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Competitiveness Increasing in Mining Companies through Application of Operation Research Methods

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Abstract **– Quantitative models of operational research are an important tool for optimizing production factors in an enterprise, and they are a tool for decision-making, serving for competitiveness increasing. They enable to look for the right solutions of problems in business processes and optimize all resources in the enterprise. The aim of the contribution is to point out the possibilities of optimizing the operation of mining machines through management tools - optimization mathematical models. In this contribution, we used operation capability control model of the machines and a model of a critical element. The results of the models determine the optimal inspection interval for 10 months of machine operation and the optimum belt conveyor change interval is 11th working shift. Through quantitative models of operational research, we were able to solve the problems of the mining company. Based on the operational research models used, we found that the ball mill in the capacity reserve positions should be monitored within its life cycle in 10 months of its operation, and conducted a comprehensive control focusing on the functionality of the ball mill. On the belt conveyor, it is necessary to carry out a belt check after 11 each working shift, since this interval represents the minimum operating costs and at the same time, it is the time when the belt conveyor can be repaired.**

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1. Introduction

Whether we like it or not, we live in a competitive world, in which operations research is one of the tools that could be used for competitiveness increasing. Operations research was originally concerned with improving the operations of existing systems [1]. The first appearance of operations research as an academic discipline came in 1948 when a course in non-military techniques was introduced at the Massachusetts Institute of Technology in Cambridge. The application of the latest management methods becomes today, during the ongoing European integration processes, a requisite for the success of the business within the environment of international markets [2].

Prosperity of the firms depends in present time mainly from the timely and proper decision of management about the way for obtaining of financial, raw material, material, technical and human sources, decision about work efficiency achieving for individual working places and employees in the production, about efficiency of firm's fixed capital using, about optimal management of stocking and sales, about localization of clients and transport, about the environment of the firm [3]. Competitiveness can be seen as current and future capability of the company to generate and sustain financial and non-financial income and profit [4].

Present management cannot run without significant using of quantitative methods during solving of economic problems of the firm because this approach decrease costs [5]. Exact accesses during decision and development of computer techniques have become decisive impulse and basis for development of quantitative accesses in management, and therefore this article will be orientated mainly to the using of models for renovation during solving optimizations of the renovation time for machinery and equipment [6]. In production firm it is necessary to use production equipment that is main production tool, and its service situation is necessary assumption for securing of fluent production [7].

Due to this reason, it is necessary to search time intervals for the renovation of production equipment. During the duration of its using there is rising high cost for its service, securing of repair and maintenance, and the firm has to inevitably minimize such cost [8]. The financial situation of the firm is very important for the reproduction process of equipment [9]. Using quantitative models of operation research creates a sort of solving problem regarding reproduction biomass boiler. Optimize model of reproduction determines the time when it is important to make reproduction [10].

The aim of the contribution is to point out the possibilities of optimizing the operation of mining machines through managerial tools - optimization quantitative mathematical models, and to find possibility for competitiveness increasing.

2. Theoretical backgrounds

Various management approaches have been developed historically to support managerial decision-making and address important practice issues. The main important approaches were:

1. Process approaches - with an emphasis on the analytical classification of the management process for universally applicable conditions, recommendations on how to rationally provide partial processes and their integration into an integrated whole (representatives: H. Hayol, L. G. H. Koontz, H. Weihrich) [10].
2. Psychological and Social Approaches - Based on Human Behavior, Needs and Motivation Analysis (E. Mayo, A. H. Maslow, B. F. Skinner).
3. Systemic approaches - based on integral, comprehensive understanding of considered phenomena or processes (C. Barnard, R. L. Ackoff, C. W. Churchman, R. A. Johnson).
4. Empirical Approaches - Based on the analysis and evaluation of managerial knowledge, whose leaders understