as metal anchors, props and other elements

that could damage the belt conveyor. There are four grates on the analyzed G-1 branch (Fig. 3). The method of unloading the WO on the grating, recorded in the BPMN notation, is shown in Fig. **6**.

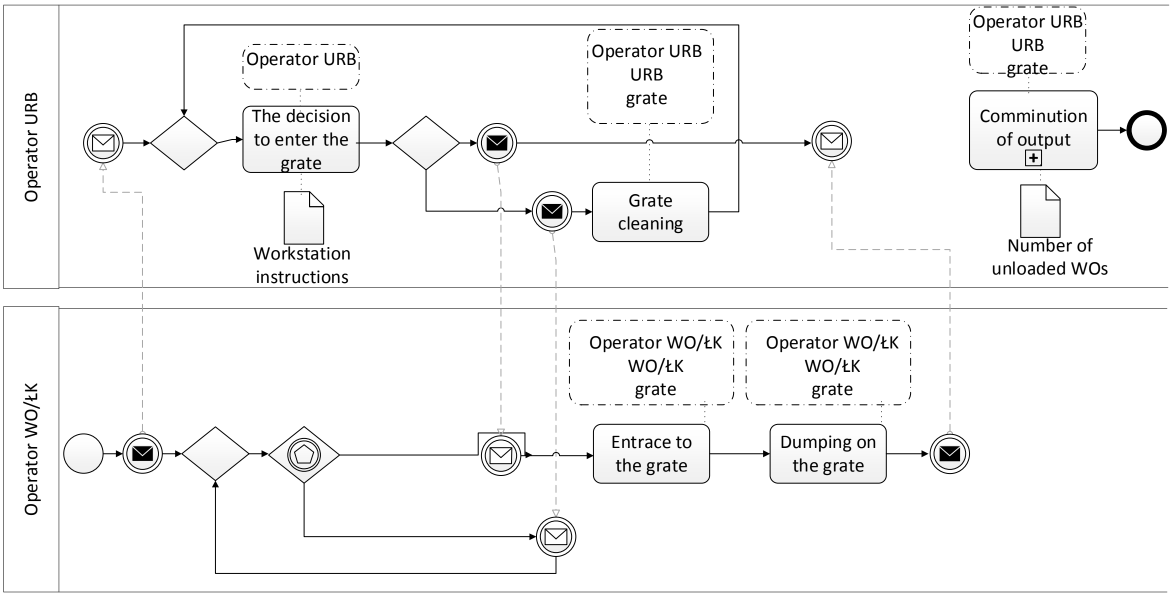

Fig. 6. Model of the process of unloading the WO on the grate recorded in the BPMN notation.

4. The haulage vehicle goes back to the mine face to be loaded again after having been unloaded on the grate.

In order to consider the mining process to be stable, it should deliver the established amount of copper ore to ore enrichment plants. Since the haulage vehicle has a constant and limited capacity (20 t), the amount of the ore getting to the processing plants depends on the number of haulage rigs unloaded on the grate. The shorter the time of the rigs and haulage process, the more haulage rigs can be unloaded on the grate during a work shift. The time of the rigs and haulage process depends on many factors and directly affects the total costs of this process.

The production cost model is based on the activity-based costing method for the operation process. The application of the calculation of costs of operations, including cost factors, that is, such process parameters that unambiguously determine the value of variables of separated cost components, enables a significant reduction of costs at the operational stage, which actively influences the cost planning in the future. The first stage in determining production costs is to determine the value of cost components, that is, the costs of direct operations comprising the cost of the operating process. On the basis of information available in financial and accounting systems about costs incurred in previous periods, information on the existence of separate activities in the mining system example specified the costs of direct operations. Having calculated the costs of direct actions and specific measures of the volume of processing of these operations, the rate of costs of individual actions that is, the so-called unit cost of operation can be calculated (Więcek and Więcek, 2018). The activities, their structure of operating costs of the loading and haulages process, and the calculated cost rate are presented in Tab. 1. In this table, the individual operational cost items were scaled in relation to the actual values due to the protection of information, which were given in unit costs (uc).

Tab. 1. Costs of the loading process and output disposal.

Operation	Cost structure	The unit cost of operation
Loading	- operating costs of the loader operator - amortization of the charger - consumption of materials (fuel) - costs of planned maintenance - indirect costs (including supervision, consumption of auxiliary materials, insurance costs, costs of failure)	10 [uc/loading]
Output haulage	- operating costs of haulage operators - amortization of haulage rigs - consumption of materials (fuel) - costs of planned maintenance - indirect costs (including supervision, maintenance costs, consumption of auxiliary materials, insurance costs, costs of failure, maintenance and maintaining the corridor)	30 [uc/haulage]

During the observation of the charging operation, it was noticed that its cost depends partly on the road of the loader. This road can be from 3 to 30 meters, and it is a variable cost component (kzj). Regardless of the route being traveled, in each case, the loader operator performs maneuvering in the place of the face and maneuvering in the parking place of the haulage rig, and this part of the cost is of a permanent nature (Ks).On the basis of measurements of loading time, change of unit cost depending on the route x_1 can be recorded using the linear function (3).

$$K_l = k_{zj} \cdot x_1 + K_s = 0{,}012x_1 + 0{,}64. \quad (3)$$

The same applies to the cost of delivering the output to the grate, which takes place on the designated roads. The distance of x_2 haulage can vary and depend on the place of loading and the place of the grating, for which permission to enter was obtained. The cost depending on the distance has the character of a variable cost (kzj). The coefficient of this cost reflects the time of the transport of the output and the time of returning the rig from the grate to the face. A fixed part of this cost (Ks) is the time of loading the output onto the rig, as well as the time of entering and pouring the output on the grate. On the basis of observation and measurements of the time of this operation, the change of its unit cost from the transport path is presented by the function (4).

$$K_h = k_{zj} \cdot x_2 + K_s = 0{,}005x_1 + 0{,}55. \quad (4)$$

The cost of output disposal also depends on the condition of the road, which may have a different angle of inclination and a different condition depending on the rocks forming it. The state of the d path is a discrete variable that takes values from the set $\{1,2,3,4\}$. It affects the function of the cost of the haulage through the parameter k_d accepting values:

- 1 for $d = 1$ - the advantage of an even and dry road,
- 1,4 for $d = 2$ - the advantage of an even and wet road,
- 1,2 for $d = 3$ - the advantage of an uneven and dry road,
- 1,6 for $d = 4$ - the advantage of an uneven and wet road.

When analyzing process stability depending on the route of the loader x_1, the route of the rig x_2, condition of the road d and crate number k different variants were generated W and a change of input attributes. The charger has a medium lifting capacity of 4 tonnes, and 20 tons for two two-way haulers. The total cost of loading and hauling for a given variant, depending on variables x_1 and x_2, taking into account the expected extraction n, which is a function of $x_{1,}x_2$ set by the artificial neural network, can be determined according to the formula (5).

$$K_{lh} = \frac{n}{4}(0{,}012x_1 + 0{,}64) \cdot 10 + \frac{n}{20}(0{,}005x_2 + 0{,}55) \cdot k_d \cdot 30. \quad (5)$$

Method of building the neural network

The elements that interfere with the loading and hauling process, apart from mining machinery failures, are variable ambient conditions. They cause that the transport time of the output and the time of the return of WO from the grate to the face is very different. The loading and unloading time depends mainly on:

1. The condition and length of the transport route from the face to the grating. The condition of the road is affected by the type of rocks on the floor, slope angle, and condition of wailing. Heavy road transport causes that after some time ruts are formed, and the mud layer reaches up to 80 cm.
2. Time of WO loading by ŁK. This parameter depends to a large extent on the way the loader must go from the place where the ore is located to the standstill point of the hauler. The rigs are loaded in Figure 2 chambers, that is, places where the corridors cross between the pillars. This route can be from 3 to 30 m.

These parameters, as well as the grate number, were selected as independent variables when building the ANN model, as presented in Fig. 7.

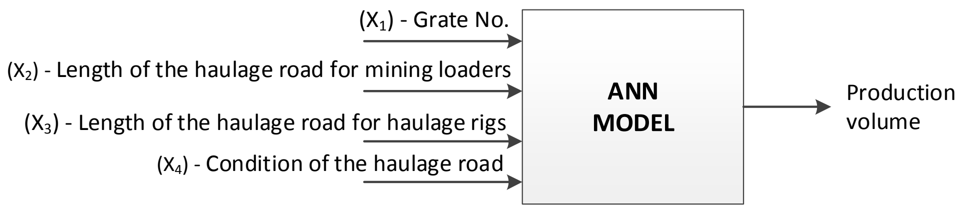

Fig. 7. Independent variables and the dependent variable used to build the ANN model.

In order to predict the amount of the excavated ore under the rigs and haulage process in the G1 division, at the assumed input values, a unidirectional neural network (perceptron) was built. The results of observations and measurements of times in the rigs and haulage process were used as the learning data set. In total, 211 measurements were made for 20 days, in 3 work shifts. The measurements were made by shift foremen with the use of forms prepared especially for this purpose. Four values have been introduced to describe the road condition:

1 - mostly even and dry road,
2 - mostly even and wet road,
3 - mostly rough and dry road,
4 - mostly rough and wet road.

The experiment was performed in the SAS Enterprise Miner 6.2 environment. The first step was to investigate the correlation between independent variables and the dependent variable. The results containing the correlation value are shown in Tab. 2.

Tab. 2. Values of the correlation between variables.

Independent attribute (variable)	Correlation value
Grate No.	-0.06787
Length of the haulage road for mining loaders	0.01009
Length of the haulage road for haulage rigs	-0.32767
Road condition	-0.07535

The obtained results indicate that it is pointless to use a linear regression method (absolute values of the correlation are below 0.5) for the analyzed problem. Therefore it is justified to use neural networks which form non-linear regression models.

As a part of further experiments, a model of a multilayer perceptron network was built, for which the number of neurons in the hidden layer was changed. In order to confirm the results of the correlation analysis, a neural network based on the generalized linear model was also built. Fig. 8 shows a screenshot of the SAS Enterprise Miner program 6.2 with models built in it.

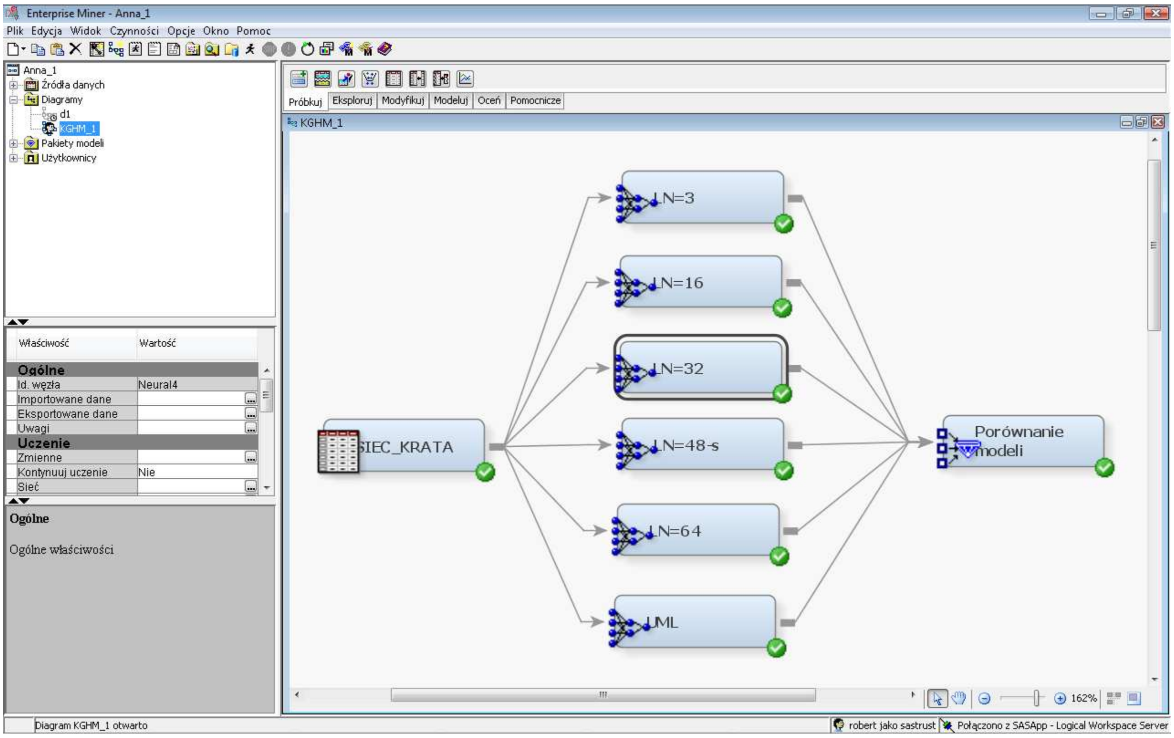

Fig. 8. The SAS Enterprise Miner 6.2 environment with models of neural networks covered by the analysis and their comparison.

For the neural network models built, a series of experiments for a different number of independent variables was conducted. The purpose of these experiments was to establish for which combination of independent variables the neural network will determine the value of the output in the best way. When building the models, different numbers of independent variables were considered. Their selection was dictated by previous experiments, that is, it depended on the absolute value of the correlation (Tab. 3). In experiment No. 1, all input attributes are used, while in experiment No. 2 the attribute "Length of the haulage road for mining loaders" (the lowest absolute value of the correlation) was discarded. In experiment No. 3 the attribute "Grate number" (the next lowest absolute value of the correlation) was discarded in addition. The results are presented in Tab. 3, where the values obtained represent the network selection criterion, that is, the mean square error. These results concern the analysis of the input data set, which was also used for the network training process.

Tab. 3. Results of the experiments conducted with the use of a neural network

Neural network model	**Mean squared error**		
	Experiment No. 1	**Experiment No. 2**	**Experiment No. 3**
MPN – NN=3	1228.59	1643.71	2375.39
MPN – NN=16	1072.43	1369.98	1851.50
MPN – NN=32	427.08	866.69	1033.93
MPN – NN=48	327.15	764.22	1019.25
MPN – NN=64	348.80	772.59	999.05
GLM	2440.74	2450.18	2537.86

Where:
MPN - a multilayer perceptron network,
NN - number of neurons in the hidden layer,
GLM - generalized linear model.

The analysis of the results confirms that linear models are not suitable for resolving this problem. In the case of each experiment, the worst results (with the highest mean square error) were obtained for a neural network built according to the generalized linear model. The best results were obtained for a multilayer perceptron network with 48 neurons under experiment No. 1. This neural network model was used for further experiments.

Determination of the stability of the rigs and haulage process with the use of a neural network with 48 neurons in the hidden layer

The selected neural network model was used to determine the stability of the process of ore mining in the G1 division. For this purpose, test data were prepared, and the "score" node of the SAS Enterprise Miner 6.2 environment was used.

The test data contain various variants of changes in input attributes (independent variables). For such data, the selected neural network model predicts the values of the output, which are interpreted in the context of the stability of the mining process. Sample test data, along with the predicted production volume, are presented in Tab. 3, Tab. 3, and Tab. 3. The planned output volume was set at 330 t. For the needs of the study, an assumption was made that the ore production is stable if the absolute value of the variation in the production does not exceed 20 tonnes. This corresponds to unrigs two haulage rigs per shift. Tab. 4 shows the production volume predicted by the ANN model depending on the length of the haulage road.

Tab. 4. Predicted production volume for the grate No. 1, the road for mining loaders 70m and road condition 2 at variable lengths of the haulage roads.

Network inputs				**Network outputs**
Gate No.	**Road for mining loaders** [m]	**Road for haulage rigs** [m]	**Road condition** [m]	**Anticipated output** [t]
1	70	900	2	350
1	70	1000	2	335
1	70	1100	2	315
1	70	1200	2	268
1	70	1300	2	240

The data included in Tab. 3 presented in the context of the process stability, are shown additionally in Fig. 9.

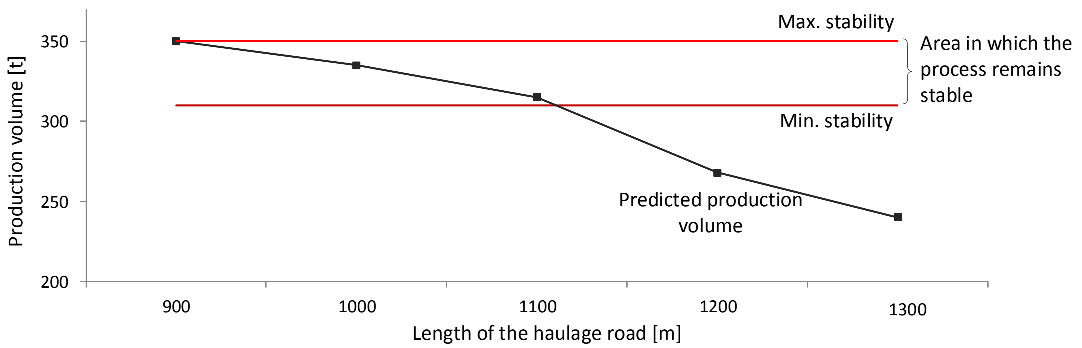

Fig. 9. Predicted production volume for the grate No. 4 at variable lengths of the haulage roads.

As it results from Table 4 and Fig. 9, the process becomes out of unstable, if the haulage road is extended to 1200 m. At this length, it is not possible to execute the assumed production plan. This is an indication for the decision-maker that the values of input variables should be changed, for example, by improving the condition of the roads.

Tab. 5 presents the production volume predicted by the ANN model depending on the condition of the haulage roads.

Tab. 5. Anticipated output for the grate No. 3 at variable road conditions.

Grate No.	**Road for mining loaders** [m]	**Road for haulage rigs** [m]	**Road condition**	**Anticipated output** [t]
2	50	1200	1	325
2	50	1200	2	299
2	50	1200	3	259
2	50	1200	4	185

The data presented in table 5 are illustrated also in Figure 10 in the context of the stability of the production process.

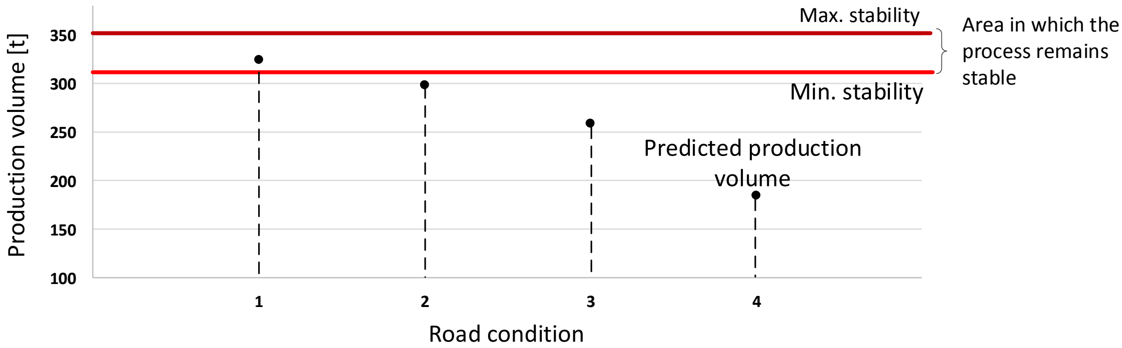

Fig. 10. Predicted production volume for the grate No. 3 at a variable condition of haulage roads.

As it results from table 5 and figure 10, for the the assumed lengths of the haulage road and the distance traveled by a mining loader when rigs a haulage vehicle, the process will remain stable only if the haulage road is even and dry. In other cases, it is not possible to execute the assumed production plan without changing the values of other input parameters.

Table 5 shows the production volume predicted by the ANN model, depending on the length of the haulage road travelled by a mining loader when rigs a haulage vehicle.

Tab. 6. Predicted production volume for the grate No. 4 for a variable length of the haulage road for the backhoe loader used to load haulage rigs.

Grate No.	**The road for mining loaders** [m]	**The road for haulage rigs** [m]	**Road condition**	**Anticipated output** [t]
1	30	1000	4	300
1	40	1000	4	264
1	50	1000	4	225
1	60	1000	4	194

Fig. 11 illustrates the data from Tab. 6 in the context of the stability of the rigs and haulage process, that is, the planned production volume of 330 t ± 20 t, depending on the length of the road traveled by a mining loader.

As can be seen from Tab. 6 and Fig. 11, there is no possibility that with the given parameters, it is possible to implement the production plan. In this case, it would be necessary to check whether the implementation of the plan will be possible if the weaning will take place on a different grate or the condition of the haulage will be improved.

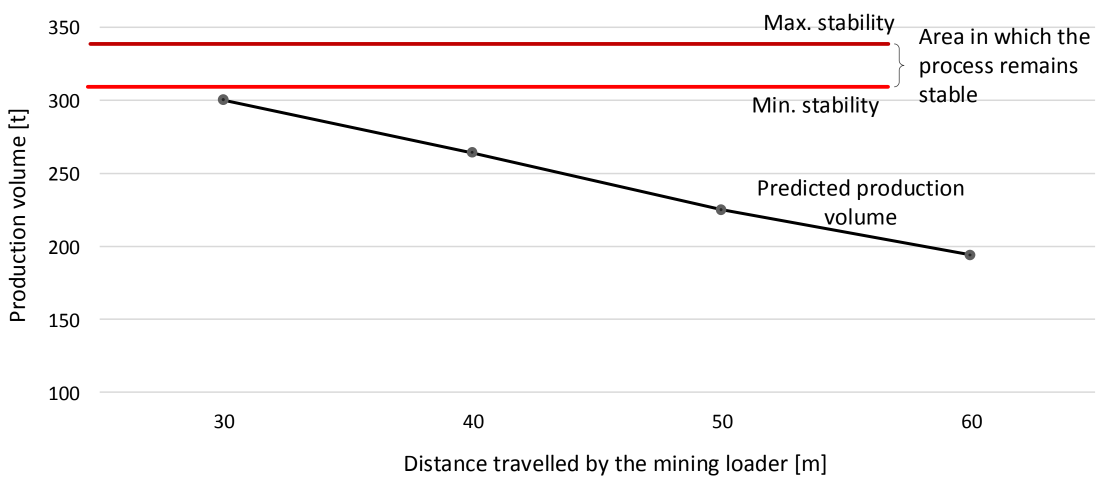

Fig. 11. Predicted production volume for the grate No. 1 at the variable length of the haulage road for the mining loader.

Optimization model of the loading and haulage process

Managers wanting to influence the total costs of the process should check, using the appropriate tools, previous process input parameters, and their implementation, and become familiar with the reasons for exceeding the assumed cost level and should predict the consequences of decisions and their impact on improving operational efficiency from a cost perspective. By analyzing the impact of alternative decisions at the production process control stage, one can estimate the level of total costs before decisions are taken and the resources needed to implement them are used. Process optimization often leads to problems where there is a need to solve the issues of process quality assessment based on more than one objective function. The Pareto method can be used to solve the above issues (Plonka and Oginski, 2014). Let us denote the considered set of variants of the studied process as W, where:

$$W = \{W_1, \dots, W_R\}. \quad (6)$$

A given variant has a specific set of value of cost-generating factors x_1, x_2, d, k, set by an artificial neural network, that is, such process parameters that unambiguously determine the value of variables regarding separated cost components and the way they are determined. The solutions received at this stage differ in the length of the loader's route, the frequency of the loader's haulage, the length of the haulage's road, the frequency of the haulage rig, the condition of the road, the availability of the grate, sometimes the haulage. Taking into account the above differences, it is necessary to select the variants according to the basic criteria: cost, obtained output and, indirectly, the processing time.

The optimization criteria for the selection of parameters are:

- mining in tonnes n, which is a function of variables x_1, x_2, d, k set by an artificial neural network, where $d \in \{1,2,3,4\}$ is a variable depending on the condition of the road, and k is the number of the grate,
- the total cost of loading and haulage, which is a function of variables x_1, x_2 and d. Crate number k is related to the variable x_2. The analysis of the generated variants aimed at comparing them with respect to the optimization criteria and determining the area of possible solutions is presented in Fig. 12. Limitations on optimization are:
- extraction, for which the process is stable (s_{min}, s_{max}) the size of the planned production ranges from 310 t to 350 tons,
- eligible cost k_{dop} – the value of this cost of 5,600 uc results from the adopted budget, in which the average cost from previous periods was reduced by 7 %.

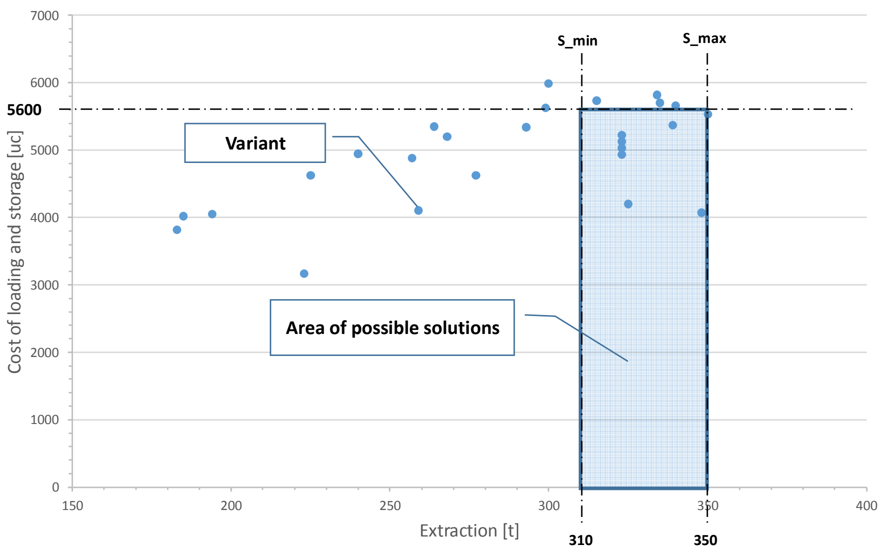

Fig. 12. Optimization of the loading process and spacing in the Pareto sense.

By introducing an additional restriction related to the permissible cost, for which $K_{lh} \leq K_{dop}$ the number of acceptable variants obtained in the previous step was reduced in determining process stability. If the variant $W(x1, x2, d, k)$ it is located in a set of possible solutions, the process will remain stable while maintaining the appropriate level of costs.

The generated variants can also be analyzed in terms of the economic efficiency of the loading and haulage process in order to compare them with each other and choose the final solution from Pareto solutions, for which profitability is the highest.

Economic efficiency of loading and haulage process

The measure of the economic result in the created model is the profitability calculated as the difference of revenues obtained at this stage of the process and the actual costs of loading and haulage. The starting point was determining the size of resources possible to extract for the adopted variant, from a set of possible solutions. Contractual income was determined as the product of the number of products/output to be obtained at this stage and the contractual unit internal price in the amount of 4uc. The use of internal prices allows establishing the responsibility for the size of the generated profit for separate units. If there is no internal price, the contractual revenue can be determined on the basis of the allowable cost. In this situation, the unit is only responsible for the level and cost control. The actual loading and hauling costs are in turn determined as the product of the quantity of extracted ore and the actual unit operational costs.

Finally, the function determining the profitability of extraction depending on the size of the output n and ways of loading accordingly x_1 and haulage x_2 is given in the model (7). It is important to remember that n is a function of variables x_1, x_2, d, k, set by an artificial neural network.

$$D(x_1, x_2, n) = 4 \cdot n - \left(\frac{n}{4}(0{,}012x_1 + 0{,}64) \cdot 10 + \frac{n}{20}(0{,}005x_2 + 0{,}55) \cdot k_d \cdot 30\right), \qquad (7)$$

where kd is a coefficient depending on the variable value d, that is, the condition of the route.

Finding optimal ways of loading and hauling boils down to determining the vector (x_1, x_2) from the area of possible solutions, maximizing the function D in this area. Knowing the parameters of the artificial neural network, that is, the weight between individual neurons of the network and the form of the neuron activation function, this problem can be solved using the so-called gradient method. For this purpose, however, it is necessary to set the values of discrete variables d and k in advance (k_d), to ensure the differentiability of the function D.

In the gradient method, the first data vector is randomly determined $\left(x_1^{(1)}, x_2^{(2)}\right)$ from the area of possible solutions and the function gradient is calculated D in point (x_1, x_2) according to model (8) – in the record, as variables of the function, the variables d and k are omitted, whose value is fixed.

$$\nabla D(x_1, x_2) = \Big[(1{,}575 - 0{,}03x_1 - 0{,}0075x_2) \cdot \frac{\partial n}{\partial x_1}(x_1, x_2) - 0{,}03 \cdot n(x_1, x_2),\ (1{,}575 - 0{,}03x_1 - 0{,}0075x_2) \cdot \frac{\partial n}{\partial x_2}(x_1, x_2) - 0{,}0075 \cdot n(x_1, x_2)\Big] \quad (8)$$

where:

$\frac{\partial n}{\partial x_i} = \frac{\partial f}{\partial net}(x_1, x_2) \sum_{j=1}^{m} w_j^2 w_{ji}^1 \frac{\partial f}{\partial net_j}(x_1, x_2)$, $\quad i = 1{,}2$,

$net_j = \sum_{i=1}^{2} w_{ji}^1 x_i$, $\quad j = 1, \dots, n$ – input *j*- this neuron of the hidden layer,

$net = \sum_{j=1}^{m} w_j^2 f(net_j)$ – the input of the output neuron,

$f(t)$ – neuron activation function,

w_{ji}^1 – connection weight *j*- this neuron in the hidden layer of *i*- this network input,

w_j^2 – connection weight - this neuron in the hidden layer with the output neuron.

Having set a gradient ∇D in point $(x_1^{(1)}, x_2^{(1)})$ a new point is defined $(x_1^{(2)}, x_2^{(2)})$ according to model (9).

$$(x_1^{(2)}, x_2^{(2)}) = (x_1^{(1)}, x_2^{(1)}) + \eta \nabla D(x_1^{(1)}, x_2^{(1)}), \quad (9)$$

where η is a predetermined positive constant, as small as possible.

For point $(x_1^{(2)}, x_2^{(2)})$, the function D gradient is again determined, and the next point is determined analogously. The algorithm is repeated until the gradient $\nabla D(x_1^{(n)}, x_2^{(n)})$ is close to zero (absolutely smaller than the given positive constant ε) or when the number of algorithm steps exceeds the set threshold N or the designated point does not belong to the area of possible solutions (in this case, the last point belonging to the area of possible solutions is considered the optimal point).

The discovered point $(x_1^{(n)}, x_2^{(n)})$ approximates the vector maximizing the function determining profitability.

Conclusion

When managing the production process, attention should be paid to maintaining an adequate level of costs and time of production orders. However, modern enterprises are very complex and are characterized by high dynamics of manufacturing processes. In such conditions, making decisions becomes difficult and involves high risk. The solution to this problem may be the construction of models of manufacturing processes based on which decisions will be made. On the one hand, the models allow to limit the level of complexity and interaction with other elements of the real system, on the other hand, they contain all the important elements and features from the point of view of the research objective. Models of artificial neural networks can be used to control the production system, and so to ensure its stability. The ease and speed of their construction make them a very useful tool. The only problem remains a large amount of data needed in the network learning process, which, however, in the era of the universality of information systems, parameterization and standardization of production processes cease to be a problem.

Incorrect decisions made due to the lack of appropriate tools for comprehensive process control lead to high costs, and failure to comply with the production plan will result in a loss for the entire undertaking in a given period. The use of the method of determining the costs of the copper ore exploitation process presented in the article allows identification of the costs of activities and related cost factors, and at the same time ensures the reliability of services and managers in controlling the loading and haulage process. Thanks to the proposed solutions, it is possible to inform decision-makers for existing work conditions about the ability to implement a given mining plan, the cost of this process and the possibility of reducing them by paying attention to the parameters of options from the possible solutions and parameters of the optimal variant for the given output. The use of the above solutions enables a significant reduction of costs at the stage of controlling the operation process which has an impact on the total costs and economic efficiency of the enterprise and actively influences the cost planning in the future when making important decisions for this process.

The proposed methods require the implementation of the operation cost calculation, the registration of input parameters, internal price setting for units, and for the charging process and discontinuation of the output from the proposed artificial neural network, determination of the cost limit and application of the proposed optimization model in the Pareto sense. The proposed solutions have been adapted to mining systems operating under the conditions of a given enterprise.

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Design of the construction and research of vibrations and heat transfer of mine workings

***Elena Pivarčiová*[1], *Kseniia Domnina*[2]** *and* ***Zuzana Ságová*[3]**

The creation of safe conditions for the operation of underground facilities is one of the main tasks of ensuring the stability of mine workings. Today, in conditions of great depths and external dynamic loads, it is necessary to ensure not only the strength of the linings but also their resistance to seismic, vibration, and thermal effects. The solution of this problem is the usage of multi-layer combined linings, which expand the possibility of using various materials for fastening openings in difficult mining and geological conditions.

This paper presents a study to determine the usage of concrete for standing support of walls and roof in a mine. It deals with the research of vibrations and heat transfer of mine workings. The construction of a three-layer vibration-resistant rigid-pliable lining for mine workings has been developed. Its pliable outer layer is made of foam concrete reinforced by PET fiber, the inner layer is the sprayed concrete layer with PET-fiber reinforcing, and the middle layer is a closed concrete ring of the rigid lining.

In the article, the mathematical model of impact-wave deformation of the lining ring from external seismic and impulse loads is formalized. The course of temperature fields above the heated sample is also studied.

Key words: *vibration, heat transfer, mine workings, concrete lining.*

Introduction

In the mining operations within mines are used large quantities of concrete products, primarily in roof supports. Other uses are for walls, floors, rail ties, and also for small temporary buildings, props, and blocking for machinery (Budaj et al., 2018). Concrete is used to support mine roofs. Concrete props are loaded perpendicularly to the roof and floor for maximum strength. Props are used in faces, mine entries, and along haulage corridors (Stone et al., 1985). Standing supports in the form of posts and wood cribs have been used since the earliest days of underground mining and remained the most common form of support in coal mines until new support products were developed in the early 1990s (Barczak, 2005). Roof support is essential to the safety of every underground miner. It has three primary functions: first, to prevent major collapses of the mine roof; second, to protect miners from small rock falls that can occur from the immediate roof skin; and third, to control deformations, so that mine openings remain serviceable for both access and escape, as well as for ventilation of the mine workings.

Application of concrete is necessary to resist instead of vertical load stress, maximum horizontal stress, and the minimum horizontal stress underground. The roof load is the vertical force that applies to roof support most directly. Longwall mining concrete and pillar recovery can concentrate large vertical loads on gate entries and pillar lines. Appropriate wood and concrete pillar sizing are essential for limiting the roof stresses and deformations to levels that can be handled by roof support. The correct column can greatly reduce the loads applied to the roof. Vertical supports column, like concrete, wood, or longwall shields, develop loads in response to the convergence between the roof and floor (Mark and Barczak, 2000).

There are localities where wood is not only unusual but where the wooden types available are not suitable for even light ground support. Concrete sets deserve consideration for these localities. Wood props are sometimes used where the roof above the seam consists of relatively massive rocks that do not cave easily. In most circumstances, wood props are not suitable for coal faces where the system of work is such that they would have to be advanced during each cycle (Wing, 2002).

The usage of concrete sets is appropriate for light ground support when suitable wood is difficult to get. Because this substitution of concrete for wood may be principally an economic problem, the relative costs must be carefully compared. Concrete supports column for mines serve a purpose much different from those for ordinary concrete structures. Concrete is used as a substitute for wood when the latter is difficult to obtain in quantity or when mine conditions are conducive to rapid deterioration of wood. Reinforced concrete is unlikely to fail instantly (Michaud, 2017). Foam concrete blocks and lightweight aggregate blocks also can be used to build roadside packs. Without reinforcement, packs built of these materials are liable to collapse under relatively

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small loads. The number of concrete supports column under each bar should be sufficient to maintain the required support density over the width of the face working (Wing, 2002). Before 1980, timber was the dominant support material with wood cribs and timber posts used exclusively for tailgate and breeder support. Concrete, with the compressive strength and material modulus an order of magnitude higher than wood, had to provide superior roof support as was thought at the time (Barczak, 2005).

This paper presents a study to determine the usage of concrete for standing support of walls and roof in a mine. It deals with the research of vibrations and heat transfer of mine workings.

Analysis of the problems

As a rule, the problem of ensuring the strength of all types of linings is solved. However, at present, the volume of mine workings carried out in complex geological conditions (high seismicity, neotectonic phenomena, etc.) is continuously increasing. In this case, an additional requirement for resistance to seismic and vibration effects should be presented to the linings, which is not reflected in any regulatory document.

During operation, linings are exposed to natural (seismic activity) and man-made (caused by human activity: blasting and construction work, traffic) vibrations. Vibration can cause damage to the lining, reducing its operational reliability: decrease stability, degrade the carrying capacity.

Natural and man-made vibrations, perceived by the constructions of the linings, differ in their nature. Vibration from natural sources is concentrated in the lower frequencies, characterized by high power in the source and extends over long distances.

Vibration can cause significant damage, so in places of constant or expected action of vibration sources, special requirements should be placed on the lining structure:

- the lining material must be resistant to dynamic loads;
- structural lining elements must be interchangeable;
- fastening elements of the lining should not only ensure the rigidity of the connection but also dampen vibration.

At great depths, traditional single-layer supports (metal, concrete, ferroconcrete) are ineffective, because the main material of the structure of the lining forms an almost rigid structure, and with intensive displacements of the contour rocks, the production is destroyed. Under the conditions of dynamic action, fiber-reinforced concrete structures are the most effective.

Materials and methods

Overview of existing types of the lining of horizontal mine workings and requirements for them

In recent years, the approach to safety at underground facilities has changed significantly. Mines are becoming deeper and deeper, which poses a serious challenge for the industry to control mine workings at elevated temperatures, strains, and pressures. To solve these problems, it is necessary to introduce not only a more advanced technique but also advanced technologies for mine working and consolidation of rocks.

The main means of ensuring the sustainability of mine workings throughout the entire service life is the erection of lining.

The lining of mine workings performs a number of important functions to protect the underground structures from rock falls, to ensure the design dimensions of workings, the perception of external and internal loads, to prevent the destruction of rock mass from weathering. There are many lining structures that are successfully used in large depths. In the modern classification of the lining of mine workings, the main classification feature determining the type of lining is its purpose, that is, for which group of underground workings lining is intended (Baklašov and Kartozija, 1984). On this basis, the lining can be divided into the lining of capital (overburden), preparatory, and treatment workings.

In accordance with the current classification, all currently existing lining of capital and preparatory mine workings are divided into three classes according to the main structural and technological features: frame, solid and anchor (Aksenov et al., 2012). In turn, the linings of the first two classes depending on their contour are divided into two subclasses: with an open and closed contour. Besides, the solid lining can be monolithic and prefabricated. The class of anchor linings is also divided into two subclasses: with the fastening of anchors in the bottom part of the well (with distance lock devices) and with the fastening of anchors along the entire length of the well or a significant part of it.

Each of the subclasses of the frame and solid linings is divided depending on the conditions and nature of the interaction of the lining with an array of rocks and constructive solutions into groups: rigid, pliable, hinged, hinged-and-pliable. In addition, each of these subclasses, as well as classes of anchor linings, depending on the material used for their manufacture are metal, wood, concrete, reinforced concrete, polymeric and mixed. The subgroup of lining determines the material of the main (bearing) structure or element of the lining.

By the nature of the work, linings are enclosing, insulating, and bearing. Fencing linings are designed to protect people and equipment from accidental local dumping of pieces of rock. Insulating linings are designed to protect the outcrops of rocks in the workings from weathering, waterlogging, leaching and cracking. Bearing linings have the main purpose to perceive the load from the mountain pressure.

According to the deformation characteristics linings can be rigid (offset up to 50 mm), little pliable (up to 100 mm), pliable (up to 300 mm) and very pliable (more than 300 mm).

By the structure, linings can be single-layered and multi-layered.

According to the methods of erection, linings are ordinary and special (hammered, crushed, submerged, lowered, pre-compressed, etc.).

By the ability to move linings can be stationary and mobile.

In accordance with the main regulatory documents, the mining lining must meet a set of technical, economic, and functional requirements:

- to withstand the pressure of rocks without breaking and to ensure the working condition of the production throughout the entire service life;
- to be technological (simple to manufacture), transportable, easy to use during construction in the mine, available in service during operation;
- not to interfere with the implementation of production processes in the development;
- to be resistant to corrosion and decay;
- to ensure minimum material and labor costs for the construction and operation of the lining.

Influence of vibration on the lining

Vibration is a mechanical oscillation: a combination of impact and alternating load. Tension or compression deformations occur when oscillations propagate in a solid. Wave motion is an oscillatory process in which the oscillation energy is transmitted in the direction of wave propagation. The cause of the oscillatory process is constant or single external influences. As a rule, single external oscillations are harmonious and obey the sinusoidal law. Oscillations are constant with a constant impact of forces; oscillations turn into damping when the action of forces ceases.

If the solid in which the oscillation process takes place is based on an elastic base, then the vibrations are reflected from this base, and the waves go in opposite directions. The phenomenon of resonance, that is, the summation of the vibrational wave energies may occur. Resonance can also occur under the action of a variable in time, but constant in duration load. The impact of an impulse can create waves that go parallel to each other and overlap, increasing the amplitude of the oscillatory process. Resonance is undesirable for the construction, as it leads to the destruction of the construction of any strength (Gao et al., 2018).

Direct and reverse impulses (compression and tension) of the oscillatory process alternate each other. Alternating loads appear in the solid, which leads to the phenomenon of material fatigue and destruction of its structure. Fatigue always occurs, but the time of steady state may be different. It depends on the strength of the impulse of the oscillating wave impact and the strength characteristics of the construction. These elements are determined only by experience (Lu and Zhao, 2013).

To ensure the strength of the concrete lining, the stresses arising in the construction must meet the following condition:

$$\sigma = \frac{R_{im}}{A_{im}} \leq [\sigma], \tag{1}$$

where R_{im} is the impact force; A_{im} is the area of the impact: for the lining of a circular cross-section $A_{im} = \pi d \frac{\lambda}{2}$, where d is the diameter of the lining, λ is the wavelength of the impact; $[\sigma]$ is the permissible tensile or compressive stress for the concrete lining.

The impact force can be determined in two ways.

1. Based on the theory of oscillations of mechanical systems, harmonic oscillations are described by the equation (Birger, 1968):

$$x = A\sin(\omega t + \varphi), \tag{2}$$

where A is the oscillation amplitude; $\omega = \frac{2\pi}{T}$ is the circular oscillation frequency, where T is the oscillation period; t is the current time; φ is the initial phase.

With harmonic oscillations the speed and acceleration also change according to the harmonic law:

$$\upsilon = A\omega\cos(\omega t + \varphi);\tag{3}$$

$$a = -A\omega^2 \sin(\omega t + \varphi) = -\omega^2 x.\tag{4}$$

According to Newton's second law:

$$F = ma = -mA\omega^2 \sin(\omega t + \varphi) = -m\omega^2 x.\tag{5}$$

2. Evaluation of the concrete quality can be carried out by the impact wave method, which is based on measuring the velocity of propagation of longitudinal waves in it, caused by mechanical impact. In its physical essence, the impact wave method is based on using of the dependence "R_b – v_{im}", where R_b is the indicator of the concrete compressive strength; v_{im} is the speed of the impact wave.

According to the condition, the impact force must be such as to ensure the creation of a sound impulse in the construction, but not even cause a local violation of the concrete structure. The generated sound impulse propagates at a certain speed in concrete. To determine the speed on the surface of the investigated construction, it is necessary to install two sound receivers sequentially at a given distance. The sound impulse received by the first receiver is converted into an electrical signal, which turns on the microsecond meter after amplification.

When it reaches the second sound receiver, the sound wave, in the same way, turns off the microsecond meter, which will record the distance between the two sound receivers by the sound pulse.

The speed of the sound wave of a mechanical impact is calculated by the formula:

$$\upsilon_{im} = \frac{l}{t_{im}} 10^3,\tag{6}$$

where l is the distance between the sound receivers; t_{im} is the time of propagation of the impact wave.

The strength is determined on the basis of the dependence "R_b – v_{im}".

The value of R_b for concrete can be calculated by the following formulas:

for $R_b \leq 30MPa$

$$R_b = q\upsilon_{im}^4;\tag{7}$$

for $R_b > 30MPa$

$$R_b = \frac{R_0 \upsilon_{im}}{8{,}87\upsilon_0 - 7{,}87\upsilon_{im}},\tag{8}$$

where q is the coefficient calculated as $q = \frac{R_b^{act}}{\upsilon_{im}^4}$, where R_b^{act} is the actual compressive strength of concrete; R_0 is the strength of concrete at the construction site, where the maximum velocity of the impact wave v_{max} was found not less than at five sites; v_0 is the initial velocity of the impact wave.

The proposed vibration-resistant structure of the lining

A promising construction that extends the use of various materials for securing workings in difficult conditions is a multi-layer combined lining.

For effective sound absorption and vibration isolation, the following lining construction is proposed (Fig. 1).

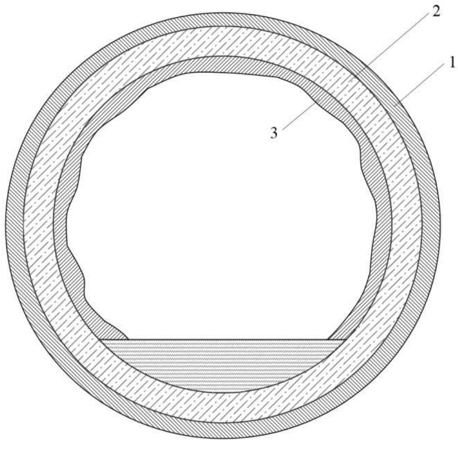


Fig. 1. The proposed construction of a fiber-reinforced lining: 1 is the layer of reinforced foam concrete; 2 is the layer of precast fiber concrete; 3 is the sprayed concrete layer.

The lining has a circular cross-section, which is the best option both in terms of structural parameters, providing durability and reliability, and in ease of manufacture.

The design of the lining is three-layered, consisting of three shells with a layer of moving material between them. The middle layer (2) is load-carrying and has a rigid structure. The outer (1) and inner (3) layers are pliable and vibration-proof, providing sufficient resistance to the displacement of the output circuit in the formation of fracture zones. The material for the load-carrying layer (2) is selected depending on the geological conditions and is calculated by the formulas (1)-(8). The materials used to create a pliable layer must meet the requirements of sufficient strength and the ability to resist loading, sufficient cheapness, the ability to work for a given service life of production, as well as technological applications in real conditions. In the proposed lining construction as the material of the outer layer (1), it is recommended to use non-autoclaved foam concrete reinforced by polyethylene terephthalate fibers (PET fiber) (Domnina and Pivarciova, 2019; Qaizada et al., 2016). This layer is intended for damping natural and human-made vibrations, and one of the conditions for its creation is that both the material of the layer and the reinforcement must dampen vibrations. Foam concrete absorbs sound and vibration well without reflection due to the cellular structure. PET fiber is a high-strength polymer material (Sviatskii et al., 2018). The polymers simultaneously possess the properties of both liquids and solid elastic and plastic bodies. Plastic deformations absorb impact load by changing their own shape, and they do not return to their original shape and size. Plastic materials during operation accumulate changes in shape before losing steady state as supporting structures, and they must be calculated for a certain number of strokes, after which they are not workable. It is necessary to take into account, plastic deformation due to large forces often turns into deformation of fluidity, in which the action of the impact force is not felt, there is only the movement of the compressed layer. However, when elastic barriers are reached, the impact may remain noticeable, so it is more advantageous to use plastic deformations rather than fluidity deformations. Plastic deformations absorb impact without return.

The middle layer of the lining (2) is proposed to be made of heavy concrete. The lining construction is assumed to be in block design.

The usage of the sprayed concrete as the inner layer of lining (3) allows simplifying the process of attaching a pliable layer on the walls of the middle layer significantly. As a pliable element, sprayed concrete with PET fiber inclusions can be considered. The significant difference of such an element is that the bearing element in the composite is the matrix, and the pliable element is the inclusion of fibers. After the stresses in the matrix reach their limit values, the matrix is destroyed, and the pliable elements, in this case, they are PET fibers, provide the movement of the contour of production on the technologically acceptable value.

As a moving material between the layers, it is proposed to use graphite deposition with a thickness of up to 5 microns. The purpose of graphite is to reduce friction between concrete layers.

Impact-wave model of ring deformation from external seismic and impulse loads

In our case, the most realistic model of impact deformations is presented in Fig. 2. It is convenient to consider a separate layer of lining as a rod along the line of action of the impact force P_z: $L = d_r$, where d_r is the diameter of lining ring. Since the speed of passage of an impact wave is close to the speed of sound, and the rate of deformation of the layer of lining as a ring is too slow, it can be neglected. During this time, the impulse will have time to deform the entire material of the layer, and the shape of the ring will not change. If the impulses come with great frequency, the ring can break from the fatigue of the material, and not from changes in its shape.

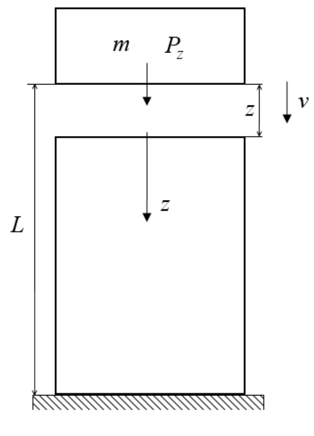


Fig. 2. Impact scheme: L is the length of the rod, v is the speed of the impact force, m is the mass of the soil.

Between the impact force and the rod, there is an element with a certain compliance δ. In our case, this element is the outer layer of the lining (1) made of fiber foam concrete). Since plastic deformation goes layer by layer, the next stage of the continuation of the impact deformation repeats the first one with the only difference that the length of the rod becomes less by the amount of plastic deformation of the previous layer Δz. The impact speed remains constant. The work of the impact force is not only on the course of deformation but also on the heating of the deformable layer of material (Virieux et al., 2012).

So the mathematical model of impact -wave deformation of the lining ring from external seismic and impulse loads can be represented by (Repko, 2005):

$$\left.\begin{aligned}
&P_z = \frac{v}{\delta k_1 c}\cdot e^{-k_2 cT}\cdot \sin k_1 cT; k_1 = \sqrt{\frac{1}{E\cdot F\cdot \varsigma\cdot L\cdot\delta} - \frac{1}{(2EF\delta)^2}}; k_2 = \frac{1}{2EF\delta};\\
&P_{-z} = \frac{\frac{\pi\cdot l}{W}\tau_n\cdot v(L-W)}{v^2\cdot\Delta T_0 - W\cdot v}\cdot z^2 + \left[\frac{\tau_n\cdot\pi\cdot l\cdot(L-W)}{W} - \frac{\pi\cdot l\cdot\tau_n\cdot v(L-W)}{v^2\cdot\Delta T_0 - W\cdot v}\right]\cdot z;\\
&\frac{cT}{L} = \pi\sqrt{\varsigma}; W = \frac{4(1-v^2)P_z}{\pi\cdot b\cdot E}\cdot\frac{\pi}{2}; l(P_z = 0) = 0;\\
&U_m = \frac{mv^2}{2}; \tau_n = [\tau_n]; \tau_{\min} = 0{,}01[\tau_n]; z = v\cdot T;\\
&\Delta\theta = \frac{z_0 - \left[\left(1+\frac{vP_z}{2abE}\right)z_0 - \frac{P_z}{bE} - \frac{v}{2}\frac{P_z{}^2}{a\cdot b^2\cdot E^2}\right]}{\beta\cdot z_0} \le [\theta],
\end{aligned}\right\} \quad (9)$$

where P_z is the impact force;

v is the speed of the impact force;

δ is the coefficient of compliance of the outer fiber foam concrete layer;

c is the speed of the impact wavefront;

T is the compression time per a single stroke;

E is the modulus of elasticity of concrete;

F is the cross-sectional area of the rod;

ς is the mass equivalent to the part of the mass enclosed in a strip of positive or negative impact wave of the oscillatory process of the soil;

L is the rod length;

P_{-z} is the impact resistance force;

l is the width of the load bearing support;

W is the volume of the compressible lining layer;

τ_n is the ultimate shear stress occurring in a lining layer;

ΔT_0 is the duration of one impulse;

z is the impact half-wave length: $z = \frac{\lambda}{2}$;

cT is the length of the passage of the impact wave;

a, *b* are parts of the impact area;

U_m is the impact energy;

m is the mass of the soil located in the strip of positive or negative impact wave and transmitting vibration to the structure of the lining;

$[\tau_n]$ is permissible ultimate tangential stress;

τ_{min} is minimum tangential stress;

$\Delta\theta$ is the temperature difference before and after impact;

z_0 is the value at which the maximum tangential stresses τ_{max} occur at the impact force P_z, leading to plastic shear;

β is the coefficient of volumetric thermal expansion of concrete;

$[\theta]$ is the permissible temperature in the impact zone.

Using the task (9) the stresses arising from vibrations and the heating temperature of concrete rings from the action of impact waves are determined. It is necessary not only for the modeling of strength and stability of constructions to vibration but also to establish the safety of explosive proportions of combustible gases in the mine.

Fatigue issues require a separate approach. It is necessary to conduct a number of experiments to determine the fatigue of concrete, and the results of the experiments should be compared with the conditions of the passage of impact waves in specific mines.

Visualization and analysis of concrete temperature fields

Monitoring of the stress resulting from the heating temperature of the concrete rings from the impact of the impact waves is necessary to determine the safety of explosive proportions of combustible gases in the mine (Xiaobing and Xueping, 2011).

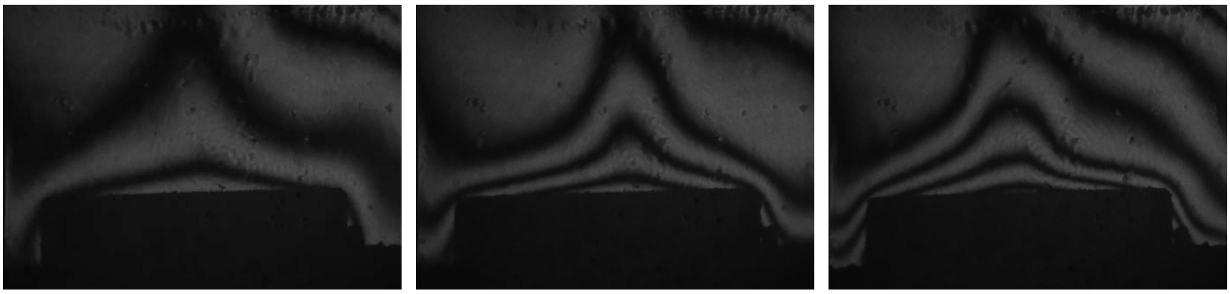
Therefore, part of the research was devoted to the visualization and analysis of temperature fields over heated samples of concrete reinforced with polyethylene terephthalate (PET) fibers, which are obtained by recycling polyethylene terephthalate waste.

Holographic interferometry was used to visualize the temperature fields. This method has been able to detect temperature fields without touching and to monitor and record in real time the on-going process in the boundary layer at the concrete interface – the ambient environment. By a quantitative analysis of the images of holographic interferograms, the temperatures of the isothermal curves above the heated samples were determined.

The goal was to gain new knowledge about the thermal properties of concrete. The samples of size 40×40×15 mm were used to measure heat transfer. An infrared emitter with a power of 225 W was used as a source of heating.

In Fig. 3, we can see the course of temperature fields above the heated sample. We can observe a uniform increase in the thickness of the thermal boundary layer. Interference strips represent isothermal thermal field curves. By a quantitative analysis of holographic interferograms, the temperatures of the isothermal curves were determined. For more information about the method used and the relationships used, see the literature (Pivarciova and Cernecky, 2011; Černecký et al., 2014).

start the experiment *8 minutes of heating* *12 minutes of heating*



14 minutes of heating *22 minutes of heating* *31 minutes of heating*

Fig. 3. Holographic Interferograms of concrete temperature fields.

In Fig. 4, there is a graph showing the temperature above sample calculated from holographic interferograms.

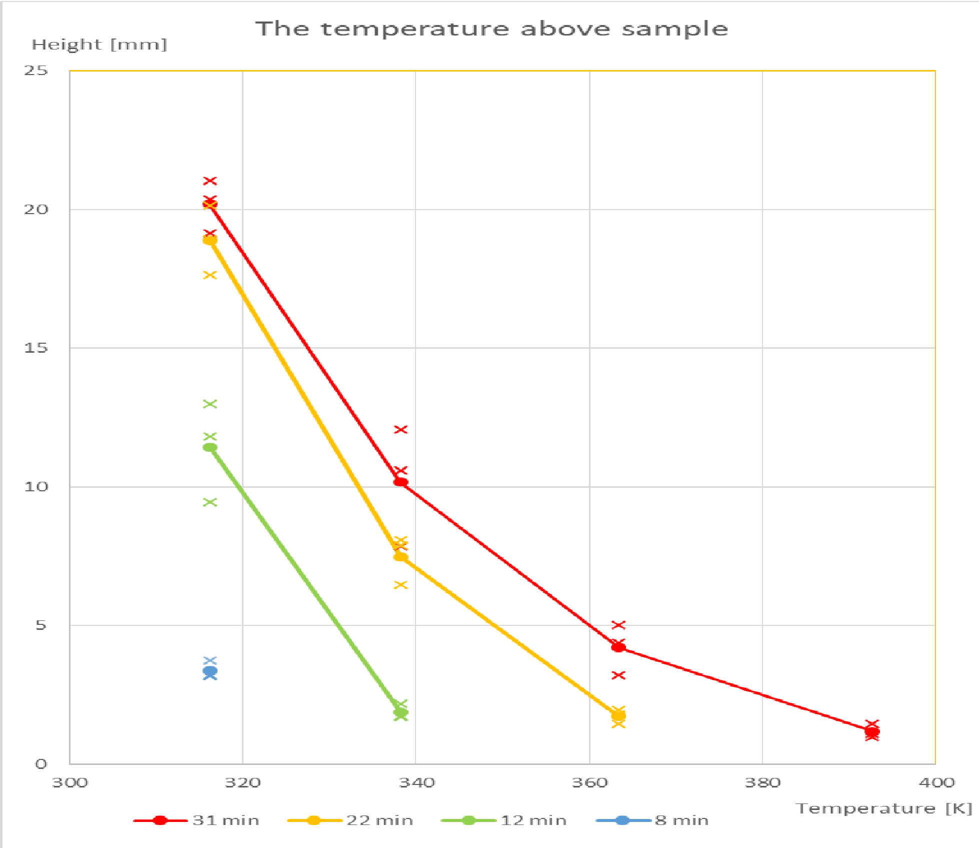


Fig. 4. Temperature above sample.

Heat transfer is a combined case of heat sharing between two fluid-separated walls. From warmer fluid to solid wall, heat passes through convention, conduction, and radiation; solid wall transmits heat through conduction and from the wall to the cooler fluid again by convection, conduction, and radiation.

Along the solid wall in the direction of the liquid stream, a thin layer of fluid is formed, called the thermal boundary layer. It is formed by the adhesion of the fluid molecules to the surface of the solid body. Sharing of heat in this layer is only convection as if the fluid was still. The large temperature gradient in the boundary layer results from the low thermal conductivity of the fluids.

In the transport process, it is also difficult to find that their mathematical analysis is only possible with a number of simplifications, but it also gives rise to systems of differential equations which in many cases cannot be solved. Due to the complexity of the theoretical solution of transmission phenomena by mathematical and modeling methods, which always presuppose certain simplifications, optical methods can be used to solve these problems.

One possible application of holographic interferometry is to visualize the temperature distribution. The interference method allows not only to evaluate the observed phenomena quantitatively, but also gives a comprehensive picture of the size and shape of the temperature fields at a given time, and the measured values are not influenced by the sensor. Another advantage of this method in real-time is the possibility of recording the entire time course of heating. This method allows monitoring the temperature field as a whole, not just local variations, as measured by thermocouples.

The demonstration of the temperature field in the neighborhood of the heated oven in the case of natural convection of air is shown in Fig. 5. In the interferogram image, the temperature boundary layer is visible, in which the air flows upwards. Behind the boundary layer is the surrounding environment with constant air temperature. The thermal boundary layer gradually evolves around the circumference of the oven and extends towards the top. This expansion of the boundary layer causes a reduction in the temperature gradient as well as a reduction in the heat transfer parameters.

An experimental and numerical investigation of the influence of insulation defects on the thermal performance of walls is deal work (Nardi et al., 2019).

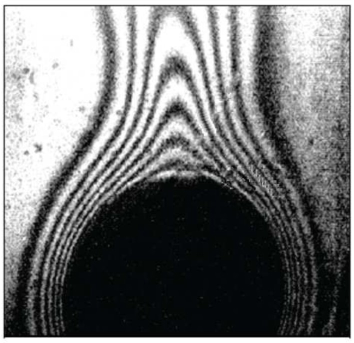


Fig. 5. Demonstration of the holographic interferogram of the temperature field in the surroundings of the heated oven in the case of natural convection of air.

Results and Discussion

In our research, we proposed a new construction of a three-layer vibration-resistant rigid-pliable lining for mine workings. Multi-layer concrete constructions are good because they simultaneously have high strength, wear-resistant, sound insulation, and low thermal insulation properties.

Depending on the purpose and conditions of operation, multi-layer concrete constructions can be used as road surfaces in Siberia and the Far North and airfield coatings. Rational distribution of materials in depth should be established on the basis of the laws governing the formation of a stress-strain state of the structure.

They can also be a solution to the problem of sound insulation of compressor stations and busy highways (usage as enclosing panels). In recent years sound insulation instructions and standards have been updated. The main factor in the updated instructions affecting modern construction is the tightening of the requirements for isolation from impact noise. Problems of reduced stress in mining are also devoted to work (Baranov et al., 2017).

Thanks to the developed mathematical model (9), we can also predict impact-wave and heat deformations of the lining ring from external seismic and impulse loads. In the future, it is necessary to build the methodology for refining the mathematical model based on the calculated experiment.

The course of temperature fields above the heated sample is also studied. As we can see in Fig. 3, the thickness of the thermal boundary layer increases uniformly. The results of the interferometric visualization of the temperature fields are represented by the images of interferograms. Based on holographic interferograms, the temperature above the samples was calculated (Fig. 4). In the future, we can conduct a qualitative and quantitative analysis of interferograms, which will allow us to determine the local heat transfer coefficients α necessary for subsequent calculation of the heat conductivity coefficient λ.

Conclusions

The creation of safe conditions for the operation of underground facilities is one of the main tasks of ensuring the stability of mine workings.

Today, in conditions of great depths and external dynamic loads, it is necessary to ensure not only the strength of the linings but also their resistance to seismic and vibration effects. The solution of this problem is the usage of multi-layer combined linings, which expand the possibility of using various materials for fastening openings in difficult mining and geological conditions.

At this stage of research, the construction of a three-layer vibration-resistant rigid-pliable lining for mine workings has been developed. It is distinguished by the fact that the pliable outer layer is made of foam concrete reinforced by PET fiber, and the inner layer is the sprayed concrete layer with PET-fiber reinforcing. The middle layer is a closed concrete ring of rigid lining, ensuring the stability of the mine workings during given service life.

Further researches are aimed at exploring the prospects of creating mixed multi-layer types of linings.

***Acknowledgments**:The paper was elaborated with the support of the Ministry of Education, Science, Research and Sports of the Slovak Republic within grant project VEGA 1/0086/18: Researching Temperature Fields in a Set of Shaped Heat Transfer Surfaces.*

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Stakeholder engagement in corporate social responsibility reporting. The case of mining companies

***Patrycja Hąbek*[1], *Witold Biały* and *Galina Livenskaya*[2]**

Despite the increase of corporate social responsibility (CSR) reporting worldwide, the practices still lack accountability and credibility. In the paper, the authors highlight the issue of undervalued stakeholder involvement in the process of improving the quality of CSR reporting. Thus, this paper aims to answer the question of how stakeholders engage in the process of CSR reporting within the mining industry, and if the mining companies use the stakeholder's feedback to improve this process? The data in the study was analyzed using content analysis of corporate social responsibility reports of coal mining enterprises. The reports were collected from the sustainability report database of the Global Reporting Initiative (GRI). The results indicate that stakeholder communication in the studied reports is more focused on providing than obtaining information from stakeholders. All of the studied companies declare that they engage in dialogue with stakeholders but with different groups. Feedback mechanisms are not very well developed and need more attention from reporting companies.

Keywords: *corporate social responsibility, stakeholders, CSR report, communication, mining industry*

Introduction

Corporate social responsibility (CSR) reporting is becoming more and more popular practice nowadays (Petera, 2015; Habek, Wolniak, 2016; Ryszko, 2017) also among mining companies (Jonek-Kowalska, 2016b). It is, among other things, the result of increasing expectations about the transparency of the organization's activities. CSR reporting can be defined as the practice of providing information to external and internal stakeholders on the economic, environmental, and social results achieved by an organization in a specific period of time. Companies have been paying growing attention to the importance of showing their CSR commitment through clear and verifiable data and information, similar to more traditional financial documents (Harmoni, 2013; Kołodziej, Maruszewska, 2015; Hąbek, Brodny, 2017). In order to fulfill the growing information requirements of the users, organizations tend to report on the broader economic, social and environmental performance in the form of the annual report (with a section dedicated to CSR issues), separate CSR report or integrated report. A CSR report is one of many forms of communication with both external and internal stakeholders. To fulfill its role, the report should include information which is expected by the interested parties. If stakeholders are involved in the reporting process, the report is likely to include suitable indicators, the data disclosed is authenticated and presented in a way which is understandable for the recipients of the report. The recipients of reports feel satisfied if they find the required information in them. Therefore, we can assume that taking into consideration the expectations of stakeholders in the reporting process influences the quality of the reports developed. In an international study carried out due to the development of the guidelines of the Global Reporting Initiative, stakeholder engagement is mentioned as one of the main motivations making companies reporting: 67 % of respondents indicated confidence-building among key stakeholders, 62 % indicated the involvement of investors, employees, and other stakeholders, and 23 % communicate risks, opportunities, and performance to investors (GRI, 2012). Stakeholder dialogue is a basis for the implementation of the CSR concept in practice. A socially responsible organization identifies the requirements and expectations of its stakeholders and considers them when making business decisions. A company desiring to learn from its stakeholders would ask for feedback or carry out a dialog with stakeholders to understand their expectations (Grunig, Hunt 1984; Morsing, Schultz, 2006; Bowen et al., 2010). Companies should collaborate with stakeholders to understand their views and concerns on various environmental, social, corporate governance and economic issues and to incorporate and address those views and concerns in their business decisions (Hąbek, Molenda, 2017; Kozlova et al., 2016). CSR report, in turn, should inform stakeholders how a company has addressed those stakeholders' interests and expectations in its activities.

Because there is a strong interdependence between mining companies and well-being of local communities where they operate and because mining activities also affect other actors and vice versa, it is important to build positive relationships with their stakeholders (Zasadzień, 2014; Midor, Zasadzień, 2015; Jonek-Kowalska,

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2016a). Therefore, the responsible management of a mining enterprise requires stakeholder engagement and building lasting relationships to meet their needs and expectations (Bluszcz, Kijewska, 2014). Stakeholder engagement can be understood as practices the organization undertakes to involve stakeholders positively in organizational activities (Greenwood, 2007). This paper aims to answer the question of how stakeholders are engaged in CSR reporting process within the mining industry and if the mining companies use the stakeholder's feedback to improve this process. Hence, the remainder of the paper is organized as follows. First, the stakeholder theory and CSR reporting are outlined with particular reference. Secondly, we describe the method used and data sources. Thirdly, the findings from the study of CSR reports of mining companies are presented. The paper ends with a discussion and relevant concluding reflection.

Literature Review

Social responsibility requires building a clear relationship with the internal and external environment. Responsible enterprise is one that cares about the interests of its employees, the local community, and the environment in which it operates (Gaweł, 2015). This means running a business based on building lasting, transparent relationships with its stakeholders (Adamczyk, 2009). In the initial model of Freeman as stakeholders are mentioned: owners, customers, suppliers, employees, competitors, government-administration, and community (Freeman, 1984). The concept of doing business based on building transparent, long-term, and lasting relationships with all stakeholders is called the stakeholder theory. The basic assumptions of the theory are as follows (Berman, Jones, Wick, 1999):

1. The company has relationships with various groups, which are called stakeholders of the organization. Stakeholders influence the organization's activities and are influenced by its activities.
2. This theory analyzes the nature of these relationships from the point of view of the benefits that they can bring to both the organization and its stakeholders.
3. Each stakeholder presents and strives for inner value expects certain expectations. At the same time, he tries to make his expectations dominate the expectations of other stakeholders.
4. This theory focuses on the strategic decision-making process.

In the literature of the subject, we meet different stakeholder classifications. Rogers and Wright (Rogers, Wright, 1998) identified four stakeholder groups based on the types of pressures that are exerted on companies through their relationships: capital market stakeholders (mainly debt and equity holders), product market or consumer stakeholders (mainly those associated with primary business operations), internal organizational or labor stakeholders (such as current and potential employees), and political and social markets (in terms of compliance to society's demands and expectations). There is also another typology in which internal and external stakeholders are identified. Internal stakeholders (insiders) are those who control the business of a company, either by ownership (shareholders) or by virtue of their position in the company (board members, managers, employees). External stakeholders (outsiders) include customers, suppliers, and other groups outside the company interested in doing business. The environment is also a party entering into relationships with the company. It is often called a silent stakeholder. Unlike man, he is unable to convey his demands and expectations directly. Companies, by their activities, violate the balance of natural environment and are therefore obliged to take measures to prevent its degradation (Rybak, 2004).

Stakeholder theory is a fundamental element of corporate social responsibility and building stable relationships with stakeholders will not be possible without effective communication with them. Morsing and Schultz (2006) suggest that organizations develop three distinct communication strategies with stakeholders: informing, responding, and involving. The first strategy refers to a one-way communication process where the organization "informs" the target audience. This strategy is controlled by top management without the intent to learn or change. Sharing information in this model is done by developing and distributing media, news, and press releases. Companies engage with stakeholders to minimize their production and transaction costs by reducing uncertainty (Thorelli, 1986; Williamson, 1991; Herremans et al., 2016). The "response" to stakeholders is based on two-way communication. However, the flow is asymmetrical, suggesting that more information is transferred from the organization to the stakeholder than vice versa. Strong lines of communication, often not face-to-face, exist from the organization to the stakeholders. The organization does not change based on the information it receives from stakeholders but rather aims to change the behavior and views of the public (Herremans, Nazari, Mahmoudian, 2016). The "involve" strategy, is two-way communication in the form of a dialogue in which both participants are demanding change from one another. The most expected situation is when both participants change in response to the information exchanged. Meetings are often face-to-face, involving joint decision making or joint management of a project. Stakeholders may suggest corporate actions (Morsing, Schultz, 2006), and the process can result in capacity building. Dialogue often results in ideas and increased knowledge for all parties regarding continuous improvement (van Huijstee, Glasbergen, 2008). If engagement is face-to-face, the organization conveys the information, and the stakeholder responds, provides feedback or asks questions enabling organizational learning (Herremans, Nazari, Mahmoudian, 2016).

Stakeholder dialogue is a basis for the implementation of the CSR concept in practice. A socially responsible organization identifies the requirements and expectations of its stakeholders and considers them when making business decisions (Wolniak, Hąbek, 2015; Cierna, Sujova, 2015). A CSR report is a form of communication with both external and internal stakeholders. To fulfill its role, the report should include information which is expected by the interested parties. If stakeholders are involved in the reporting process, the report is likely to include suitable indicators, the data disclosed is authenticated and presented in a way which is understandable for the recipients of the report. The recipients of reports feel satisfied if they find the required information in them. Thus, stakeholder engagement is an important element that should contribute to the process of preparing a CSR report. This is emphasized, for example, in GRI guidelines. The guidelines of the Global Reporting Initiative are widely-used non-financial reporting standard, recognized by companies across the world (Alavi, Hąbek, Cierna, 2016). More than 70 percent of reporting enterprises and organizations use the GRI Guidelines when communicating their impact on sustainable development (Deloitte, n.d.). In the most recent GRI G4 guidelines, the stakeholder inclusiveness principle was transferred to the first position out of four principles for defining report content in order to emphasize its significance and priority compared to the remaining principles and the whole process (Anam, 2013). For example, G4-26 indicator of this guidelines applies to the organization's approach to stakeholder engagement, including frequency of engagement according to the type and stakeholder group, and an indication of whether any of the engagement was undertaken specifically as part of the report preparation process.

Acquiring the knowledge about expectations and interests of stakeholders should be a starting point for the process of preparation of that kind of a report. We have to bear in mind that not all of the organization's stakeholders will use the report. The stakeholder engagement process can help to learn and understand stakeholder expectations and needs. Organizations typically initiate different types of stakeholder engagement, which can be a valuable input into the reporting process. The stakeholder engagements process can take such forms as: one-to-one meetings, interviews, questionnaires and surveys, knowledge exchange groups (including steering groups, advisory panels, multi-stakeholder forums), workshops, focus groups and other types of meetings, including social events, practical demonstrations, including participatory events (for example, training, games). It is important to document the process of stakeholder engagement to make the report more credible. The organization documents its approach for defining which stakeholders it engaged with, how and when it engaged with them, and how engagement has influenced the report content and the organization's CSR activities. Systematic stakeholder engagement enhances the usefulness of the report. Executed properly, it is likely to result in ongoing learning within the organization and by external parties, as well as increase accountability to a range of stakeholders (GRI, n.d.). This paper presents how stakeholder engagement is documented in CSR reports of selected enterprises of the mining industry.

Methodology

The data in this study were analyzed using content analysis, which is a widely used qualitative research technique. The content analysis was conducted in the following steps:

1. Selection of research material.
2. Repeated reading of texts that entered the sample.
3. Development of a category system.
4. Definition of each category in system.
5. Building tables with quotes.

In the conducted research, the category system was developed before reading the research material, based on the researcher's intuition and expertise of the analyzed problem (Hąbek, 2013; Hąbek, Wolniak, 2016) and then it was compared with the individual reports. As to limit the subjectivity of the analysis, suggested by Szczepaniak (2012), the categorical key in the content analysis was complemented with detailed definitions for each category, and tables with quotes were constructed to provide direct contact with the empirical material. The construction of the categorization scheme is an essential stage of content analysis research. Figure 1 presents the category system developed for the study.

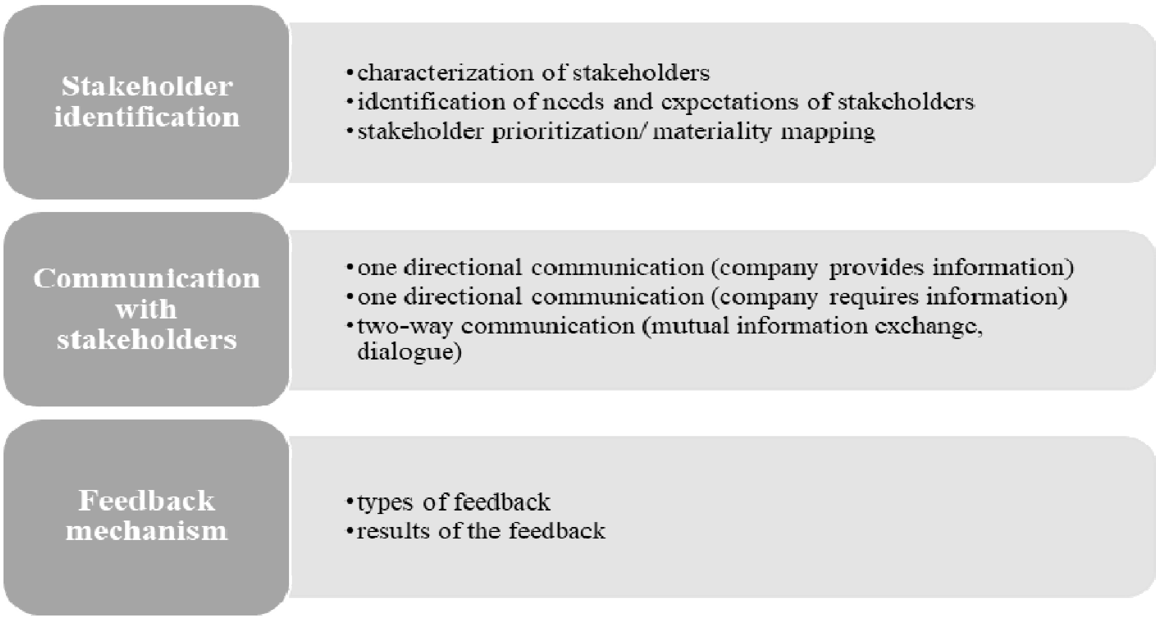

Fig. 1. The category system for the content analysis of CSR reports of mining companies.

A list of detailed definitions for each category in the categorization scheme is presented in Table 1. It contains guidelines on what is included in each category along with how the quotations from the studied reports are attributed.

Tab. 1. Definitions of the categories.

STAKEHOLDER IDENTIFICATION	
Characterization of stakeholder groups	All information about the company's stakeholders, their division into specific groups, ways of identifying them (research, interviews, brainstorming, checklists, lessons learned, etc.)
Identification of needs and expectations of stakeholders	These fragments of the report devoted to presenting the needs and expectations of individual stakeholder groups
Stakeholder prioritization/ determining materiality issues	Those parts of the report where materiality issues are determining. These fragments of the report presenting the stakeholders maps, the methodologies to assess the significance of the organization's impacts, the topics, and indicators raised by the stakeholders. All information on stakeholders prioritization.
COMMUNICATION WITH STAKEHOLDERS	
One-way communication – company provides information	These sections of the report describing ways of providing information to stakeholders. All information about education, stakeholder training, press conferences, open days, publishing reports, newsletters, advertisements
One –way communication – company request information	These sections of the report describing the acquisition of information from stakeholders, such as questionnaires, interviews, focus groups, audits, stakeholder meetings and forums, market research.
Two-way communication – mutual information exchange, dialogue	These sections of the report that describe the mutual information exchange with stakeholders in the form of stakeholder panels and moderated stakeholder dialogues, sessions, the participation of stakeholders in management meetings, etc.
FEEDBACK MECHANISM	
Feedback	These sections of the report that encourages stakeholders to formulate an opinion on the report or CSR policy of the reporting organization. These sections present the types of feedback, feedback forms, etc.
Feedback results	The report presents the results of the feedback. All information regarding taking into account feedback results in the next reporting period.

Building the tables with quotes provides the reader contact with empirical material without having to refer directly to the entire published text. As a result of the conducted analysis tables with quotes related to each category from the categorical key are presented in the results section of this paper.

Selection of the research material

The content analysis was based on corporate social responsibility reports of coal mining enterprises. The reports for this study was collected from the sustainability report database of the Global Reporting Initiative. Based on criteria such as the 2016 report, region-Europe, sector-mining it was found 33 sustainability reports in the database. Out of the 33 reports, only 3 have been published by coal mining companies, and these reports have been chosen for further analysis. Only publicly available sustainability reports, bilingual, or published in English, was examined in this study.

Results

The study was based on three reports of coal mining enterprises: Evraz, Glencore and Lubelski Węgiel Bogdanka S.A. Evraz is a multinational enterprise which beside coal mining principle activities is manufacturing steel and steel products, iron ore mining and enrichment, manufacturing vanadium products, trading operations, and logistics. EVRAZ coal segment not only supplies its steel mills with necessary raw material but also provides coking coal to major Russian coke and steel producers and serves export markets with its own seaport. Glencore is also a multinational enterprise, commodity producer and trader, operating worldwide. Its business covers over 90 commodities encompassing metals & minerals, energy products, and agricultural products as well as related marketing and logistics activities. Lubelski Węgiel "Bogdanka" S.A. is one of the leaders in the hard coal market in Poland. The energy coal sold by the company is primarily used for the production of electricity, heat, and cement.

Evraz discloses its sustainability data in an annual report. Its report has been prepared on the basis of the International Integrated Reporting Framework and the GRI G4 Sustainability Reporting Guidelines. Lubelski Węgiel „Bogdanka" S.A. (LW Bogdanka) prepared an integrated report in accordance with GRI G4 in 'core' option using the International Integrated Reporting ("IR") Framework. The LW Bogdanka's report also takes into account indicators specific for the mining sector, which are described in the mining and metals GRI sector supplement. Glencore disclosed CSR data in a separate CSR report. The report complies with the core level of the Global Reporting Initiative (GRI) G4 sustainability reporting guidelines, including the metals and mining sector supplement. Glencore sustainability report as the only one of the analyzed reports has been independently assured.

The content analysis of these reports has been divided into three categories: stakeholder identification, communication with stakeholders, and feedback mechanism. The results of the analysis taking into account the relevant categories are presented in Tables 2, 3, and 4.

Tab. 2. Quotes in the category stakeholder identification.

STAKEHOLDER IDENTIFICATION		
Characterization of stakeholders groups	EVRAZ	Not mentioned
	GLENCORE	"We interact with many diverse stakeholders around the world. We are committed to building transparent and constructive relationships with our partners to deliver sustainable, long-term benefits to all of our stakeholders. A key part of our commitment to operating responsibly is to develop, maintain, and strengthen our relationships with all of our stakeholders. We engage with all stakeholder groups to build meaningful relationships and understand their expectations and aspirations. Engagement, both on regulatory matters and with our stakeholders (our people, labor unions, our host governments, our communities, our host governments, NGOs, business partners, investors, customers) is common to all the material topics identified".
	Lubelski Węgiel Bogdanka S.A.	"The list of stakeholders applicable at the LW Bogdanka Group covers the following groups: Full-time employees of LW Bogdanka S.A., trade unions, potential employees, former employees, subcontractors' employees working in the mine, State Labour Inspection, Regional Labour Inspectorate in Lublin, Mine Rescue Stations in Jaworzno. State Mining Authority in Lublin and Regional Mining Authority in Lublin and Central Mining Institute, Local Building Supervision Inspectorate in Łęczna. Environmental organizations, Regional Environmental Protection Inspectorate in Lublin, Polesie National Park Management, State Forests (Forest District Office in Świdnik. Institutional customers, individual customers, key suppliers, and subcontractors. Shareholders with a particular focus on the strategic investor, that is, the Enea Group, banks, Warsaw Stock Exchange, Polish Financial Supervision Authority. Media, universities, and academic employees, technical and sector organizations, governmental (central) administration, non-governmental organizations. Local government administration, local residents, social leaders, local non-governmental organization".
Identification of needs and expectations of stakeholders	EVRAZ	"In 2015, the Hot Line received c.1,000 requests, and all were examined. The most popular enquiries concerned labour management relations (including c.200 regarding contract details), followed by salaries, social services (transportation, conditions in non-production premises, nutrition, conditions at sites) and PPE (periods, volumes, content of supplements, lifecycle, rules of use and washing), which accounted for c.100 requests each".
	GLENCORE	"Each asset must complete a stakeholder assessment, covering all stakeholder circumstances, needs, and concerns, as well as potential impacts, risks, and opportunities for that asset. From this assessment, the asset must design an engagement strategy, which may include procedures for information sharing, consultation, and collaboration. This strategy is aligned with the asset's business objectives and changes to its lifecycle, as well as local concerns and the broader socio-economic situation in the region. Senior management at each asset is aware of progress in implementing these strategies, which we also report on to the local communities involved. We require assets to review the strategies at each stage of their lifecycle to ensure that we continue to be aware of stakeholder priorities and needs. Some of our stakeholders have faced economic and social discrimination in the past.

		These may include indigenous people, women, children, disabled and older people, and victims of conflict. Wherever we operate, we look for these groups during our stakeholder assessments and determine the most appropriate ways to engage with them".
	Lubelski Węgiel Bogdanka S.A.	Not mentioned
Stakeholder prioritization/ determining materiality issues	EVRAZ	Not mentioned
	GLENCORE	"In line with the Global Reporting Initiative (GRI) guidance on materiality, our assessment process begins with a Group-wide review of material topics at global and local levels. This identifies topics raised during structured engagement activities by a broad range of internal and external stakeholders. It considers the issues that affect our peers and the entire sector, assessing media coverage and feedback from local communities. We consider a topic material if senior management determines that it may significantly affect our business operations or have a significant impact on any of our stakeholders".
	Lubelski Węgiel Bogdanka S.A.	"In the course of work to review the earlier strategy of the corporate social responsibility for 2012-2015, comprising the workshop, not only materiality of particular groups was specified but also current and targeted forms of dialogue and involvement of particular stakeholders were identified. The map of stakeholders used for the preparation of the CSR Strategy for 2014-2017 has been considered still valid".

Tab. 3. Quotes in the category communication with stakeholders.

COMMUNICATION WITH STAKEHOLDERS		
One-way communication – company provides information	EVRAZ	"EVRAZ pays great attention to its internal communications processes and constantly seeks to build an efficient system, designed not only for keeping information flowing, but also for increasing employee loyalty and motivation. The Group searches for, evaluates, and implements best communications practices, such as a corporate intranet, bulletins, and internal advertising campaigns. Its goals are to provide up-to-date, full , and transparent information regarding its business and strategies, progress and bottlenecks".
	GLENCORE	"We provide our stakeholders with information in a wide range of ways, tailored to the local context, that varies across the Group. These include radio broadcasts, site publications, regular town hall meetings, and individual meetings with the community".
	Lubelski Węgiel Bogdanka S.A.	"One of the novelties under development since 2015 is a new Intranet platform, which for now offers only the functionality of e-learning, but is eventually to take over the functions of Intranet for the mine and be the electronic "employee zone". All employees of subcontractors who work directly in mining or mechanical processing of coal undergo mandatory training on hazards and accidents prevention. This mandatory training is to familiarise the employees of external entities with the procedures in force at LW Bogdanka S.A., which are of direct and key importance for ensuring safety on its premises".
One-way communication – company request information	EVRAZ	"One key way in which the Group seeks feedback from employees is the EVRAZ Compliance Hot Line".
	GLENCORE	"All our assets must carry out community perception surveys every three years to check on the effectiveness of their engagement strategies. We not only send out information to our supply chains; we also bring learnings from other stakeholders back to our operations and assets. This includes continual improvement of our facilities and procedures to allow for the potential health impacts of production activities. We require our assets to operate grievance mechanisms, to receive and address concerns from external stakeholders. Depending on the location and context of the asset, these mechanisms may range from informal complaints channels to formally dedicated grievance mechanisms. Channels for communication include dedicated phone lines, complaints registers at public places, SMS hotlines and the offices of assets in local towns".
	Lubelski Węgiel Bogdanka S.A.	"In mid-2014, a study of organizational culture and internal communication system took place for the first time in the history of LW Bogdanka. The study included group workshops (FDI) and personal interviews (IDI) with representatives of the Company's various organizational divisions. As a consequence of this study, an internal communication strategy document was developed in 2015, which was then implemented to the greatest extent possible, given all the restrictions that occurred simultaneously in 2015".
Two-way communication – mutual information exchange, dialogue	EVRAZ	"The backbone of the relationship between EVRAZ and trade unions is a social partnership. Regular discussions and formal and informal meetings of the management and unions are conducted at all EVRAZ facilities. EVRAZ seeks an ongoing dialogue with the communities in which it operates. Ongoing engagement with civil society at all levels of the organization, including a fact-finding mission to Colombia to understand and address key NGO concerns".
	GLENCORE	"Wherever we work, we engage in open and continuous dialogue with indigenous communities to understand their culture, views, and aspirations. This helps us work with them to minimize our impact and maximize the benefit we bring to them. Our policy and approach are aligned with the *ICMM Position Statement on Indigenous People and Mining*. The geographies and markets in which we operate are extremely complex, and we conduct dialogues on local, national, regional and international levels".

	Lubelski Węgiel Bogdanka S.A.	“The topics discussed with the framework of dialogue are diversified and depend on a given partner. For example, talks with unions, which are considered a key partner by the Management Board, are naturally focused on employee-related and social issues in the context of changes in the more and more challenging market. For people living in areas of mining activities mining damage is the crucial aspect. Moreover, more broadly defined local communities are mainly interested in how the mine is going to support local development, which includes local events and investments, but also the creation of new jobs. The monitoring of the objectives of the CSR strategy involves verification of key stakeholder groups and the current and desired forms of dialogue with them. In the case of these key groups, the communication is very regular, direct, and often at the highest level, which enables consultation of relevant matters regularly. In 2015, 22 dialogue sessions with the trade unions were held”.

Tab. 4. Quotes in the category feedback mechanism.

FEEDBACK MECHANISM		
Feedback	EVRAZ	General contacts to the company
	GLENCORE	We welcome feedback on this report or any other aspect of sustainability at Glencore. You can send general comments to gcp@glencore.com. Otherwise, you can contact: Corporate sustainability Michael Fahrbach Tel: +41 (0) 41 709 2571 michael.fahrbach@glencore.com
	Lubelski Węgiel Bogdanka S.A.	Contact point Marketing, Public Relations and CSR Department Lubelski Węgiel BOGDANKA S.A. marketing@lw.com.pl csr@lw.com.pl Tel. (+48) 81 462 56 38, 81 462 54 36 Fax (+48) 81 462 54 26
Feedback results	EVRAZ	Not mentioned
	GLENCORE	Not mentioned
	Lubelski Węgiel Bogdanka S.A.	The content of the previous Reports and this Report was defined on the basis of the results of a workshop held in connection with the development of the CSR Strategy for 2014-2017 in October 2013. The preparation of the Report itself involved interviews with managers responsible for relationships with individual stakeholders. This approach made it possible to define the content of the Report under observance of materiality, completeness, and stakeholder inclusiveness principles.

Stakeholder Identification

According to analyzed reports, two of three analyzed companies are identifying their stakeholders. LW Bogdanka presented them very precisely in the report but did not identify their needs and expectations. Glencore mention about its stakeholders in some general statements but identification of needs and expectations in Glencore is done through stakeholder assessment, covering all stakeholder circumstances, needs, and concerns, as well as potential impacts, risks, and opportunities for the company. The results of this assessment serve to design an engagement strategy, which may include procedures for information sharing, consultation, and collaboration. Evraz did not characterize its stakeholders in the report and identification of needs and expectations of stakeholders was executed only via hotline request examination, which is not an active way to recognize stakeholders demands. Unfortunately, also, Evraz did not present information concerning prioritization and materiality issues related to particular groups of its stakeholders. Glencore determines materiality issues according to GRI guidelines. Material topics are raised during engagement activities of Glencore with both internal and external stakeholders. Material issues are determined by senior management. LW Bogdanka presents only a general statement that materiality of particular groups was specified and the stakeholders’ map but the results are not included in the report. None of the analyzed company present in the report prioritization of its stakeholders.

Stakeholder Communication

All of the analyzed reports include information about providing information to stakeholders. EVRAZ pays attention to its internal communications processes. All reports specify types of communication; LW Bogdanka focuses especially on communication with employees. The analyzed reports also disclose information about types of requesting information from stakeholders. In Glencore’s report, we can find the most information on acquiring information from stakeholders. It discloses different types of communication, such as perception surveys, grievance mechanism. Channels for communication include dedicated phone lines, complaints registers at public places, SMS hotlines, and the offices of assets in local towns. Report of LW Bogdanka presents information about surveying internal communication system which results serve as a basis to develop an internal communication strategy document. Evraz also focuses on information feedback from employees in the form of compliance hotline. All of the studies companies declare that they engage in dialogue with stakeholders. Evraz's report includes assertions concerning dialogue with trade unions, employees, and civil society but without specifying the details of the dialogue. Glencore engages in dialogue with indigenous communities. In LW Bogdanka the communication with key stakeholder groups is very regular, direct, and often at the highest level, which enables consultation of relevant matters regularly. Only in the report of LW Bogdanka quantitative information is given regarding the dialogue with stakeholders (22 dialogue sessions with the trade unions).

Feedback

Little information can be found in the reports on obtaining the feedback from stakeholders which may serve as an input to the next reporting process. Only Glencore has provided information encouraging stakeholders to formulate an opinion on the report and provide full contact details to the person in a company responsible for these issues. Evraz has provided only general contact details to the company. LW Bogdanka gives contacts to the CSR department. Information on taking into account feedback results in the next reporting period can only be found in the report of LW Bodanka which used the result of the workshop and interview with managers of the company to define the content of the report.

Summary

Business organizations are under many pressures from their internal and external environments. Conducting dialogue with stakeholders is fundamental to the concept of social responsibility. Building stable relationships with stakeholders will not be possible without effective communication with them. CSR report is one of the possible means of that communication.

This paper aims to answer the question of how stakeholders are engaged in CSR reporting process within the mining industry and if the mining companies use the feedback from stakeholders to improve this process. By using sustainability reports as a means of data collection, this study focus on how stakeholders are identified and engaged in the CSR reporting process. The authors apply content analysis on data from reports of mining companies collected from a Global Reporting Initiative database.

The results revealed that stakeholders engagement in CSR reporting process of the mining companies leaves space for improvements in each analyzed company. The companies are focused especially on internal stakeholders communication, and the process of identification of stakeholder needs and expectations are not yet well developed. The most undervalued element in the analyzed reports is getting feedback. The assessed reports very rarely contain information that would allow readers to contact the person responsible for the development of the report or for the reader to express his or her opinion. This is alarming information because if there is no feedback mechanism, the dialogue with stakeholders is difficult or even completely blocked. It is important first to identify the stakeholders and to know their expectations and then choose how to communicate effectively with them. The appropriate form of communication should be oriented not only on information but above all on dialogue with the broad environment. It is important not only to go in one direction: enterprise - stakeholders but also to receive and process feedback messages. Stakeholder engagement is crucial for conducting successful reporting process because knowing stakeholder needs and expectations should be the starting point in defining materiality and relevance of information disclosed in CSR reports. To increase or enhance the quality of a CSR report, it is important for companies to know what stakeholders demand, and what stakeholder see as acceptable.

CSR reports should be developed for the stakeholders and with their active participation. They should be developed to meet the information needs of both internal and external stakeholders. Therefore none valuable CSR report will be developed without stakeholder engagement in this process, and for stakeholder engagement, two-way communication is essential. Reporting companies cannot forget about using feedback mechanisms that aim to improve the reporting process.

The research methodology used in the study is limited by various factors. The restrictions relate particularly to two issues. The first limitation is related to the lack of available data. We analyzed reports from companies of different types and operating in different countries, which may influence their approach to CSR issues. The second limitation concerns the types of analyzed reports. Each of the studied report was of different type (separate CSR report, integrated report, and annual report with CSR section); therefore, the amount of text devoted to CSR was different. Possible future directions for research focused on stakeholder engagement may take into account the cultural context of the reporting companies, which may have a considerable impact on stakeholders attitudes and expectations.

***Acknowledgments**: This article was prepared within the statutory research titled "Methods and tools for improving products and services on the selected examples" work symbol 13/030/BK_17/0027 performed at Silesian University of Technology, Institute of Production Engineering.*

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The political frame of the European Union for mining of non-energetic raw materials

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The goal of the present applied raw material policy is to provide effective using of the domestic raw material base with regard to industrial, energetic, environmental policy, and local planning. The Slovakian raw material industry is in a breakthrough situation. Therefore, there is a task for all society to give vast effort to provide that also Slovakian raw material policy would begin to grow. In the presented contribution we search raw material policy in Slovakia from the systematic view, analyzing individual elements of the system - relations with supplier-consumer, legislative, property, personal, economic, political and other relations in the frame of the system, as well as relations with its surroundings. We made a model of new raw material policy that defines systematically and objectively conditions, goals, and measurements and tools for filling of these goals with the aim to revitalize Slovakian raw material policy. Such a model could provide sustainability of the mining industry in the country.

***Key words:** raw material policy, mining, non-energetic raw material, economic growth, sustainability*

Introduction

The raw material policy of the state is a strategic document that defines the main goals and priorities for raw materials base using. Ministry of Economy in Slovakia is responsible for raw material policy in period minimal 20 years, as well as for its actualization. Present economic development, providing of energetic needs, state of unemployment and social development, new legislative, the strategy of sustainable using of natural sources, skills of previous research and development, and using of the raw material base, demand acceptation of new raw material policy (Cehlár and Maras, 2001).

The goal of present applied raw material policy from 2004 was to provide effective using of the domestic raw material base with regard to industrial, energetic, environmental policy, and local planning. The entrance of Slovakia to EU, using of possibilities and regarding obligation, resulting from EU membership, as well as regarding present geopolitical situation and its impacts to the national economy in Slovakia, demands a new understanding of raw material policy, its content and aim (Ministry of Economy, SR, 2003). The new policy must be conceived considerably wider – primarily it must provide raw material security for sustainable development of the country.

Therefore, except of the present support of domestic raw materials using, of course at observing of necessary balance between living environment protection and industrial needs, it must also include policy against all possible useful energetic sources for the need of the country, either sources in abroad (business policy), or in home (support of waste recycling).

One of the most important present development trends is the development of a circular economy. Application of this philosophy and principles to the conditions of raw material economy changes present narrow and isolated view to the raw materials and it brings wider and more integrated perceiving of "raw material concept" as the object of raw material industry, following and solving whole life cycle of raw materials – whole raw material flow, not only its initial period.

A very difficult task is to create adequate space for all multispectral interests in the prepared raw material policy, which should also be with regard to raw material criticality as well as sustainable development. The raw material policy is basic planed document, describing the desired behavior of the raw material industry as a whole and in this way, also all its elements.

Despite all the mentioned problems, the Slovakian raw material industry is in a breakthrough situation. Although it is at the bottom of the synopsis development, surroundings expect its future growth and competition, not sleeping, is still growing. Therefore, there is a task for all society to give vast effort to provide that also Slovakian raw material policy would begin to grow.

The goal of raw material policy should be to define priorities for Slovakian raw material industry from the view of need to provide sustainable development of national economy and society, as well as to define measurements and tools for providing of stable development of single raw material industry and its competitiveness in international level in measure, adequate to created conditions (Cavender, 1992). The goal of

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the presented contribution is, therefore, to make a system for raw material policy creation in concrete conditions of the country. The larger the system, the greater the number of factors, decisions, constraints, and risks it involves (Straka et al., 2018). Knowledge of these factors is very important not only for the development of relevant policy concepts in the country but also for the national and international benchmarking (Khouri et al., 2017).

Literature review

Nowadays, global environmental change can no longer be excluded; it must be solved through global sustainability, in which humanity can operate safely (Rockström et al., 2009). From this view, humanity cannot transgress boundaries and sources of the planet. It could have namely influence to the society, ecology, and economy of countries.

Mining activities divide communities and countries (Gray, 2018) due to different geological, legislation, political, social, and economic conditions. Therefore analysis of mining activities must be regarded from the view of the growth economy, encouraged by government tools – together with ecological integrity (Gentry and Neil, 1984). Only by this way state can be more supporters of mining, not resister of it. State and government should participate in the decision – making process regarding conditions of mining from a legal and political perspective (Pelaudeix et al., 2017). Openness, transparency, and public participation of the state is a longstanding issue. The state must adopt such decision to public participation with the aim to prevent mining activities from harmful impact to environment, society, and economy. Therefore, also in areas of mining principles of corporate, social responsibility must be regarded (Curran, 2017). It is using the support that community would be in opposition to mining activities and on the other hand, it could support the economic development of the regions, and in this way also the state development. Also, ordinary people should participate in decision making in the context of mining and mineral extraction (Ruwhiu and Carter, 2016) due to the multi-dimensional character of mining, which demands land using, where people are living. It is also necessary to take into account that mining industry is a very specific field which is typical with many risks like capital intensity, long pre-production period, high risk, non-renewable resources and specifics associated with human resources (Rybár et al., 2005). In this context, there has to be a relation between mining companies and inhabitants by way of meaningful participation at negotiations about mining activities. It must be covered by appropriated legislative tools, providing positive economic, social, and environmental indexes. Consequently, there is a necessity to use safe methods for mining and the use of mineral resources (Straka et al., 2016).

Several authors studied why there is resistance to the mining activities, for example, Deonandan (2015). Proper legislation could decrease such resistance, drawing attention to economic development. However, within such studies, little attention is given to understanding how and which measure social movements can affect the development of mining and its environmental impacts (Bebbington et al., 2008). Social movements have significant influences on forms taken by the extractive and mining industries (Colving et al., 2015). Development of the society must be done due to the mentioned by being co-produced by movements, mining companies, and other actors, in particular, the state. A very interesting model for including of state and society to decision making about mining activities with environment considering was made by Colvin et al. (2015). This conceptual model and its interpretation through the social identity approach raise several implications for the current theory, practice, and institutions involved in the wicked socio-political level.

The principle of sustainable development has become a central idea of environmental law (Frenz, 2003). This area has to be around in legal discussion and political declarations for some time, resulting in the serious legal framework, in which the mining industry can operate positively. According to the mentioned study, there is a need for future generations safeguarding. Moreover, ecological, economic, and social interests must be reconciled. This principle could imply new restrictions for the mining and energy industries (Rybár et al., 2005). The importance of legislative is obvious in mining and implementation of new technological solutions by OZE using (Horodníková et al., 2008). The effective policy of the state in the area of mining activities could solve the problem.

Methodology

The raw material policy is a very complex document. If it is to be valid, complex, systematic and objective, it must result from whole raw of documents, accepted at European, national and regional level, and it must include a number of influences, interests, and demands. To understand the complexity of raw material policy creation, there is necessary to use knowledge and methodology from the theory of systems and to make decomposition of the problem.

From the systematic view, there is possible to consider the Slovakian raw material industry as a single system. Elements of the system present all research, mining, processing, metallurgical, recycling, education, environmental organizations, as well as state and administration institutions. Relations present various supplier-consumer, legislative, property, personal, economic, political, and other relations in the frame of the system, as well as relations with its surroundings.

System of “Slovakian raw material industry” presents a subset in the vertical level of European and worldwide raw material industry. In horizontal level, it presents part of the Slovakian national economy. However, this system can be further divided into subsets, for example, regional, commodity, or professional subsets, etc.

Composition of the system must be understood since it corresponds with its goals composition. If to describe system behavior, there is most effective to make it through a description of the goals and to make a description of the goals through its elements. It is for that reason that real system, or its elements, always react to any external stimulus by adaptation change in necessary context for filling of its goals.

The state is the dominant element of the system “Slovakian raw material industry.” The interest of the state is to provide raw material sources in the measure, in which there would not be any obstacle for sustainable development of the society and on the other hand, the state must provide long term effective using of raw material sources (not wasting) with synergic creation of new sources. Mentioned must be done through defining rules and coordination of “other” subjects activity – through all system elements.

In the contribution, we will deal with the description of individual system elements interests, for example, interests of geologists, miners, metallurgists, recyclers, applicators of raw materials, consumers, environmentalists, politicians, etc. However, from the systematic point of view there is necessary to underline that all such interests present together one set of interest that has its very complex structure, in which some interests contradict each other, others are in antagonistic relation, some have only objective or only subjective characteristics, some are short term or long-term, resp. permanently applied. From the view of waste, we can speak about an individual or whole society interests that have various priority and support.

Results

Providing reliable and undisturbed access to raw materials becomes a more and more important factor for EU competitiveness, and in this way, it also presents a decisive factor for the success of Lisbon partnership for growth and employment. European commission realizes this situation and therefore in November 2008 EC accepted initiative in the area of raw materials, in which target measurements are defined for providing and improvement of the access to raw materials in EU.

Initiative in the area of raw material policy is based on three pillars:

- Providing of Access to raw material at international markets at the same conditions as other competitive industrial subjects,
- Determination of proper frame conditions in the whole EU with the goal to strengthen the sustainability of raw materials supply from European sources,
- Increasing whole sources effectiveness and promotion of recycling with the goal to decrease in EU consumption of primary raw materials and relative dependence from import.

Initiative results from the knowledge of complex analysis of competitiveness in the area of non-energetic raw materials mining in EU, and it demands to integrate Access, through which correspondent policies and EU tools could act in mutual balance in the interest of availability of basic raw materials and their sustainable mining and using.

The first pillar connects active diplomacy in the area of raw materials, and it provides righteous, fluent, and secure access to raw materials. Its reaction is also the fact that the majority of European metal minerals must be imported (in 2007 there was business deficit more than 20 milliard EUR). Political dialogue with third countries, developing economies and their regional grouping, observes the principle of “common interest”. One of the important directions is the support of sustainable access to raw materials in the area of development policy, while there is mainly strengthening of dialogue with Africa and measurements, connected Africa in area of raw materials access, administration of natural sources, as well as transport infrastructure, with regard to sustainability and social responsibility.

Dependence on import threatens production sector in the EU by influences of the external market. In future years, the price of many minerals could rapidly increase due to the rapid industrialization of developing countries, for example, Brasilia, China, and India (Torries, 1997). The number of states with rich natural sources limit presently also export in favor of own domestic producers, which disadvantages the EU industry in economic competition. European Union will solve any task of unrighteous business in accord with initiative in the area of raw materials.

The second pillar is orientated to the solving of fear of industry in connection with the availability of raw material sources in EU, mainly to the correspondent regulation frame. Different regulation processes, planning, and rules, connected protection of the living environment, health and security, can limit mining or increase mining costs. At the same time, access to mining could be expensive and time-consuming, mainly in places, where the soil is used to other activities. European Commission will, therefore, cooperate with member states at improving frame conditions, on which mining depends, with the goal to simplify and accelerate administrative processes.

The aim of the EU initiative will also be an effort to improve research and mutual change of knowledge about raw material deposits in the whole EU. One of the goals is to provide that areas with high potential of raw materials would not be without benefit. The initiative also presents support for research projects, orientated to the development of a new technique for mining, which could consequently decrease the impact on the living environment.

The goal of the third pillar is to support higher sources of effectiveness and recycling. Presently vast volume of products at the end of the life cycle is not processed further by a reliable process with the goal to obtain precious materials, mainly metals, used in top technologies, which could be recycled. From Europe, mainly waste products are exported without effective control and perspective processing. European Commission wants to cooperate with member states at improving possibilities to verify the goal of such waste export, damages decreasing in the living environment, and increasing recycling rate for waste elements. Mentioned elements of EU initiative are also illustrated in Figure 1.

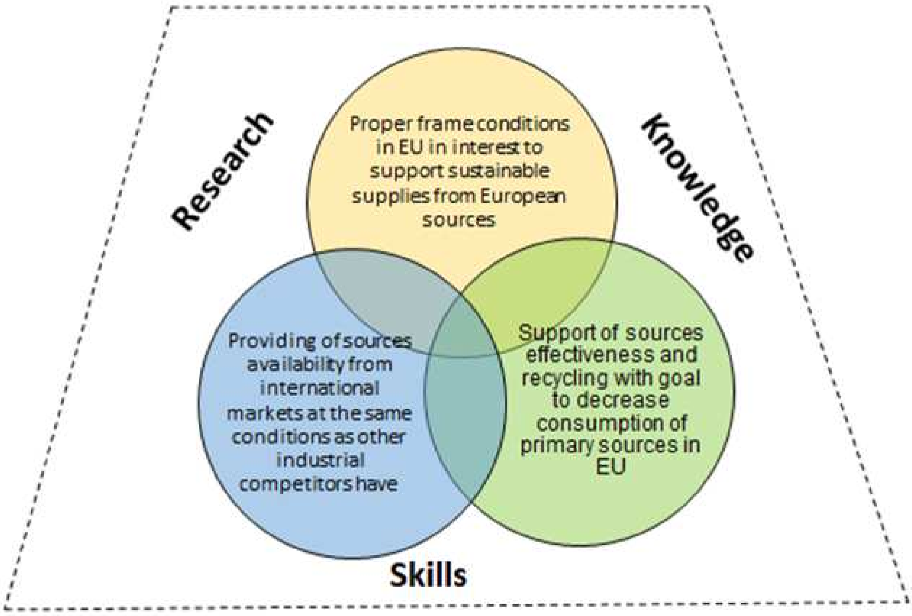

Fig. 1. Key elements of EU initiative in the area of raw materials, Source: UN, 1997.

Indexes influencing mining of non-energetic raw materials in Europe

In connection with the second pillar of initiative in the area of raw materials, there is a limited whole raw of factors that could influence the competitiveness of European mining. They include the whole spectrum, beginning with fear, connected with diversity and complexity of processes for obtaining the allowances in individual member states, till conflicts with other possibilities of soil using, shortage of qualified working power and demands, connected living environment, health, and security. They also reflect the need of the modern technique of mining and improving knowledge about possible deposits of raw materials.

The mining industry is connected with places of known or commercially vital deposits of minerals. The appearance of minerals is conditioned by geologic activity in the past and knowledge about its structure, which depends greatly on the level of investment to geological mapping, finding, and research. The mining industry cannot be therefore acting only in areas, in which there would not be conflicts with other possibilities of soil using, with wider society, or protected areas, or areas with visual importance.

Most important is soil availability. It results partially from the characteristic of non-energetic raw materials mining. In spite the EU has many deposits of raw materials, they are not evenly distributed, and they have different quality. It is possible to mine only at places, where minerals are appearing. Moreover, not all deposits are commercially vital and decision to use concrete locality is considerably influenced by market demand, as well as by a measure of necessary initial investments and costs on raw materials transport to the final user.

Transport cost is higher the more the goods have to be transported, and they limit effectively geographical availability of such minerals.

In practice, it means that a number of quarries exist in surrounding cities, where raw materials are necessary. From a similar reason, new quarries are placed primarily in the surrounding of existing services, in spite, finally, also new spaces on „green meadow“ are searching and used. The need for Access to concrete land also means that individual development project can be in conflict with competition possibilities of land using or conflicts with wider social interests, or they can have big unacceptable influence on the living environment, although in absolute numbers the space of the land, necessary for non-energetic raw materials mining is rather low (less than 1 % of EU area). Mentioned must be following, especially in any individual case since there is very important where exactly the plan to develop mining will be realized and by what way it will be done. One of the most often mentioned problems in non-energetic raw materials mining is a problem with obtaining of new allowances with the goal to replace mined localities or to search and use new sources.

The base for new raw material policy creation

The national raw material policy can be defined from the national level and European level. The differences are as follows:

The base for the elaboration of new raw material policy at the national level is to present time valid Actualization of raw material policy in Slovakia for the area of raw materials, accepted by government Decree SR No 722 from 14th July, 2004, in which raw materials were defined as a necessary condition for fluent development of the Slovakian economy.

It consisted of an analysis of domestic sources and determination of rules for protection and saving of raw materials using in accord with principles of sustainable development. The aim of actualization of the raw material policy was to determine long term goals and tools for their effective using and protection with respecting of principles of sustainable development of the society and protection of the living environment.

Demand on national raw material policy from European level: raw material policy became an inseparable part of industrial policy in EU, and at the level of individual member states it demands connection with industrial policy, innovation policy, the effectiveness of sources, living environment, and economic competition. This integrated perspective enables the industry to use necessary raw materials by the intelligent and permanent sustainable way, which contributes to strategy Europe 2020. Raw material policies at the level of member states should, therefore, include the following:

- Support of sources effectiveness, mainly primary energetic and raw material sources, by the way, to divide economic growth from growth of sources consumption,
- Strengthening of research and development with regard to critical sources replacement,
- To support existing or new mining of raw materials in such member states that are in balance with valid environmental, social and health or security legal decrees,
- To support the supply of raw material from the domestic offer, those should be one of the pillars of all measurements of raw material policy,
- To hold and increase employment in the European mining sector with providing permanent education and working power training, while the transition to sustainable mining activities should be accompanied by social dialogue at all levels,
- To make consistent policy “urban mining” (obtaining of raw materials from communal waste), which goal is to renew and make access to mentioned sources,
- To support raw material recycling and the need to provide the highest level of recycling everywhere, where it is economically and technically possible, including using of mining wastes that consist of considerable volume and spectrum of various metals.

Except mentioned EU policy as a base following European policies, directives, goals, tools, and priorities had been analyzed, as well as national policies, plans, initiatives and measurements with impact to demand of raw material industry (Tab. 1).

By comparing of basic state and identified development changes, growth factors, and demands on raw material policy, there is a conclusion there is necessary radical change of raw material policy. The new raw material policy is necessary.

Process of raw material policy creation is divided into six steps; mainly, there is necessary:

1. To define aim, vision and strategic goals – priorities of the raw material industry as an integral part of the national economy,
2. To define tactic, which means measurements and tools, by which help defined strategic goals will be achieved,
3. To define the present, mainly long term disposal and need for raw materials and their importance and use at national and EU economy,

4. To define possibilities – ways for covering raw materials needs:
   - By purchase abroad,
   - By mining and processing of own protected primary and secondary sources,
   - By waste recycling – tertiary sources using,
   - By substitution (for example metals substituted by plastics, etc.)

5. To complexly evaluate advantages, risks, and impacts of individual alternatives of raw material needs and to decide objectively about optimal alternatives,
6. To define operative measurements and tools and ways for their application with the goal to provide raw materials available for their economical consumption in the economy (company) with the best conditions.
7. The mentioned process is also illustrated by the algorithm in Figure 2.

Tab. 1. Analysed policies in EU.

EU policies, directives, goals, tools, priorities with impact on raw material policy
European raw material initiative
European innovation partnership and Knowledge innovation community KIC RM
Digital economy
European technological platform for sustainable raw material sources
EU policy in the area of raw materials: ERA-MIN
EU policy in the area of raw materials. Circular economy
EU tools: European Institute of Innovation and Technology (EIT)
EU tools: Horizon 2020 - SC5
Natura 2000
National policies, initiatives, and tools with impact on raw material policy
Government Program Statement SR
The strategy of permanent sustainable multispectral development and strengthening of competitive ability of Slovakia
Strategy for research and innovation for intelligent specialization SR
Slovakian economic policy
Energetic policy SR
Circular economy SR
Strategy Industry 4.0 SR
Digital economy – unified digital market
Environmental policy SR
Program for the waste economy in SR 2016-2020
The conception of geological research in Slovakia

Source: Natura, 2000

The raw material policy has direct relations to all three basic areas of permanently sustainable development. At the same time, three states policies – economic, social, and environmental – are orientated to these three areas of the growth (intelligent, inclusive, and sustainable). Due to this reason and for these relations, the raw material policy must be conceived by the way to direct development and activity of Slovakian raw material industry the most with regard to those three states policies. For any of these areas of sustainable development, a single strategic goal of raw material, the policy was defined. At the strategic level, it is defined for all three areas of sustainable development by valid priorities of raw material policy, as well as by vision and aim of Slovakian raw material industry. All areas, visions, goals, and priorities are included in Table 2.

Tab. 2. Areas of raw materials policy.

Policy	Economic policy	Social policy	Environmental policy
Principles of sustainable development	Intelligent growth	Inclusive growth	Sustainable growth
The strategic goal of raw material policy	Creation of economy, based on innovation and knowledge and righteous economic competition	Support of economy with a high measure of employment that will provide social and local development and coherence	Support of more ecological and competitive economy that will use raw materials more effectively
Aim	Long term, secure and economically and environmentally effective, providing raw materials for the need for sustainable and multispectral development of Slovakia and its regions.		
Vision	The prosperity of Slovakian raw material industry, achieved by effective using mainly of the domestic raw material base in accord with economic, social and environmental policy of the state, national historical, natural and cultural values and multispectral regional development.		
Priority I.	Providing raw material security of the state in accord with state economic, social, and environmental policy according to the needs of sustainable multispectral development of Slovakia and its regions.		
Priority II.	Sustainable multispectral development of Slovakia and its regions.		
Priority III.	Transition from raw material chain to raw material flow in accord with the circular economy.		

Source: UN, 1997

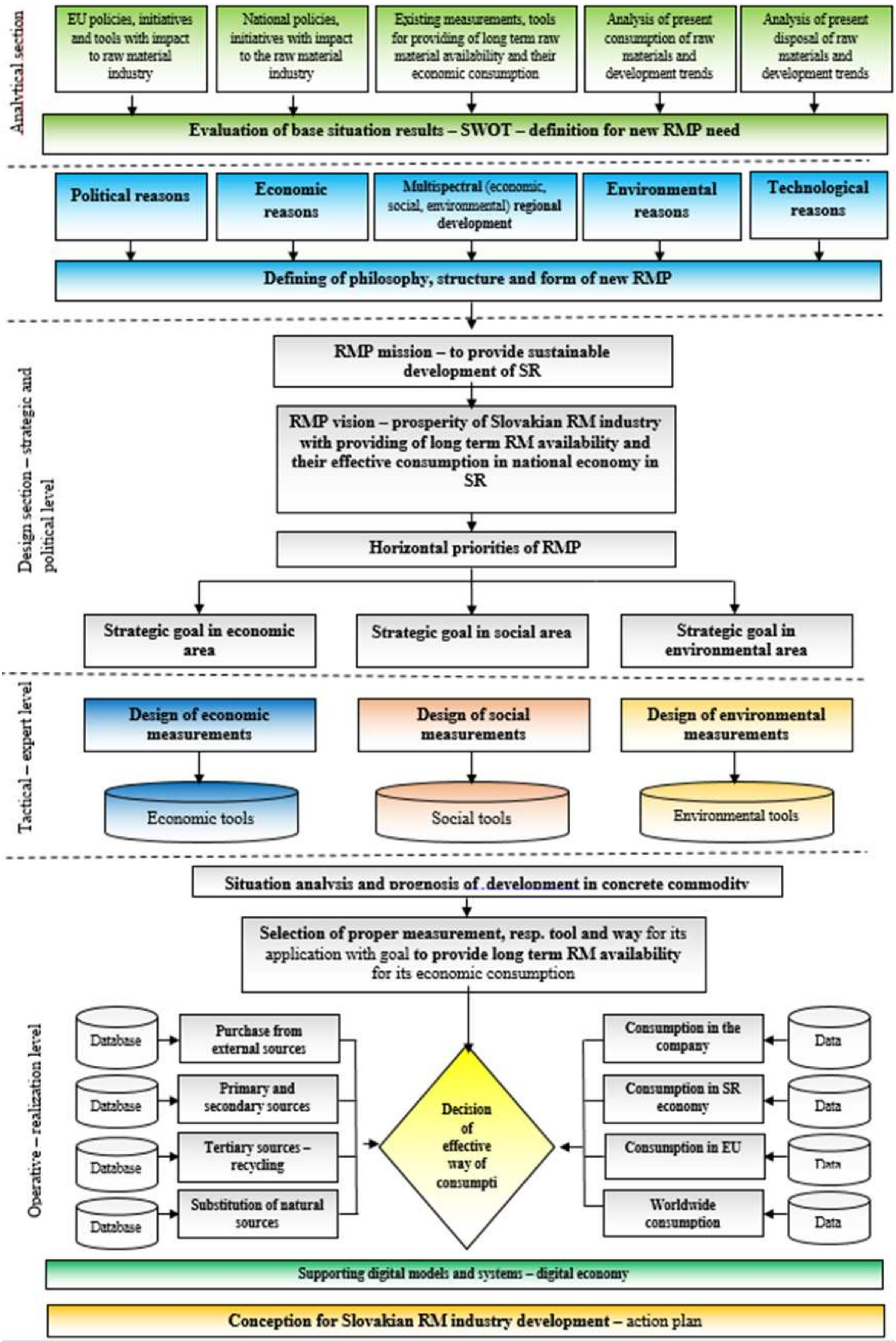

Fig. 2. Algorithm for raw material policy creation.

Except for mentioned three state policies, the raw material policy has direct connection also to the European policy, in which energetic, raw materials and the way for their providing is solved. Importance of using domestic raw materials is also emphasized in other national policies. It is part of government program declaration in Slovakia, the strategy of sustainable multispectral development and strengthening of Slovakian competitiveness, strategy for research and innovation for the intelligent specialization of Slovakia, strategy for the building of circular and digital economy, strategy Industry 4.0, and program of the waste economy in Slovakia and other policies and documents.

Conclusion

Proper geopolitical and market conditions present a unique historical chance to revitalize the Slovakian raw material industry. Suggested concept of new raw material policy defines systematically and objectively conditions, development goals, as well as concrete steps (measurements and tools) for filling of these goals. Realization of such a suggestion can be an example of effective management and targeted support of development in the concrete industrial sector.

Detail elaboration of all tasks, connected with raw material policy, exceeds the scope of this contribution. Similarly as all development activities, also mining of non-energetic minerals must find a balance between its goals and goals of other economic interests, as well as with natural environment and wider social interests, with the aim to provide sustainability of mining operation.

Acknowledgment: *The contribution is a partial result of project solving VEGA No 1/0515/18 „The decision-making model of process of evaluating raw material policy of regions”.*

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Modeling of underground mining processes in the environment of MATLAB / Simulink

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The article is focused on the creation of a computer model for the planning of the mining process and its application in the planning of the mining activities. The use of computers and specialized software in mining has brought great new possibilities to speed up and refine the planning process. The paper deals with the use of software tools in mining and their application, the overview of available market planning software and their functions. The main part of the article is the design of a computer planning model of mining. The presented article is focused on modeling in MATLAB/Simulink environment, preparation of input data, a description of its function and its application. MATLAB is a worldwide popular software for technical computing and simulation. It is a convenient tool for simulating mining processes. The purpose of the article is to point on possibilities of modeling of mining processes in the MATLAB environment. The emphasis on creating the model was based on the simplicity and difficulty in inputting the input parameters and the overall work with the created model. At the end of the article, additional options for expanding and improving the model are summarized.

Key words*: model, modeling, mining, MATLAB, process*

Introduction

The development of computer technology and its introduction into all areas of human activity has brought new opportunities and accelerated many activities. This trend did not exclude mining and mineral mining (Bauer, 2014). In countries that are among the leaders in the mining industry abroad, their use is already standard. These programs have facilitated, accelerated, and streamlined many of the activities involved in the design, planning, and management of mining operations. Traditional methods for designing and modeling surface and underground operations are based on manual calculations of mining parameters and manual output of graphical outputs (Fahrman, 2016). The basis of this method is a long time for data processing and the design of an optimal solution that greatly complicates work. Specialized software enables faster, more quality, and more creative work. IT applications in mining, allow the introduction of new methods for surface and deep mining, which differ significantly from traditional methods (Rybár et al., 2017; Blistan et al, 2015) . Planning and designing underground mining operations involves a comprehensive process of integration of three-dimensional data through the use of information from exploration, engineering, and extraction processes. Planning of the deposit mining process involves the transfer of knowledge and technology between disciplines such as geology, technology, research, accounting, and management (Blistan, 2007). Since operations are becoming more and more complex, effective communication is becoming more and more complex (Hall, 2018). Methods of reducing the number of errors and risks in exploration, mining, planning, and operations will help increase the safety and productivity of mines (Kaiser et al., 2002). The introduction of innovative technologies in the process of raw material extraction planning in Slovak mining companies is essential for increasing the efficiency of mining, reducing the costs of mining and operation and also for the maximum rational utilization of mineral resources (Cehlár et al., 2017).

Computer modeling in the mining industry

At present, there is a whole range of software solutions that cover the full range of mining industry activities, including comprehensive mining planning solutions to specialized programs designed to address specific technological processes in mines and quarries such as drilling and blasting, ventilation or geotechnical modeling. This subchapter briefly sums up the available software and its specifics in the mining planning process.

With the onset of computing, mining techniques have evolved into new design methods. New methods have emerged since the 1960s in the US, the UK, Australia, and South Africa. Classical methods are based on manual calculations of technical and technological parameters and graphical interpretations. Methods require long and

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demanding work over a longer period of time, especially when different solutions are being developed (Miladinovič et al., 2011).

Benefits of using software:

- quick update option,
- three-dimensional view of objects,
- thanks to the third dimension, high transparency,
- considerably faster creating different variants of projects or models,
- digitally stored data can be used in different types of software,
- the ability to run different types of simulations and calculations,
- the ability to quickly and conveniently share data and results over the Internet.

Computer programs that are used in mining, depending on the purpose, can be divided into the following groups:

- **universal software packages:** mining computer programs for modeling and design of deposit for surface and underground mining,
- **specialized software packages:** designed to optimize surface or underground mining and analyzes of mining activities,
- **special application software:** designed to analyze specific problems associated with mining design or mining technologies, cost analyses, solving some technical problems such as slope stability, blasting design, ventilation, transport and others (Miladinovič et al., 2011).

The leaders in mining software development are companies GEOVIA, DATAMINE, MAPTEK, Hexagon Mining, and Micromine. Each company has different software packages created for specific types of operations or specialized operations within the mining industry.

Mining-technical start points for modeling of mining processes

Mining of mineral deposits has several characteristics and peculiarities that are given by the specific production process of mining, which differs, respectively. It is incomparable with manufacturing processes in other industries, in engineering or metallurgical production. As Mining Characteristics of mining of mineral deposits, we understand the content, forms, typology, and system of deposit mining, based on the application of the above mining and mining-related scientific disciplines. Mining and system characterization of the mining industry is primarily a result of mining and system analysis of technological processes and technical phenomena taking place in the production process of deposit extraction. In the production process of the mining industry and in the individual technological processes of mineral extraction, several separately existing but parallel development stages of the mining business, which are realized on the deposit for rational obtaining of the maximum amount of mineral / raw material (Bauer, 2014).

The basic and general features of mineral deposit extraction that represent the specificities of ore, non-ore, and energy raw materials extraction can be summarized as:

- stages of mining processes,
- a time sequence of mining,
- preparedness of mining,
- variability of mineral deposit quality ratios,
- the selectivity of mining,
- energy consumption of mining processes,
- the economic burden of mining,
- reduced security of mining facility,
- large surface and directional vastness of excavation,
- environmental friendliness of mining processes.

The mining of mineral deposits is characterized as a very complex, specific and dynamic production process, taking place in a constantly changing time, and the boundary of the mining area of the deposit in which the various phases of the mining process are realized (Bauer, 2014).

A process of a model making in MATLAB / Simulink interface

The computer model intended for the planning of mining processes solves underground excavation of non-ore raw material. A model is simulating mining in two positions in mine. In each position is placed one workplace, on witch the mining itself takes place. The mining method used in the model is stopping with the filling of the open underground spaces. In simulation is used non-rails transport. Each mining position is separated into smaller blocks. The geometry of mining positions and distribution to mining blocks is displayed in Figure 1.

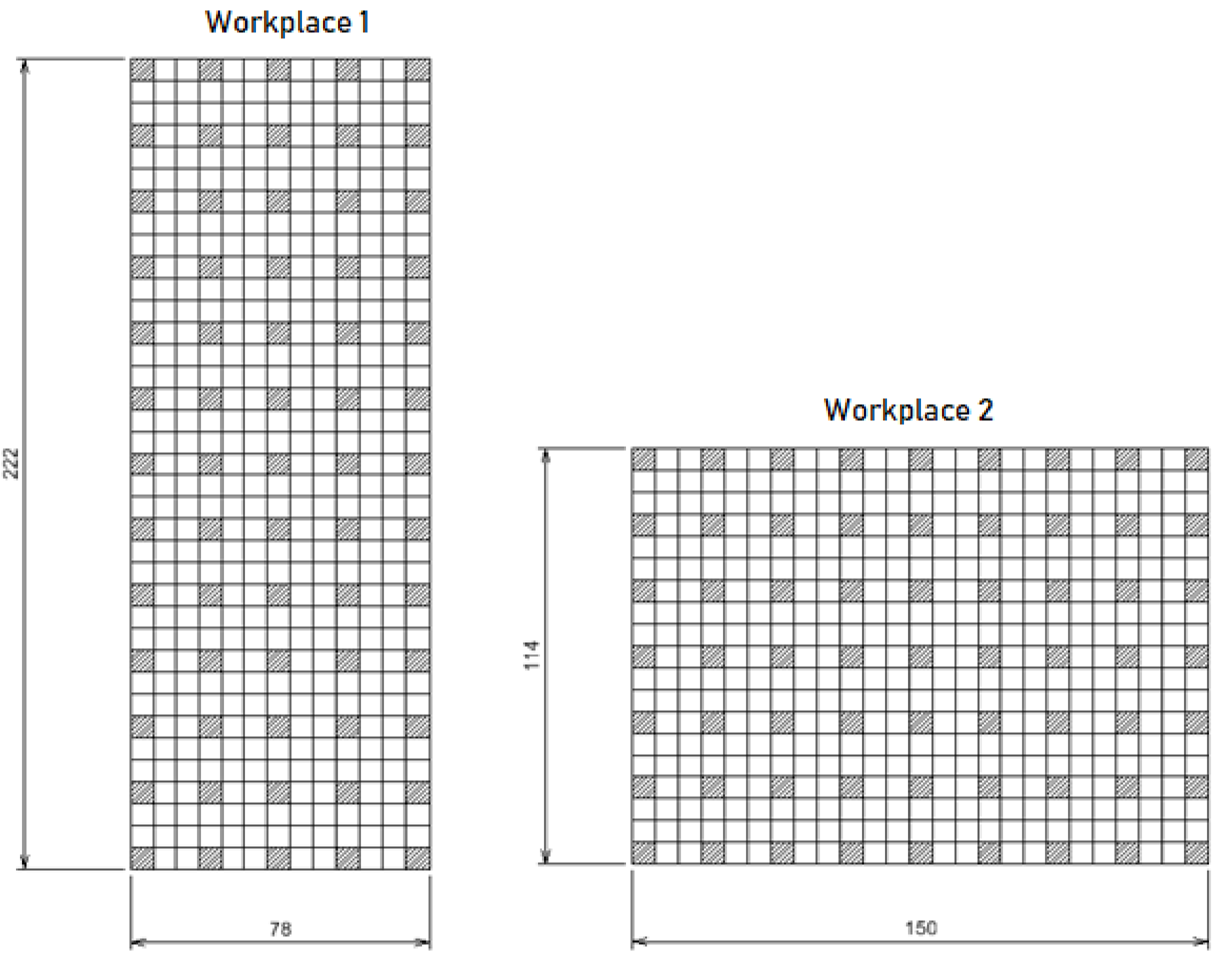

Fig. 1. Geometry of the workplaces (Janič et al., 2018).

The Modeled situation is expecting that the opening of the mine was already done and mining of new mining corridors is not expected. Mining vehicles are used for the transportation of ore. The routing of loaded and empty mining vehicles is realized in transport corridors of the mine. The timing of transportation is calculated from generally using formulas for calculation of the mining transportation performance. The model works with three products of the mining process based on the content of raw material (Fig. 2).

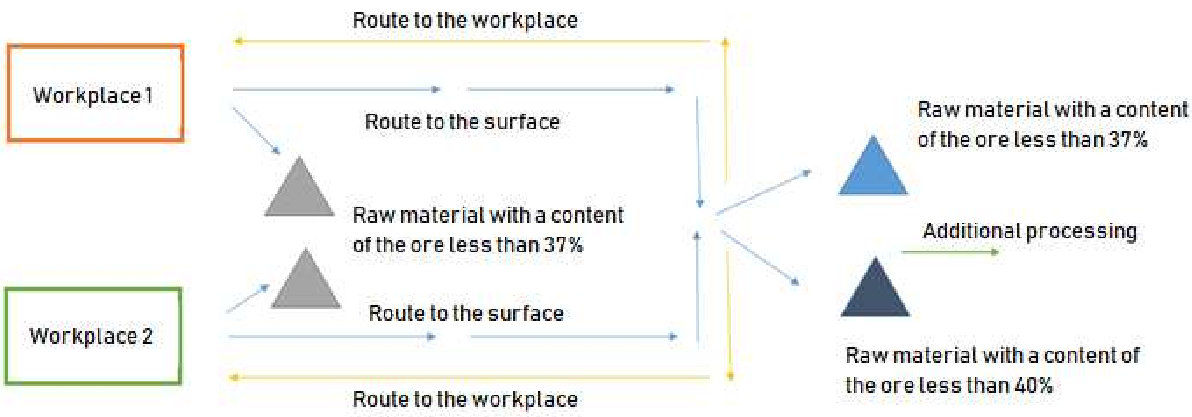

Fig. 2. Scheme of the model situation (Janič et al., 2018).

The basic software (Fig. 3) for creating the planning model is ESRI ArcGIS software and MATLAB software with the Simulink add-on. ArcGIS software is used to work with the geostationary model and its visualization, block selection, and also to visualize output data on the mining process. It will therefore mainly serve for the preparation of mineral deposit data, respectively about individual mines. The MATLAB software will be used for the main part of the modeling process, in which the mining process itself will be modeled, and the ArcGIS data and other input data will then be imported (Fig. 4).

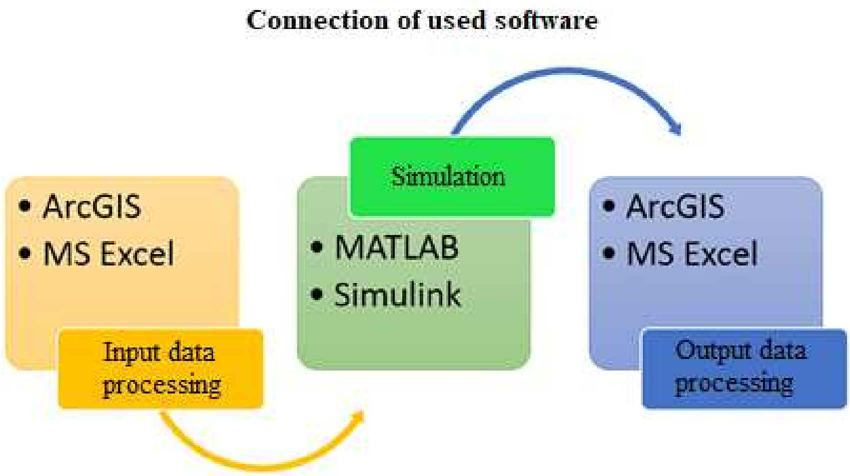

Fig. 3. Connection of used software (Janič et al., 2018).

Modeling process

The simulation model is based on the Stateflow toolbox. Stateflow is an environment for modeling and simulation of combinatorial and sequential decision-making based on logical events using state automata and flowcharts. Stateflow allows to combine graphical and table representation, also includes transition diagrams, flowcharts, transition tables and truth tables for modeling as the system responds to events, time conditions, and external input signals (Novák et al., 2005).

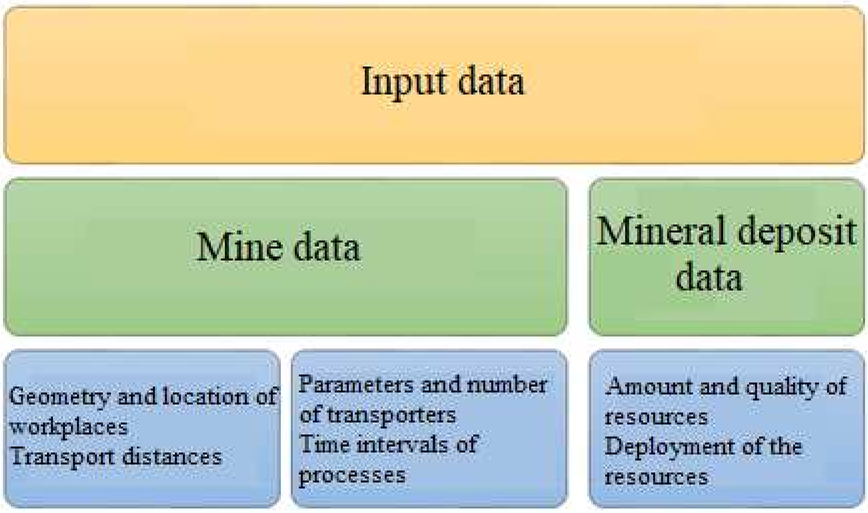

Fig. 4. Input data for the model (Janič et al., 2018).

With the Stateflow toolbox, it is possible to model the logic for supervisory control, task planning, and error management. Stateflow includes state-of-the-art animation, static and run-time control for design consistency testing and assembly before implementation. Using the Stateflow toolbox, we modeled the mining process by simulating discrete events. Each block created by the Stateflow toolbox represents one mining site (Fig. 5), with multiple blocks in the simulation scheme representing the same number of workplaces working on the same mining blocks. The mining input data can be set programmatically, using the mine_param.m script; the amount to be exploited is stored in the 1_pracovisko.xlsx and 2_pracovisko.xlsx files. Simulation is 60 times faster than real time, which means that 1 second in a simulation is 1 minute in real time.

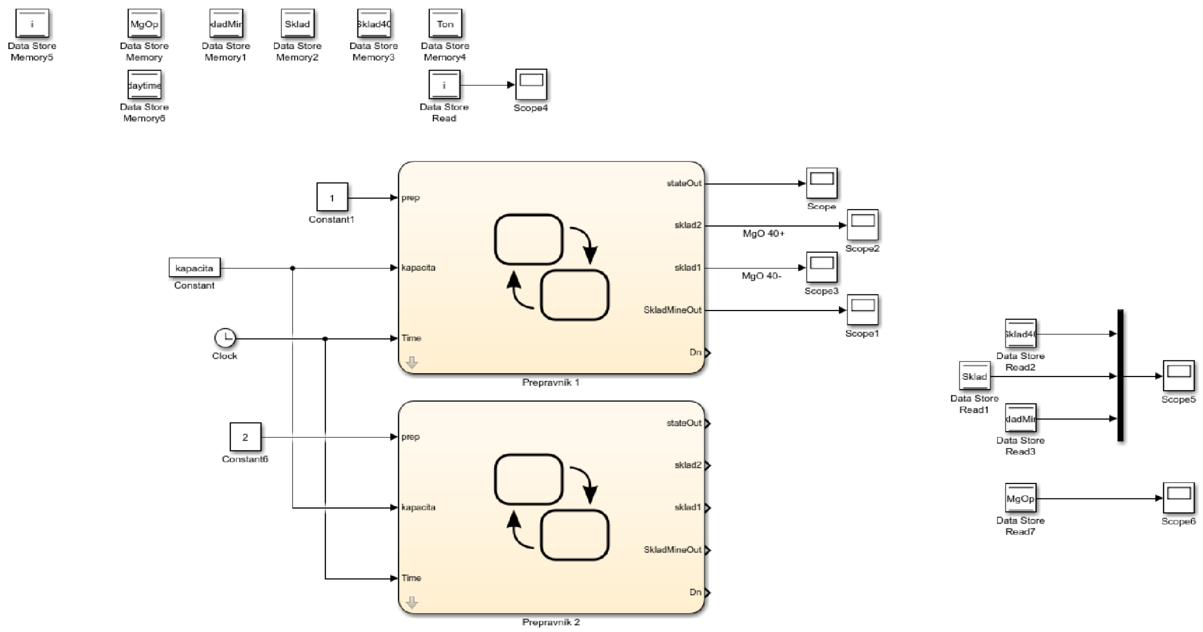

Fig. 5. Illustration of the first workplace in MATLAB / Simulink (Janič et al., 2018).

The result of the simulation is the time course of filling of the warehouses, which are according to the content of the utility component sorted into three categories. These data can be displayed directly in the MATLAB environment or can be exported to .xlsx for MS Excel. The simulation parameters can be set for the user in the mine_param.m script. As shown in the variable names, the capacity of the conveyor, the transportation time of fully loaded conveyor to the surface, the transportation time of empty conveyor to the underground, the loading time and the unload time. After changing the values, it is necessary to execute this script to save changes to the variables and also repeat the simulations. The mine_param.m script uses the import_s1.m and import_s2.m scripts that are loading and preparing the data.

The simulations themselves are stored in Simulink simulations in the mine.slx and mine2.slx files. Before running the simulation, run the mine_param.m file with the appropriate parameters. Once the simulation has finished, the data can be exported (Fig. 6). The export is executed by running the dataProcessing.m script which performs the preprocessing of the acquired data and stores the data in the .xlsx file.

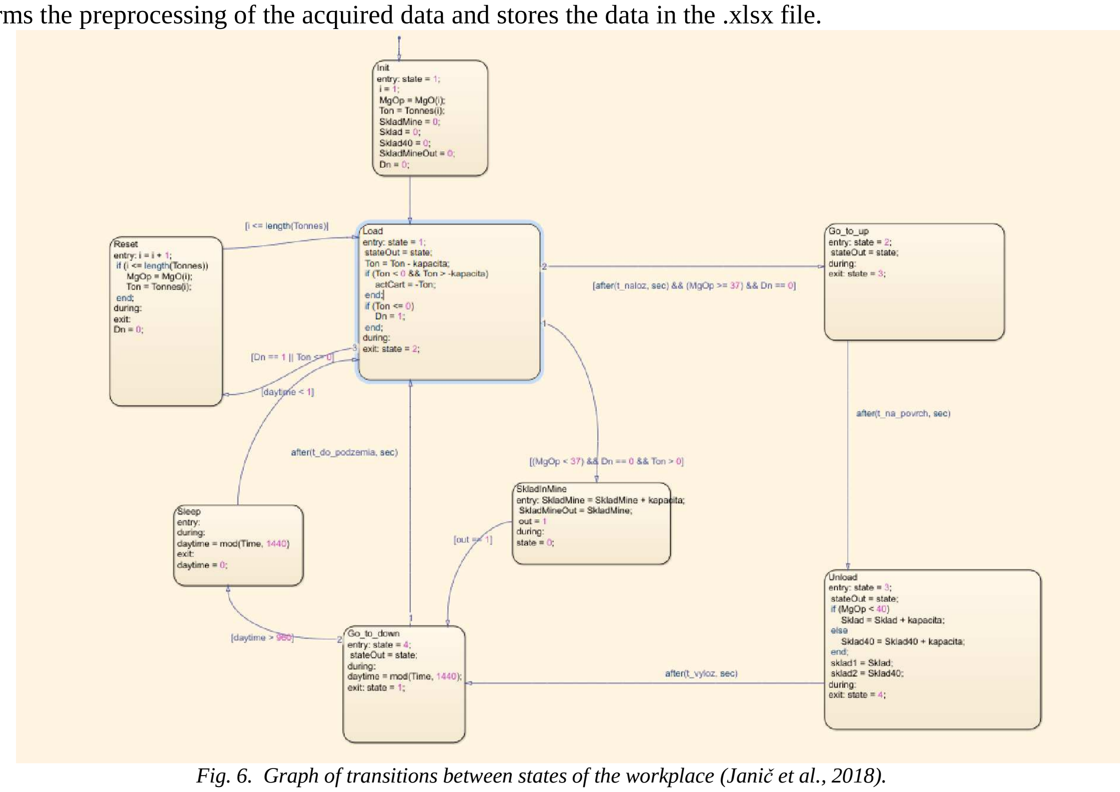

Fig. 6. Graph of transitions between states of the workplace (Janič et al., 2018).

Planning model features

The main features of the proposed planning model can be divided into three parts:

- determining the total amount of raw material extracted
- determining the amount of raw material extracted according to each set quality category
- determination of the mining process in individual mining places and workplaces

Together these features give an overall view of the mining process and its progress over time. Basic outputs from the model include spreadsheets, exported to .xlsx, and charts that can be viewed directly in MATLAB or can be created in MS Excel. A script that prevents data processing from simulation generates output:

- day-to-day mining and its breakdown by the quality of each workplace
- monthly mining and its distribution according to individual qualities for individual workplaces
- the number of mining blocks being used

After entering all input parameters of the model, it is possible to proceed to the simulations themselves (Fig.7). The length of the mining simulation for individual workplaces depends on the size of the individual mines and the time period to be simulated. Another factor influencing the length of the simulation is the performance of the workstation on which the simulation is running.

In the case of this model simulation, the simulation itself took place at the workstation with the following parameters:

- CPU – Intel Core i5 4670@3,4 GHz,
- RAM 16 GB,
- GPU NVIDIA GTX 1060 6GB,
- SSD 250 GB.

The duration of the simulation, in this case, lasted approximately 2 minutes for each workplace.

Outputs of mining simulations of individual workplaces were processed in MS Excel. Outputs are graphs and spreadsheets describing the progress of mining and the month-by-month mining scheme that was processed in AutoCAD software.

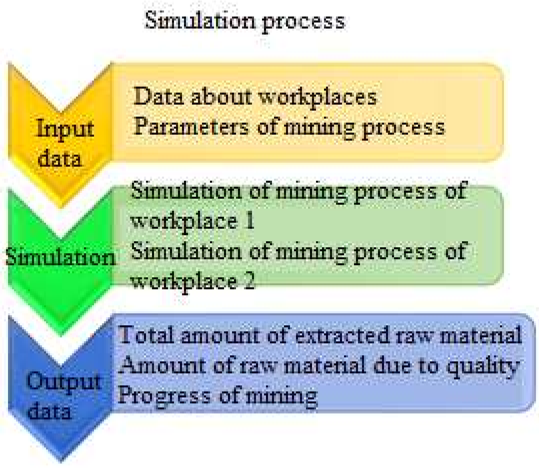

Fig. 7. Simulation process (Janič et al., 2018).

Outputs from the model

Fig. 8. is a schematic illustration of the process of each mining queue according to the months for the individual workplaces. These progress maps have been created based on the number of blocks to be mined in each month. The total number of blocks used is shown in Tab. 1 from where these values were used for the creation of the progress maps in AutoCAD software.

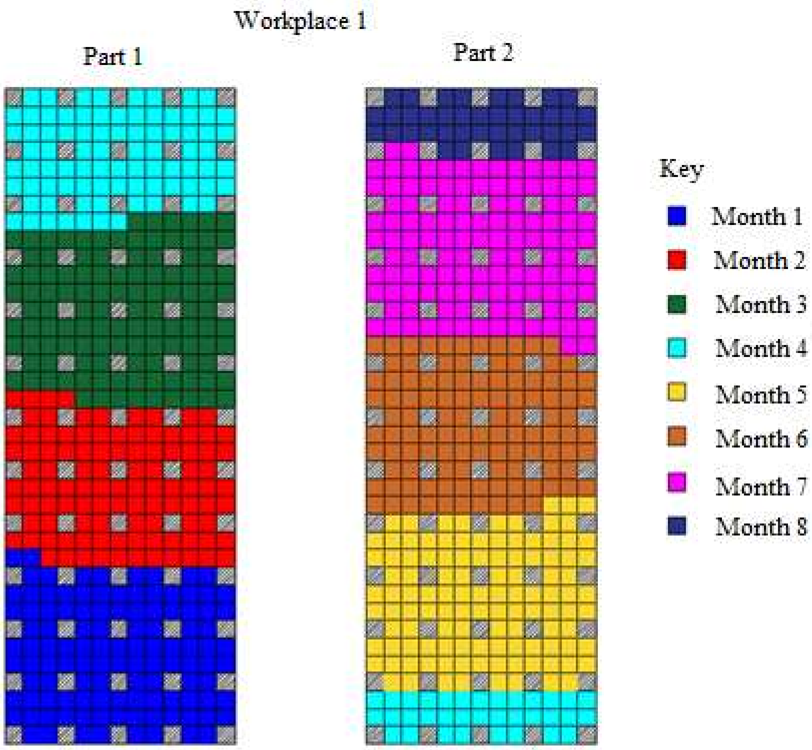

Fig. 8. Monthly progress of mining – Workplace 1divided into two parts (Janič et al., 2018).

Tab. 1. Summary of mining in workplace 1 (Janič et al., 2018).

Month	**Product 1** [t]	**Product 2** [t]	**Product 3** [t]	**Number of excavated blocks**	**Monthly mining of raw materials** [t]	**Total mining of raw materials** [t]
1	24336	33984	5760	112	64080	64080
2	50688	64872	13824	225	65304	129384
3	85968	85248	25344	342	67176	196560
4	121536	105048	37440	459	67464	264024
5	147456	136368	45504	572	65304	329328
6	172800	169704	50112	682	63288	392616
7	207072	190080	63936	801	68472	461088
8	215424	195840	67392	832	17568	478656

Model evaluation and possibilities of use in practice

The model for the planning of the mining progress of the deposit, which is the main benefit of this article, also forms the basis for further development and gradual improvement to adapt to the conditions of the particular operation as much as possible. The proposed model could be summarized in terms of advantages and disadvantages as follows:

Advantages of the proposed model

- simple input of basic mining parameters
- import of the mining data is in .xlsx format, which is supported by most geo-statistical models,
- simulation speed
- possibility to adapt to any requirements of the user.

Disadvantages of the proposed model

- in actual version is necessary to run the model from MATLAB,
- a more complicated changing procedure of some parameters (working time, number of workplaces),

- not generating graphical output automatically (mining progress).

Possibilities of the model improvement to match most of the needs of

- adding a higher number of the input data,
- adding possibilities of optimization of mining parameters with a genetic algorithm,
- creation of a model as a separated software without the need to run a model in MATLAB,
- the possibility of creation version for a mobile phone or web app,
- adding a fully graphical interface.

The proposed model can be used in practice not only in the mining planning process and its progress but also in the design process, determination of the optimum size of the transporters as well as sufficient power of mechanisms or design and choice of mining routes. The benefit of the model for practice is the rapid simulation of various variants of mining plans.

Conclusion

The article focuses on the design and creation of a computer model for the mining planning process, which should be a supporting tool in the planning process. The introduction of such advanced tools into the mining industry is justified, and abroad, these software tools are used as standard and are applied to all areas of mining. However, they are rarely used in the conditions in Slovakia and practice at all in the mining planning process. This article aimed to analyze the currently available commercial planning software, to evaluate its advantages and disadvantages. Based on this analysis, the criteria and requirements for the computerized planning model itself and the appropriate tools for its design were determined. The article also deals with the preparation and processing of data that will be used in models as input data. The main emphasis of the article is on the creation of the model itself and its use in solving the planning of the mining process in the deposit. A designed model was created in MATLAB and Simulink, which serves as a universal tool for a wide range of technical calculations. The created model was subsequently tested on a model situation, which simulated deep mining using selected mining method and mining machinery. The parameters of this simulation tried to approach the real mining conditions as closely as possible within the capabilities and functions of the proposed computer model. The proposed computer model also forms the basis for further extending its functions and gradual improvement to meet the conditions of a particular operation, eventually serving as a springboard for another version of such a computer model. A model can also be used in the process of education of future mining engineers and as a learning tool for subjects dealing with the mining of raw materials.

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Impact of changes in coal prices and CO_2 allowances on power prices in selected European Union countries – correlation analysis in the short-term perspective

***Mariusz Andrzejewski*[1], *Patryk Dunal*[1] and *Łukasz Popławski*[1]**

Spreads on power markets serve as indexes that allow assessing the future profits of electric utility companies. The spread applicable to power generated from coal, including the cost of CO_2 allowances and power plant efficiency, has been termed Clean Dark Spread (CDS). A CDS index may serve at least two basic functions. On the one hand, it provides information on the future prices of power and profitability of power generation. On the other, it facilitates hedging to be applied not just by power plants but also by other entities operating on the market. Following deregulation of energy markets, energy has started to be traded on the exchanges and trading facilities, which is also reflected on Polish Power Exchange operating on the Polish market. Following the introduction of the European Union Emissions Trading Scheme, Polish energy generating companies hedge the prices of CO_2 emissions allowances with the use of foreign trading facilities, especially EEX. Since two out of three CDS constituents are traded on trading facilities, it seems fully substantiated also to introduce quotations of coal prices in Poland. This paper is aimed to present the crucial aspects of shaping coal prices in Poland and on international markets as well as to examine the impact of changes in coal prices and CO_2 emissions allowances on shaping power prices based on a comparative analysis between Germany and Poland. This study also includes the costs incurred by the coalmines by paying environmental charges on waste resulting from their economic activity.

Nonetheless, it should be noted that those charges do not affect the financial result. The analysis of the correlation has shown that the price of electricity on the Polish market is positively and strongly correlated both with the price of coal and the price of CO_2 emissions allowance, the latter correlation being stronger. Equally worth noting is the strong correlation between coal prices in Poland and the prices of CO_2 emissions allowances. With regard to the confirmed but rather not very strong positive correlation between steam coal prices on the Polish market and energy coal prices in the ARA zone, it should be noted that there is no liquid index in the domestic market, which hampers efficient portfolio management of the spread on energy production by the coal energy sector

Key words: *Dark Spread, price of power, price of coal, cost to coal mines of environmental charges, CO_2 emissions allowances.*

Introduction

The development of the energy sector in terms of the use of derivative instruments to stabilize financial performance encouraged creating similar opportunities within purchases of primary power carriers, in particular of coal which is one of the fundamental fuels in global terms. Perennial contracts have been, and still are being replaced with spot and forward transactions, with delivery on a specified date. This necessitated the construction of appropriate price indexes which facilitate monitoring and analyzing market trends as well reporting and modelling the behaviour of other entities (Shiv Prakash and Hooman, 2018; Gavurova and Šoltés, 2013; Straka et al., 2018), and which also are applied to controlling inside companies (Gonos et al., 2016; Stojanović, 2013; Khouri et al., 2017; Rosová 2010). Owing to the price indexes, coal-based power energy generating companies from Europe can effectively hedge their Clean Dark Spread which includes three major constituents: the price of power, the price of coal and the price of CO_2 emissions allowance.

On the European market, all these constituents are traded on transparent and efficient trading facilities. Poland does not offer any efficient hedging instruments for CDSs under the assumption that coal has been purchased in Poland whereas the derivative instruments are based on international coal. Such solutions also help to mitigate the risks (Domingues et al., 2017), and it is worth noting that similar steps are taken in other countries (Madzík et al., 2016; Kozina and Pieczonka, 2017). In keeping with the preceding, this paper is aimed at evaluating the impact of changing coal prices and the cost of CO_2 emissions allowances on energy pricing.

This study presents the crucial aspects of shaping the price of coal in Poland and on international markets. It also examines the impact made by the changing coal prices, the cost of CO_2 emissions allowances as well as the environmental charges levied on waste on shaping the prices of energy by means of a comparative analysis between Germany and Poland.

Calculation of spreads on power markets

In its simplest terms, the spread should be understood as a difference between two flows of cash related to the same asset or assets within the chain of generating added value. Hence, the spread may be the difference

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between the bid price (the purchase price) and the asking price (selling price) of an asset. In the case of the energy market (to be precise, the energy generating company) spread will represent the difference between the price of energy and the cost of fuel necessary for its generation.

Due to the fact that prices of fuels are subject to fluctuations, spreads for energy generating companies using various fuels are different. For this reason, various spreads have been designated for energy generated from various fuels. The value of spread for energy generated from coal, that is, Dark Spread, is calculated using the following formula (Abadie et al., 2008):

$$DS = PE - PC \text{ [PLN/MWh]} \quad (1)$$

where:

DS – Dark Spread [PLN/MWh]

PE – Price of Energy [PLN/MWh]

PC – Price of Coal used to generate 1 MWh of energy [PLN/MWh]

On the market level, two values are necessary for fixing the spreads: the price of energy and the price of coal necessary for its generation. The price of energy is the price quoted on a certain day. Within a day, the price of energy is volatile. Hence it would be opportune to set the value of spreads with the use of the average weighted price of energy in individual hours, and the weight would reflect the volume of energy sales at a certain hour. Apart from the price of energy, the cost of fuel has a decisive influence on the value of the spread. In the case of coal, that will be the coal reference price set for a given place on the globe. For Western European markets, that price is commonly close to CIF[2] price for ARA[3] ports, as more amply explained further in this study.

Once the price of coal, the price of energy, and the average efficiency of a power plant are familiar, it is possible to establish the value of the spread. Spreads are calculated for a specified energy market – in most cases; it is the market of one country. This is due to the fact that the power systems of individual countries are independent of one another. Hence there are different quotations for energy. The values of spreads are published by the agencies which specialize in collecting information on raw materials and power markets (for example, ArgusMedia). Those centers gather information from various sources, and for that reason, there might be negligible differences in quoted spreads.

The value of the spread is decided by the efficiency of a power plant, which in turn depends on the kind of burnt fuel. The estimated efficiency ratio for coal-fired power plants is approximately 38 %. Formula (1) will be transformed once it is provided with the efficiency ratio. Because the price of coal necessary to generate 1 MWh depends on the price of 1 ton of coal and power plant efficiency, the following formula is used:

$$ER = PC / E \text{ [PLN/MWh]} \quad (2)$$

where:

ER – Efficiency Ratio [PLN/MWh]

PC – Price of Coal [PLN/MWh]

E – power plant efficiency [%]

After substitution we obtain:

$$DS = PE - (PC / E) \text{ [PLN/MWh]} \quad (3)$$

In order to unify how DS is calculated within a single market, the efficiency ratios of a power plant should be clearly defined. To give an example, those ratios for calculating German Dark Spread and Polish Dark Spread stand at 35 %. The efficiency of 35 % of burning coal was defined for coal of average calorific content of 6100 kcal/kg (1 Mg of such coal equals approximately 7.1 MWh). In case of spreads published by brokerage agencies, the negligible difference between the calorific content of coal accepted for Dark Spread calculations and the one which is applied for setting transaction costs on fuel markets is of no substance. That is because they are more a profitability coefficient for the whole industry rather than for a single company.

The spread value should be adjusted by the cost of CO_2 emissions allowance since that cost translates directly into the price of energy generated from the use of fossil fuels. It has been accepted that to generate

[2] CIF – according to Incoterms(R)2010: Cost, Insurance and Freight.

[3] ARA – main ports for European market: Amsterdam, Rotterdam, Antwerp.

1MWh; it is necessary to burn fuels, which, in case of coal, results in the emissions of 0.96 Mg CO_2 (Camargo et al., 2018). The formula, including CO_2 emissions allowance cost, is as follows:

$$CDS = DS - C\ CO_2\ x\ 0.96 \text{ [PLN/MWh]} \tag{4}$$

where:

C CO_2 – price of 1 ton CO_2 emissions allowance

After substitution, the final formula for calculating spread value is as follows:

$$CDS = CE - (CW/E) - C\ CO_2\ x\ 0.96 \text{ [PLN/MWh]} \tag{5}$$

The CDS coefficient may serve at least two functions. On the one hand, it shows market trends in these areas based on which allows predicting indirectly about the future prices of energy and profitability of energy generation. On the other hand, it allows power plants as well as other entities operating on the market to hedge.

Determinants shaping energy prices and the structure of costs of its generation

One of the most important elements of the functioning of the mining industry is planning (Nehring et al., 2018; Pawliczek et al.; 2015, Straka et al., 2017) and financial issues (Czillingová et al., 2012), especially the sources of financing (Markulik et al.; 2018) and information aspect too (Małkus and Wawak, 2015). In the process of making decisions in mining industry, not solely financial ones, more and more important role is attributed to various coefficients (Vilamova et al.; 2016, Sánchez-González et al., 2017; Zimon and Domingues, 2018) and methods (Johannsen and Fill, 2017; Lohrmann and Reichert, 2016; Camargo et al., 2018), including multicriteria ones (Straka et al., 2014), even though in Poland and Slovakia the human factor (social and political factor) (Cehlár et al., 2015), remains a significant determinant.

The value of CDS depends on the cost of energy generation in a power plant. Hence, each energy generating company may assess whether their spread, that is, profit made on 1 MWh is lower or higher than the market average and look at their competitive advantage relative other entities. Energy generating companies who wish to use spreads in their analysis of profitability and production should observe the following procedure; when spread on the market is too large, that is, it is more than sufficient to cover variable and fixed costs, it is beneficial to generate energy from a chosen fuel. When the spread is too little (or adverse), and it does not suffice to cover even variable costs, then it is more beneficial to halt energy generation and sell fuel purchased on the market or store it till spread has become larger. Such a solution is not feasible over a short period of time since a power plant cannot simply have their power blocks switched off to offset current changes of spread values. It is beyond any doubt that in the long term, spread value should remain above a certain figure, which varies from plant to plant as each of them has to bear certain costs, apart from the cost of fuel, necessary for the functioning of the whole facility. Clear values of spreads show merely the profit (or the loss) on sales of energy and they do not include other costs of a power plant. Figure 1 presents the structure of costs of energy generation depending on the type of fuel.

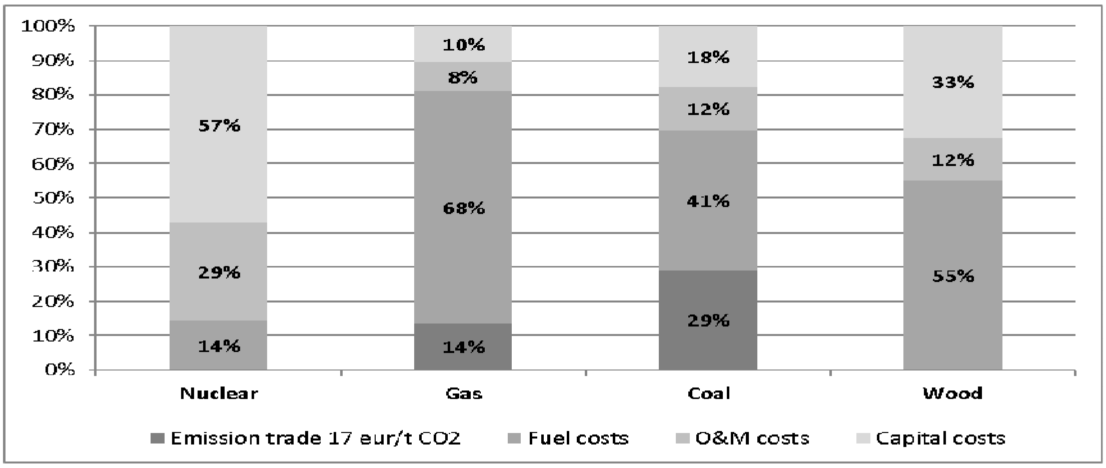

Fig. 1. Energy generation costs, including emissions trading.
Source: Authors' elaboration based on T. Risto, K. Aija, Comparison of electricity generation costs, Lappeenranta University of Technology, Lappeenranta 2008, p. 9.

All three variables used in the calculation of spread – the price of coal, the price of CO_2 emissions allowance, and the price of energy, are market variables on the international markets and as such, they are not dependent on the decisions made by the individual market entities. The market price of energy, which is subject to cyclical (daily, annual) fluctuations exert the biggest impact on the value of spreads. That price depends on the following variables (Lorenz and Grudziński, 2009; Straka, 2010; Blistan et al, 2012):

- ambient temperature (the season of the year) and the power of wind in places where wind turbines have been installed (the impact on coal-generated energy in merit order), merit order – a system of classification of the available resources in the context of power generation, with reference to the cost of generation, used by the operator of the national power generation system. In a centralized system of grid management, it means that the facility with the lowest marginal costs have power fed to the grid first to meet the demand,
- water level of rivers (as a source of hydropower and also a cooling agent for Main Activity Producer Electricity Plants), such incident occurred in Poland in August 2015, when due to high ambient temperature and low river water level, power plants in Połaniec and Kozienice experienced difficulties with cooling (and consequently with power generation),
- the profitability of coal-fired power plants calculated with the sales margin in Main Activity Producer Electricity Plants (CDS),
- the global volume of energy generation by nuclear plants and renewable sources,
- scheduled overhauls of power plants and their maintenance (usually they are scheduled for the period of lower energy and heat consumption). Also, random malfunctions of power generators and disruptions of the transmission grid,
- limitations in global rail transport of coal from the mines to the seaports,
- changes in ocean and Mediterranean freight charges and the cost of rail transport,
- currency exchange rate fluctuations.

The prices of fossil fuels are not subject to cyclical changes. They are dependent on the long term expectations of the market participants about supply and demand for a certain fuel. A similar situation may be observed on the market of emissions allowances. The prices of allowances much depend on the current economic situation. With the increase in the demand for energy (including energy generated by burning fossil fuels), the prices of allowances should rise. By comparing the three constituents, we might try to assess the value of spreads on the energy market.

When the price of one constituent changes due to non-fundamental factors (for example, owing to the changes on the stock exchange or a rapid increase in the consumption of energy caused by a rise/drop of ambient temperature which result in boosting energy price) spreads may be subject to volatile changes over a short timeframe. That is because the other factors affecting the volume of spreads will not adjust to new conditions. Due to that volatility, spreads may reach negative values within certain timeframes. However, such a situation may not persist for too long as power plants would not find energy generation profitable. A smaller supply of energy would contribute to raising its price, which in turn would result in the increased spread and restoring profitability.

The above premises refer to an energy generating company which sells energy and buys fuels on the spot market. In this way, they help to show the current profitability of energy generation with the use of a certain fuel. Nonetheless, fuels are purchased in advance with the use of futures contracts. For this reason, presenting current values of spreads in the situation when a power plant has to generate a certain volume of energy is not very helpful for an energy generating company in determining current profitability of energy generation. The situation would change once a power plant was in a position to increase or decrease the volume of generated energy. Under such circumstances, it could react to the current situation on the market and adjust its output. At this point, the analysis of the volume of spreads might be useful to adjust the volume of output to the grid. In view of the fact that energy is a commodity which may not be stored, such a solution is not feasible for a greater number of power plants. Once a massive adjustment of energy supply is not an option, the use of hedging may be the solution. By gathering market information on the prices of energy, correlating it with the forecasts and instituting proper hedging instruments for the purchase of fuels and energy sales, an energy generating company may successfully predict future profits and the costs of operation.

The greater the diversity of fossil fuels burnt by power plants, the greater the opportunity for changing the type of spread on the market. For this reason, the use of spreads will depend on diversification of energy sources on the market.

The methods for setting coal prices on the Polish and international markets

International trade of energy coal is organized via trading facilities which allow transactions without the necessity for the parties to meet face to face. GlobalCOAL, a partnership headquartered in London, which was founded in April 2001 by a group of participants in the international coal market, operates in this area. Transactions are made via a dedicated computer system which allows its users to bid in real time with the adjustments for the quality of coal.

Due to supply and demand forces, global trading facilities (mainly globalCOAL and ICE) conduct buy-sell transactions. Information about those is aggregated into price indexes. In economic sciences, a price index means a mathematical formula, most often expressed with arithmetic mean or weighted price of a selected group of commodities. It is worth noting that an index may be structured either on a wide range of commodities or their single class. On international markets, coal price indexes express energy coal prices relative to standardized quality (ICIS Services, 2018).

The most popular quality benchmark is coal with working calorific value of 6000 kcal/kg (25.12 MJ/kg) and sulfur content below 1.0 %. On international markets, coal price indexes are based on the application of Incoterms®2010, which have been described further in this chapter. Exporters prices are expressed as FOB (Free on Board), whereas importers prefer CIF (Cost Insurance Price) in the port of entry (Lorenz, 2009).

API (Average Price Index) elaborated by Tradition Financial Services in 1997 (Hiemstra, 2004) is the most commonly recognized coal market indexes. API indexes are typical derivative indexes based on weekly coefficients published by Argus Coal Daily and McCloskey Coal Report. For the European market, API 2 (CIF ARA) index is most appropriate. It has been structured as an arithmetic mean of two indexes; Argus CIF ARA and McCloskey's NWE steam coal marker. API 2 is based on the working standard coal calorific value of 6000 kcal/kg (25.12 MJ/kg).

As they are widely recognized on the market and subject to daily quotations, the above index is commonly applied in risk management. This has been proved by making that index a benchmark price for financial derivatives such as forwards, swaps or futures.

Unlike the international markets, in Poland, energy coal prices are mutually negotiated by the parties. In the command economy which operated before the economic transformation of 1989, coal prices were arbitrarily (Blaschke, 1999 and 2000) set by the Minister of Mining, and approved by the State Price Commission (Lorenz, 2011). Since 1990, price formulae started to be used in coal trade; these were mathematical formulae applied to calculate the price of coal with the use of quality parameters. According to the new formulae, the price of coal is adjusted to ash and sulfur content as these parameters are crucial from the exploitation and environmental angle.

Also, buy/sell contracts stipulated thresholds for sulfur and ash content. Once the thresholds were exceeded in a single transaction, the seller would grant the buyer a discount, for example, 1 % off the price for each 1 % of ash over the permissible limit. Such a solution was adopted from the international trade practice where the coal calorific content reference price was set for coal with 6000 kcal/kg, ash content 12-15 % and sulfur content up to 1%. Hence, the transaction price of coal depended on the volume of deviation of quality parameters from the quality of reference (model) coal. Additionally, the price of coal depended on a special We coefficient, which was set to promote coal with lower ash content. That formula, popularly called Blashke formula, was adopted as binding for the domestic energy coal trade in May 1990 by the decision of the then Minister of Finance (Blaschke and Ney, 1998).

At this point, it is worth mentioning that the basic provisions of the formula which was to promote low sulfur and ash coal were off the mark in view of high (over 30 %) inflation and devaluation of Polish currency. Paradoxically, the too large price differential of coal with a low or high content of ash and sulfur resulted in dropping demand for the former, which brought the result opposite to what was intended (Winkler, 2011).

It should be mentioned that in 1992 coal prices in Poland were freed, and the use of the 1990 pricing formula was no longer mandatory. Nevertheless, the use of formulae had become accepted market practice, and price formulae were still widely used in purchase and sale transactions of steam coal.

When Poland joined the European Union in 2004, legal regulations and numerous aspects of the markets were attuned to EU standards in various areas of the economy. The coal mining sector, by large embarked upon disintermediation, with coal mining companies entering into large contracts directly with main activity producer electricity plants. Likewise, the mentality underlying the planning and contracting quantities of deliveries changed. The change consisted in the fact that energy generating companies no longer bought coal by the ton, but rather purchased chemical energy contained in the coal, viewing coal from the angle of the purpose of energy generation. This change in mentality resulted in a changeover in how coal prices came to be calculated – the prices were quoted in Polish zlotys per gigajoule (PLN/GJ) instead of the hitherto quotation in Polish zlotys per ton of coal (PLN/t). It is also worth mentioning that as the internet matured and became a household name, coal mining companies began posting their sales offers on their websites (Lorenz, 2009). Price lists are approved by the companies' management boards based on the price of reference coal in the coal class with a calorific value exceeding or equal to 21 MJ/kg and sulfur content of up to 0.8 %. Prices for various classes are calculated as a function of calorific value and sulfur content and presented in the form of a price matrix.

It is worth noting that price lists contain potential prices for spot transactions on the FCA coalmine basis under Incoterms® 2010. At the moment, no forward purchase and sale transactions are being arranged in Poland. In long-term contracts, use is mostly made of the pricing above formulae, taking into account changes in fuel markets as well as in the domestic and global economy. In the case of large customers, purchase prices are usually agreed during trade negotiations in which the decisive factors are: current market price of coal, contracted volume, contracted coal quality specification, delivery period, Incoterms® 2010 terms of delivery, payment terms and the parties' financial standing and assessment of the resulting credit risk. It is worth noting that in the case of public or municipal customers, coal purchases are made by way of tenders based on public procurement law. Tenders are also used for smaller private customers, in particular from the industrial sector.

There have been several attempts in Poland to create a national coal price index. Particularly notable are the following:

1. Polish Steam Coal Market Index PSCMI (Polski Indeks Rynku Węgla Energetycznego) - an index of historical quotations created as a result of the cooperation of the Polish Power Exchange plc (Towarowa Giełda Energii S.A. -TGE), Industrial Development Agency (Agencja Rozwoju Przemysłu S.A. - ARP) and the GSMiE Institute of the Polish Academy of Sciences (PAN) in Krakow presented at a 2014 conference on "Issues of fossil fuels and energy in the national economy" held in Zakopane (Paszcza and Olejniczak, 2014) and available at www.polskirynekwegla.pl,
2. the concept of fixing thermal coal prices in Poland on the basis of the index of coal prices on the European market - a concept by A. Bocheński and P. Dunal (2006) presented in 2016 at the conference on the "Issues of Fossil Fuels and Energy" held in Zakopane organized by the Polish Academy of Sciences and proposing a pricing formula based on the API2 price index, which would lay ground for the publication of spot and forward prices as well as conclusion of hedging transactions in coal trade (Bocheński and Dunal, 2006).

Summarizing the considerations in this chapter, it should be noted that increased trade on international coal trading platforms has inspired groups of experts to create price indexes of thermal coal, which constitutes the main source material adopted for empirical studies. Price indexes are a very important analytical tool constituting the basis for market players' pursuit of the transaction, investment, and financial policies. The importance of coal price indexes is continuously growing due to their proliferation and improvement of their construction. The increase in the transparency of individual markets as well as the creation of opportunities to reduce the risk inherent in economic activity due to price volatility arising from the development of global financial markets indicates that the introduction of coal price indexes has proven to be a success (Andrzejewski et al., 2015).

Analysis of short-term correlation of prices of energy, coal and CO_2 emissions allowances

In line with the objective of this study, an analysis was made of the short-term correlation of prices of energy, coal, and CO_2 emissions allowances. The most popular price indexes for individual CDS components were selected for the analysis, which were considered as the most representative and reliable information regarding the discussed market variables. The analysis compares the Polish and German markets. The two markets have been selected for comparison because of their proximity to each other (Germany and Poland are neighboring states), as well as because Polish producers of coal-powered electricity acquire CO_2 emissions allowances via the German EEX platform. The analysis is based on data from EEX (European Energy Exchange, as regards energy prices in Germany and CO_2 emissions allowances), Polish Power Exchange (Towarowa Giełda Energii -TGE as regards energy prices in Poland), Argus Media (as regards coal prices according to the API2 CIF ARA index) and ARP (Industrial Development Agency, as regards coal prices on the Polish market).

It should be noted that for steam coal prices, there are no liquid price quotations on both the Polish and German market - for this reason, the API2 CIF ARA index was used for the analysis. In addition, Polish market participants carry out transactions on CO_2 emissions allowances using EEX, as there is no liquid market for this asset in Poland. The analysis utilizes the Pearson correlation coefficient and covers 13 months between April 2017 and April 2018. The results of the correlation analysis are presented in Table 1.

Tab. 1. Short-term correlation analysis of prices of coal, energy, and CO_2 allowances.

	Pearson correlation April 2017 – April 2018
API2 CIF ARA vs. Polish coal price	0.41
EEX energy price vs. TGE energy price	0.68
Polish coal price vs. TGE energy price	0.68
API2 CIF ARA vs. EEX energy price	0.72
CO_2 allowance vs. TGE energy price	0.77
CO_2 allowance vs. EEX energy price	0.45
CO_2 allowance vs. Polish coal price	0.86
CO_2 allowance vs. API2 CIF ARA	0.38

Source: author's work based on EEX, TGE, Argus Media, ARP data.

Based on the correlation analysis, the following conclusions can be drawn:

- there exists a relatively weak correlation between coal prices on the international market and the Polish market (0.41),
- there exists a relatively strong positive correlation between the energy price in Germany,
- and the same in Poland (0.68),
- the price of electricity in the Polish market is positively and strongly correlated both with the price of coal (0.68) and with the price of CO_2 emissions allowances (0.77), the latter correlation being stronger,
- the price of electricity in the German market is positively and strongly correlated only with the price of coal (0.72),
- the strength of correlation of the electricity price on the German market and the price of CO_2 emissions allowances is weak (0.45),
- there is a strong correlation between coal prices in Poland and prices of CO_2 emissions allowances (0.86),
- the strength of correlation of the coal price in the international market and the prices of CO_2 emission allowances is weak (0.38).

Costs to coal mines of environmental fees levied on economic activity in Poland

The costs borne by coal mines consist of several cost types, including the particularly interesting costs of environmental fees levied on the pursuit of business activity in Poland. It is widely alleged that the costs of waste generated by the mining industry constitute a heavy burden, which is why these charges are analyzed in part of the paper. In the general opinion of people, these costs are among the most important elements of the cost mix. In 2016, Poland generated 140 million Mg of waste, of which 8 % was a municipal waste (12 million Mg). Since 2000, the amount of waste generated in Poland (excluding municipal waste) ranged from 110-130 million Mg. The 128 million Mg of non-municipal waste in 2016 means a 2 % decrease in 2015. As in the previous years, the main sources of waste in 2016 included: mining and quarrying (about 52 % of the total generated waste, that is, 72.8 million Mg), industrial processing (21 %) and electricity production and supply (16 %). In the last decade, the largest share in the amount of generated waste has been waste generated during the exploration, extraction, physical and chemical processing of ores and other minerals (56 % in 2016) and waste from thermal processes (22 %). Out of the total amount of waste generated in 2016, 49 % of waste was recovered, 42 % was disposed of via storage, and 4 % was otherwise disposed of (2018 NFOŚiGW, Narodowy Fundusz Ochrony Środowiska i Gospodarki Wodnej, data).

Based on data from the Central Statistical Office yearbook 2017, in 2016, Poland generated over 67 million Mg of mining waste. In this case, the authors have data from all provincial marshal offices – based on the data, it appears that fees are only paid in the province of Dolnośląskie.

According to art. 26.3 of the Mining Waste Act, as regards inert mining waste other than hazardous and inert waste and waste not contaminating soil, the provisions of the Environmental Protection Law regarding charges do not apply, which means that the storage of such types of mining waste is not subject to environmental charges levied for waste storage. However, the regulations are different in the case of hazardous mining waste for which fees (and increased fees) are mandatory due to the use of the environment for waste storage. This situation occurs only in Dolnośląskie province, where the fees totaled (average currency exchange National Polish Bank ratios from the end of each year):

- 2013 - 4330 PLN (1044 EUR, by EUR/PLN 4.1472),
- 2014 - 8 923 PLN (2093 EUR, by EUR/PLN 4.2623),
- 2015 - 9 171 PLN (2152 EUR, by EUR/PLN 4.2615),
- 2016 - 8 510 PLN (1924 EUR, by EUR/PLN 4.4240),
- 2017 - 1 080 PLN (259 EUR, by EUR/PLN 4.1709).

For comparison, at the same time, total waste storage fees constituting a charge for using the environment are presented in Table 1. They were the highest in 2014-2015.

Based on CSO data, the overall volume of waste on a year-by-year basis remained more or less unchanged, so based on this simple analysis, it should be stated the that the costs to coal mines of environmental fees arising from waste management related to the pursuit of economic activity in Poland are negligible as compared to other costs – they are in thousands of zlotys rather than in millions, and do not, therefore, constitute, as claimed, a heavy burden. Based on the analysis, it should be stated that the impact of environmental charges for waste on the price of electric energy is equally negligible

Tab. 2. Total waste storage fees constituting a charge for using the environment in 2013-2017 by voivodship (province).

Voivodship	2013	2014	2015	2016	2017
Dolnośląskie	3 007 448	4 615 841	4 069 391	3 236 629	2 774 241
Kujawsko-pomorskie	1 789 633	2 350 599	2 416 800	1 994 074	1 379 796
Lubelskie	1 571 129	2 286 342	1 733 485	1 206 589	767 087
Lubuskie	1 104 969	1 566 850	1 447 111	1 305 025	947 044
Łódzkie	6 677 684	13 456 336	14 792 246	16 205 767	15 363 163
Małopolskie	2 332 641	2 845 833	2 411 271	2 747 020	1 638 264
Mazowieckie	3 076 960	3 923 566	4 005 355	3 545 675	3 224 806
Opolskie	1 111 610	1 396 499	1 207 949	1 547 813	872 602
Podkarpackie	1 773 044	1 543 357	1 586 661	1 574 453	986 285
Podlaskie	591 707	887 688	1 001 810	1 026 683	978 951
Pomorskie	2 598 741	3 704 007	2 666 300	2 902 082	1 731 197
Śląskie	3 423 642	6 122 611	6 495 613	5 844 983	4 725 149
Świętokrzyskie	768 415	787 163	889 050	832 142	647 680
Warmińsko-mazurskie	1 254 886	1 622 478	1 592 788	1 389 949	1 338 442
Wielkopolskie	5 546 521	9 878 363	10 690 589	9 123 781	6 218 738
Zachodniopomorskie	4 535 545	4 937 863	4 701 592	5 320 515	4 840 908
Total	41 164 575	61 925 396	61 708 011	59 803 180	48 434 353

Source: NFOŚiGW, 2018 data.

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Summary

The analysis of the correlation shows that the price of electricity on the Polish market is positively and strongly correlated both with the price of coal (0.68) and the price of CO_2 emissions allowances (0.77), the latter correlation being stronger. Equally worth noting is the strong correlation between coal prices in Poland and the prices of CO_2 emissions allowances (0.86).

With regard to the confirmed but rather not very strong positive correlation between thermal coal prices on the Polish market and energy coal prices in the ARA zone (0.41), it should be noted that there is no liquid index in the domestic market, which hampers efficient portfolio management of the spread on energy production by the coal energy sector. In international markets (including the ARA zone), prices of coal and derivative instruments are a consequence of the needs related to securing CDS. In the wake of the deregulation of energy markets, energy has come to be transacted on commodity exchanges and trading platforms, which is also corroborated by the existence of the Polish Power Exchange (TGE) operating in the Polish market. Following the launch of the European Union Emissions Trading System (EU ETS), Polish power generating companies hedge the prices of CO_2 emission allowances on foreign trading platforms, in particular on the EEX. Given that the trade of two of the three CDS constituents takes place via trading platforms, the need to introduce quotations of coal prices in Poland also seems to be fully justified.

One advantage of high market liquidity is that it ensures a fair and representative valuation of a given traded commodity and transparency of information on the reference market price. The very existence of such information permits the effective allocation of resources in the economy, in particular with regard to assessing the profitability of investment projects and determining business strategies. There is no price index in the Polish coal market, which would provide a reliable reference price and permit effective price risk management. The main obstacle standing in the way of its introduction is limited access to information on transactions, as well as a lack of a clear methodology for its determination. Due to the high concentration of market power in the hands of a small number of entities in the fuel and energy sector and the resulting low degree of liquidity in the Polish coal market, the concept presented by A. Bocheński and P. Dunal (2016) regarding the connection of coal prices in Poland with Europe's most common and widely acknowledged API2 price index based on the price formula seems to be justified. The main reservations voiced by the players in the Polish coal market about the implementation of such a solution regard price volatility arising from international factors, including in particular the rate of economic growth in Asian countries. It should be explicitly affirmed here that the development of risk management systems in business entities offers a positive hedge against price volatility. The introduction of a pricing formula linked to the API2 index does not mean that producers (coalmining sector) and consumers (energy sector) of coal must be exposed to the risk of price volatility. This risk can be transferred in an effective, and even total way to intermediaries and financial institutions operating in international markets, which boast high-risk management skills and massive financial capabilities. Effective price risk management in Poland will lead to stability and predictability of mining and energy companies' results (Dunal, 2018).

Referring to the wholesale electricity market in Poland, it is worth adding that it currently relies on contracts that are settled after the actual delivery, which essentially curtails the possibility of its liquidity growth and the potential for the development of financial products that could be used to effectively manage the risk by electricity generating companies. Therefore, the development of the financial segment of this market is becoming a precondition for boosting not only the liquidity of the wholesale market but also for increasing access to products that best meet the financial risk management needs of trading entities (Wojtkowska-Łodej et al., 2014).

As regards the costs of environmental charges for waste arising in the course of business operations in Poland as borne by coal mines, it should be stated that these charges do not affect the bottom line, as they account for a very small amount and percentage of costs relative to other costs. Based on the above, it should be stated that the impact of environmental charges for waste on the price of electric energy is equally negligible.

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Possibilities of Increasing of Ecological Conditions in Mining Environment by Reconstruction of the Present Engine DH30

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Solving the problems of increasing requirements on transport, while respecting actual environment criteria, new solutions are being looked for to make an optimum mutual equilibrium. One of the possibilities of increasing ecological conditions, which are decreased by means of transporting a mine, shows this contribution that suggests a reconstruction of the original diesel-hydraulic engine DH30 to two-system drive and hybrid drive. In the reconstruction, a DC and an asynchronous engine are suggested as traction engines. This reconstruction of the drive means not only increase of the ecological conditions in the mine but also an ability to use biofuel made from a crop that grew on contaminated soil. The aim of the reconstruction is to replace the combustion engine and hydraulic distribution with an electric drive while traction characteristics will remain at their values. A one-engine traction drive with an asynchronous engine with short circuit armature is regarded as one of the most prospective for an output range from several W up to MW. By using the asynchronous engine powered from semiconductive changer the problem of pulsing parts of torque is dealt with regulation. This reconstruction also means energy saving. This system also improves storing and manipulation with oil production in the mine.

Key words: *mining environment, hybrid drive, distribution of traction output, transport*

Introduction

Requirements demanded by production plants regarding minerals are currently rising, which results in the increasing traffic intensity of material flows in mining companies. Therefore, an alternative to this kind of transport must be searched (Turnbull D. A, 2013). The interplant transport of mineral raw materials plays an important role in the mining process carried out in mining companies (Andrejiová et al., 2015). 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). On the other hand, however, this transportation mode must also be well dimensioned, so that the material flow is smooth, efficient, and cost-effective (Drottboom, 2013). Reducing the cost of resources in solid mineral extraction is an urgent task. For its solution is possible used logistic approach use to management of mining company all resources, including extraction processes, transport, mineral handling, and storage (Tyurin, 2017), (Andrejiová, 2016). The selection of the mode of transport for moving bulk materials is never a simple task as there are various concerns/considerations applied to the selection of the most practical and cost-effective mode of transport to be used to move bulk materials (Verkerk, 2005). Belt conveyor system technology is acquiring its specific place in the in-plant transportation system in every company and represents a stable mainstay of efficient in-plant transportation (Grujič, 2011). The development trends in the field of conveyor belt wear, in terms of disruption damage, are mostly focused on the innovation support systems of damping components of buffer beds with impact rubber bars (Gondek et al., 2014). Impact bars are an essential component of innovative buffer beds suitable for several types of belt conveyors (Marasová et al., 2017; Ambriško et al., 2017; Gondek et al., 2014). Maintenance cost reduction can be achieved by improvements in utility properties of conveyor belts (Ambriško et al., 2016), (Grinčová,2014).

The demand for the quality of the environment has recently increased. This fact evolved its impact on criteria of devices that change energy from oil products to traction energy. The present state-of-the-art transportation systems used in hard coal mines on main and divisional routes were discussed in comparison to the conditions from previous years. Current development trends in the aspect of more and more extended use of Diesel engines as well as resulting limitations were indicated in work (Pieczora, 2008). In the last item directions of R & D work, which is aimed at designing new Diesel and electric drives were specified. The aim of the work (Arsentiev et al., 2017) was to study the possibility of using induction motors with reduced voltage power supply for traction electric underground mining locomotives; to determine the conditions of conformity of mechanical characteristics of induction traction motor with reduced voltage regarding the characteristics of a standard voltage.

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Mine engine with combustion engines, which are a typical representative of a moving detrimental emission producer. Results of researches and monitoring of smoke particles in exhaust gases as well as the mechanism of their creation and their influence to human body mean an intricate problem that is necessary to solve (Kucera and Saly, 2000). In general, these solutions could be made in two ways:

- by increasing of the efficiency both ventilation and air conditioning of subterranean spaces,
- by decreasing of detrimental emission.

The first suggestion is highly economically demanding; therefore, the second suggestion should be taken into consideration. One of the ideas which could be applied to this problem is using of two-system traction drive powered from electron accumulator (Kucera, 1996).

One of the main goals of underground rail transport is to achieve marginal traction characteristics of variable frequency induction motors in conditions of the limited magnitude of the supply voltage of the contact network DC of underground transport for electrical safety reasons (Arsentiev, Baranov, Vilnin and Kladiev, 2017).

Also, electric motor, electronic converter, and electric battery were studied for mine locomotive (Matyuschenko, 2016), (Frivaldsky, M., Drgona, P., Spanik, P., 2013).

Development trends ecological conditions in the mining environment are primarily focused on the energy consumption reduction, structural component material savings, reduction of the negative environmental impact service life extension. Assessment of transportation systems for minerals may be carried out while applying several methods (SFRA, monitoring, thermovision and procedures, especially the simulation and mathematical modeling (Kodali, 2001; Lysenko, 2005; Werelius et al., 2008; Wang et al., 2009). Appropriate tools are available to identify the process of damage to electromotors, transformers during operation (Gutten, 2007; Huynen, 2004; Gutten et al., 2009). Electromagnetic compatibility and functional safety can no longer be treated as two separate disciplines when electrical or electronic systems are considered performing safety-related functions (M. Kucera and M. Sebok, 2012). Reliable operation of electronic equipment at various technological and operation conditions requires a safe operation on communication devices. Information transfer, automatic processing, and data recording are exposed to detrimental influences from various sources (Jurčík, J. et al., 2011). Disturbance effect of environments shows unwanted bonds, interference noise, resonance and transitional phenomena that may cause incorrect operation of electronic equipment, distortion and degradation of data transfer and its recording and in extreme cases also a destruction of the equipment (FEMV, 2002). A system that is perfectly reliable, but not electromagnetically compatible has no practical use (Vaculíková, P., Vaculík, 2003). This paper deals with a device for online, real-time analysis of recuperative current with the use of a microprocessor. This system is used in railway transport for measurement and analysis of recuperative-currents from converter in railway engine. Recuperative currents from converters in railway engines flow through rail back to the distribution point. Content of higher harmonics in these currents must not exceed limits specified in international standard UIC 550-3, so exact measurement and analysis of this harmonics are necessary. Proposed device uses a microprocessor for real-time measurement and analysis of recuperative currents (Gutten et al., 2017)

The paper presents the results of changing energy values of W-10 switches for various design solutions of their contacts (Kozak et al., 2012). The experiments have been performed on a computer-supported testing stand described in (Zukowski P., Kozak C., 2010). The testing cycle consisted in recording characteristics of current, voltage drop and temperature of a normally-closed fixed contact as well as the real-time arc energy values for each switching cycle at the direct voltage and for every 20th cycle at alternating voltage. The measurements have been performed at the voltage of 120 V in order to avoid incessant burning of the arc at direct voltage. In the process of performing measurements for direct voltage, an automatic change of polarity has been applied at the starting of each subsequent switching cycle. It follows from the obtained measurement results (Zukowski P., Kozak C., 2008) that at the positive polarity of the fixed contact the mean arc energy value has been higher than in the case of negative polarity. The paper presents theoretical and experimental analyses of a possible effect of the short-circuit forces on the transformer winding (Arumugam, 2014).

Analysis of the evaluated traction drive for Engine DH30 system

Considering a present economic status complete elimination of pollution in mining spaces caused by exhaust gases from the DH30 Engine (Fig. 1) could only be done by reconstruction of the Engine.

The aim of the reconstruction is to replace the combustion engine and hydraulic distribution with an electric drive while traction characteristics will remain at their values. Scheme of such reconstruction, where the source is energy from electric/accumulator batteries, is showed in Fig. 2.

The batteries are recharged while the engine operates on a cabled section of a route. Braking with the use of a recuperator decreases demand for energy and extends the life expires of traction wheels. An important parameter which essentially determinates the actual design of traction batteries is the time spent on the uncalled route and their energy requirement.

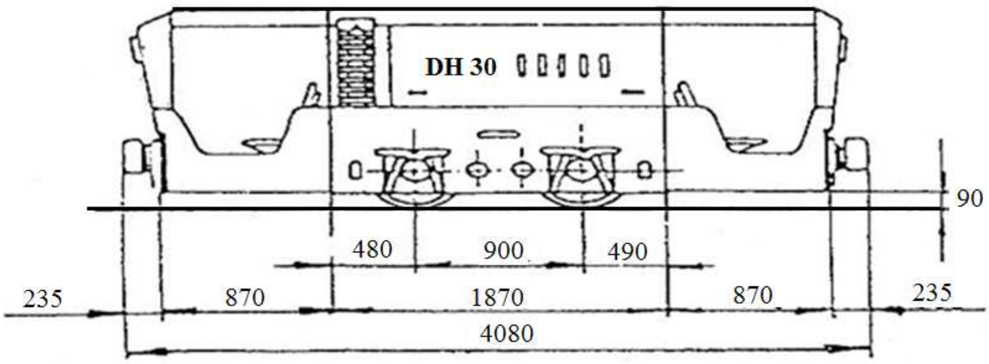

Fig. 1. Basic dimensions of DH30 Engine.

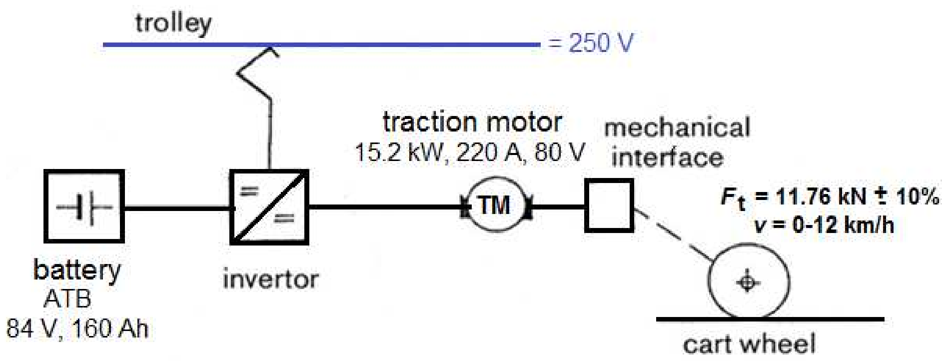

Fig. 2. Scheme of electric traction circuits of the reconstructed, two-system engine DH30.

Drive with DC Traction Engine

Exploiting of DC engine in traction application is well known. Using of power electronic it is possible to supply such drive that the energetical loading of electro accumulators will be at a minimum. High-quality power transistors/current loading 400A, voltage 120V, galvanically separated control element excitement in one integrated box together with power part/ and their ability to work at the frequency of 20 kHz, that is above a human hearing level, enable reliable and noiseless operation.

Fig. 3 shows a scheme of connection of the DC engine with the independent exciter. The excitement of the engine is powered from a 4-quadrant changer. The amount of voltage is controlled by a 2-quadrant changer. This scheme is used in applications, where quick changing from drive to the braking regime is necessary.

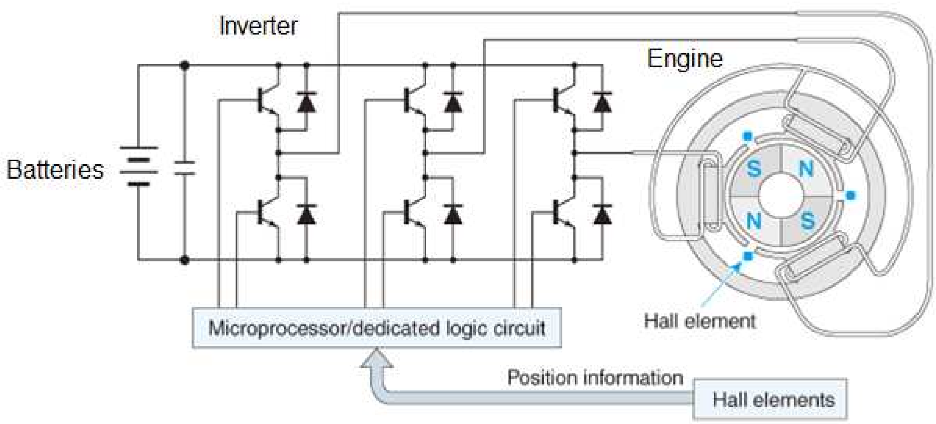

Fig. 3. Scheme of connection of the DC engine with independent exciter.

Drive with an Asynchronous Traction Engine

A one-engine traction drive with an asynchronous engine with short circuit armature is regarded as one of the most perspectives for an output range from several W up to MW. According to its output, regulation range, kind of loading, quadrant characteristics, dynamical requirements, etc., an array of solutions arise. (Glowacz A., 2019).

Each solution differs from one another with a kind of frequency changer, way of control, and technical devices. In the motoric regime, the changer changes input DC values to AC values of different rate, frequency, and the number of phases. In case of electric braking the engine changes to the generator. A scheme of connection and control of the asynchronous engine is in Fig. 4.

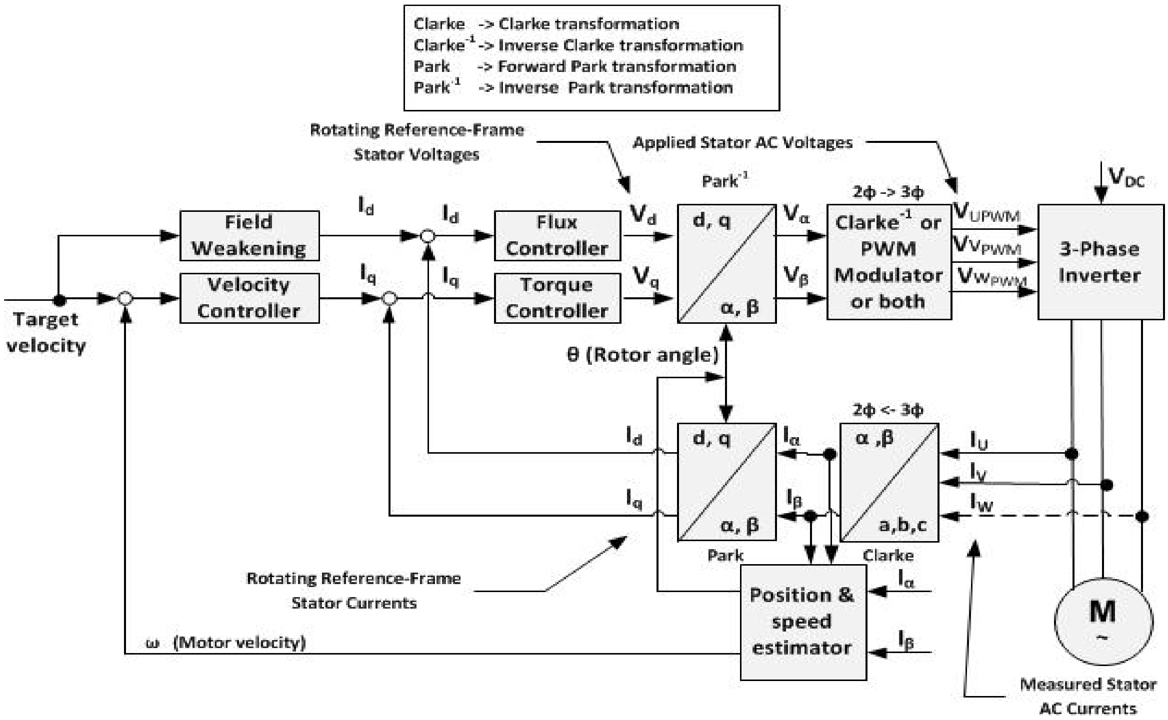

Fig. 4. Scheme of connection and control of the asynchronous engine.

Design of hybrid traction drive for DH30

Using electro-petrol and electro-diesel engines in mines have been used for more than 70 years. The first electro-petrol engine in Slovakia was introduced in The Mine Hodruša in 1928. The output of a 4-stroke petrol engine was 5.85 kW, and a clutched dynamo had an output of 6.2 kW that produced a voltage of 380 V. An Electro-diesel engine was used in Slovakia for the first time in the year of 1934. This system of traction drive has been used until the present time by the terms of transport requirements in the mine.

In a similar principle is based on the proposed reconstruction of the mining engine DH30 (Fig. 1). The essence of this reconstruction is replacing of the original diesel-hydraulic drive unit with the electro-diesel-accumulator unit where the asynchronous engine acts the traction engine. A block diagram of the electrical part of this reconstruction is in Fig. 5.

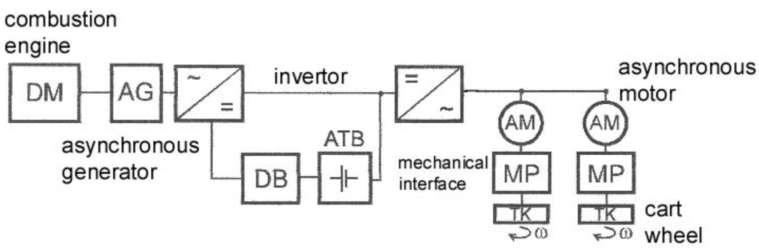

Fig. 5. Block diagram of the electrical part of this reconstruction.

Capacity ATB is less important with hybrid traction drive compared with electric drives since the engine also provides capacity. Therefore, the battery can be much smaller, saving weight. However, the battery may still be required to provide the same instantaneous power as the EV battery from time to time. This means that the smaller battery must deliver much higher currents when called upon.

Analyzing typical traction drive for mining train

In the Fig. 6, there is depicted one period of maximal power output demand, where particular partitions on tome axis mean:

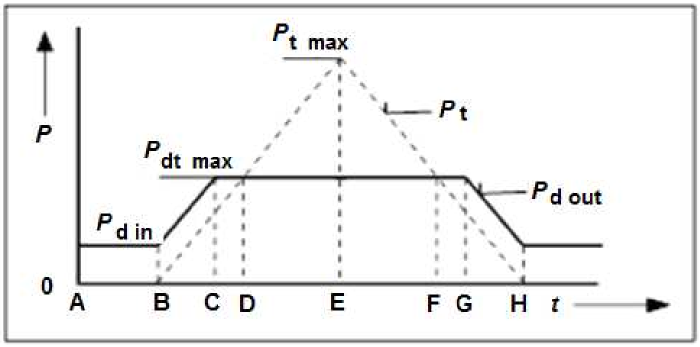

Fig. 6. One period of maximal power output.

A- Traction alternator charges ATB and combustible motor works with constant output $P_{dtNAB.}$
B-C: The demand for power output started to increase. In consequence of this demand, speed starts to rise, and the traction generator is excited. The generator was given an impulse to increase the asked value of current for the asynchronous motor.
C: Maximal output for the asynchronous motor is reached from the combustible motor.
C-D: On behalf to cover power output demand, the current for charging ATB have to be decreased.
D-E: Output is constant, and the taking current starts to rise.
E: At this moment, the combustible motor is able to supply maximal power output.
E-F: Power output decreases and together with its also the asked current from ATB.
F-G: Output of combustible motor is still maximal, but ATB starts to charge.
G-H: ATB is charged with asked current and output of combustible motor decreases together with power output.

For suggested operation cycle of simulated travel correspond the average output of the asynchronous motor.

$$P_{\mathrm{average}} = \int_0^T P(t)dt = 8.53\mathrm{kW} \tag{1}$$

- ASM motor power 15 kW,
- nominal voltage /current 180V / 30 A,
- the maximum angular velocity 2073 speed/min,
- the maximum frequency of 70 Hz.

Draft traction output for the hybrid drive system

Distribution of traction output could be done partially according to a user or according to predefined software. Autonomous control of a microprocessor unit for the distribution of traction output is depicted in normal operation only ATB /NiCd battery capacity 250 Ah/ drive with insufficient accumulator capacity, drive with using of all energetical sources, and recuperation of traction output.

In a system of control, information from the operator is processed together with information about a state of input supply, impulse changer, invertor, and traction engine. The control must fulfill specific requirements derived from a traction engine and technology of transport. It means mainly the control of a magnetic flow in the engine and torque. Drives for general purposes are often dealt with a cheap solution without speed sensors and only with a small number of another sensor for electrical values. For drives with dynamic requirements, vector control has become common. This enables to control a magnetic flow and torque in the steady-state regime as well as in transition state. Mathematical simulation of controlled traction drive with an asynchronous engine reveals very good dynamical characteristics.

The scheme of direct torque controlled induction motor with a fuzzy controller is in Fig. 7. The fuzzy controller is designed to have three fuzzy state variables and one control variable for achieving constant torque and flux control. Each variable is divided into fuzzy segments.

The number of fuzzy segments in each variable is chosen to have maximum control with a minimum number of rules. (Spanik, P., Sedo, J., Drgona, P., Frivaldsky, M., 2013).

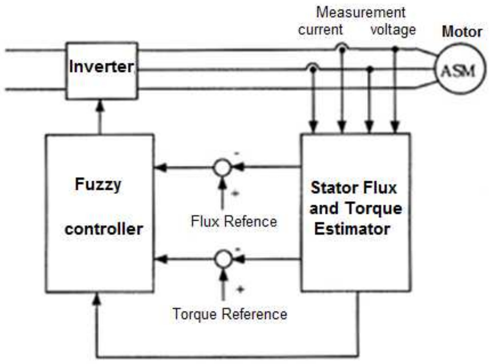

Fig. 7. Fast regulation of torsion moment.

The first is difference between the command stator flux ψS^* and estimated stator flux magnitude ψS (error in stator flux $E\psi$) given by:

$$E\psi = |\Psi^* S| - |\Psi S| \qquad (2)$$

The actual stator flux can be calculated from the voltage and current information in the stator reference frame as

$$\Psi\alpha = \int (u\alpha - i\alpha \cdot RS)\, dt \qquad (3)$$

$$\Psi\beta = \int (u\beta - i\beta \cdot RS)\, dt \qquad (4)$$

$$|\Psi S| = \Psi 2\alpha + \Psi 2\beta \qquad (5)$$

For suggested operation cycle of simulated travel correspond the average output of the asynchronous motor.

Optimal Torque Computation

This control strategy was developed by Ohio State University under a subcontract with NREL. Information for this help file was taken from the final technical report entitled "Development of Fuzzy Logic and Neural Network Control and Advanced Emissions Modelling for Parallel Hybrid Vehicle" which provides additional detail on the model and is available in the ADVISOR reading room.

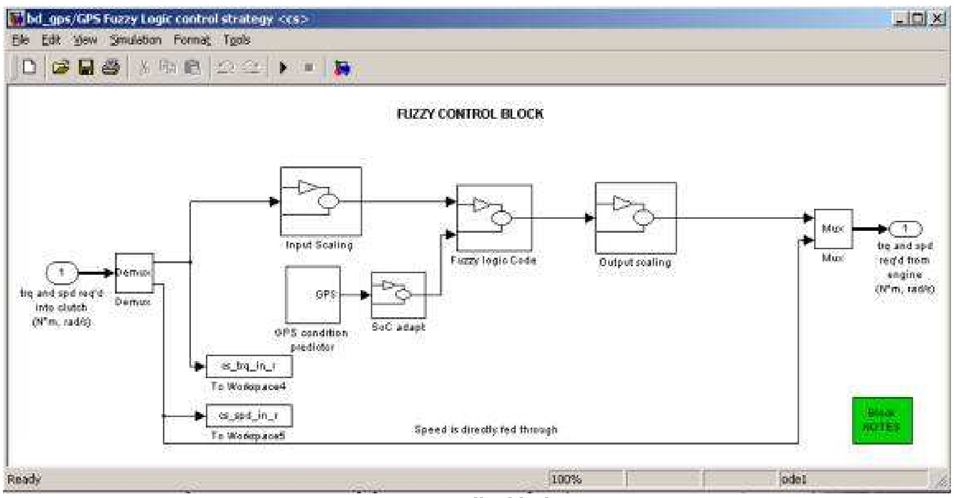

Fig. 8. Fuzzy Controller block components.

The controller programs are created using MATLAB script files and can be modified by the user. The following Fig. 8 indicates the position of the Fuzzy Logic Controller in the Simulink block in ADVISOR.

Finding an optimal IC Engine operating point

The data for an IC Engine in ADVISOR is in the form of a 2-dimensional map, indexed by torque and speed. Information regarding fuel economy [g/s] and emissions such as CO, HC, and NOX [g/s] is available for various speeds and torques (Fig. 9).

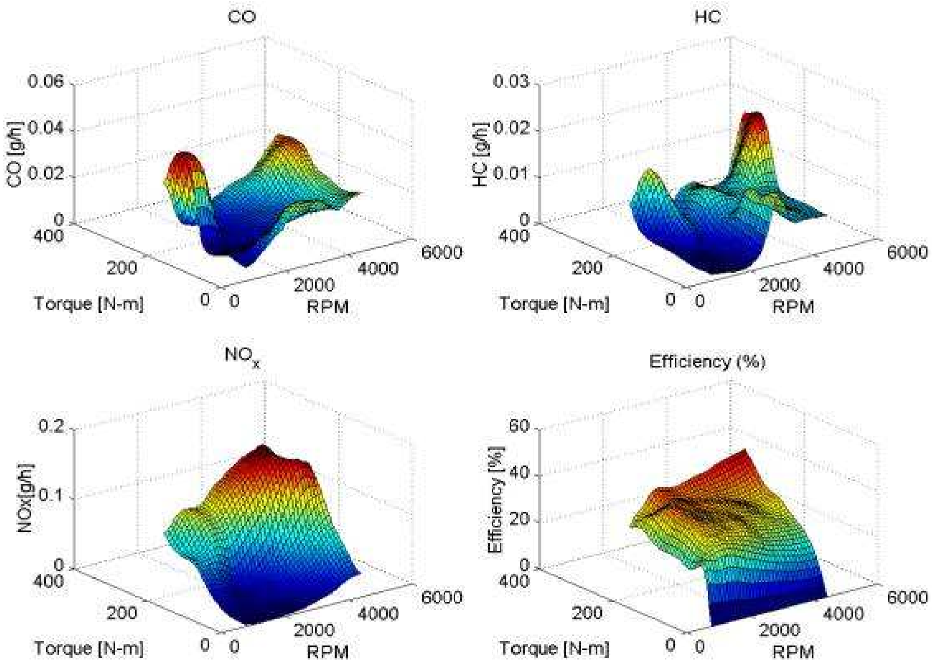

Fig. 9. IC Engine emissions – a general trend from MATLAB.

From the graph in Fig. 10, we can state that the proposed hybrid drive solution ensures sufficient traction by preserving the dimensions of the original locomotive and reducing the ecological load.

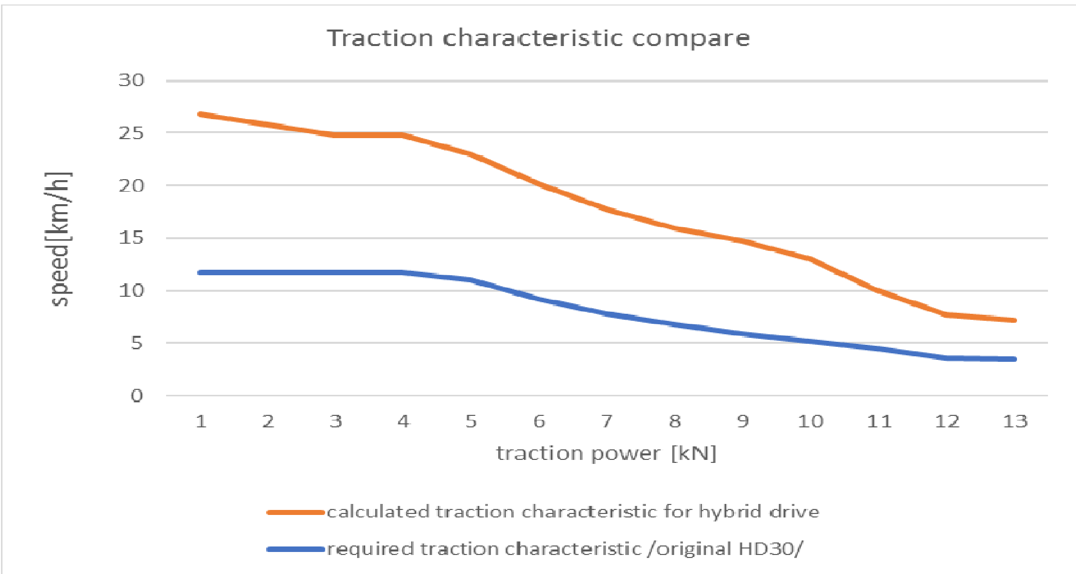

Fig. 10. Traction characteristic.

Results and conclusion

The actual operation of mine engines DH30 and DH100 involve high costs for the working environment. This article shows that using electrical energy for traction purposes highly eliminates (hybrid system) or almost completely reduces (two-system drive) detrimental influences on the working environment. Several options of reconstruction of the DH30 engine for two-system or hybrid electric traction enables to use of an asynchronous engine or DC engine as a traction engine. By using the asynchronous engine powered from semiconductive changer the problem of pulsing parts of torque is dealt with regulation. This reconstruction also means energy saving. This system also improves storing and manipulation with oil production in the mine. Another advantage apart from increasing the ecological conditions and energy saving is that, that the Elsbett engine uses a vegetable oil which can be produced on contaminated soil.

Acknowledgment:*This contribution was created with the support of projects VEGA 1/0577/17 and VEGA 1/0429/18.*

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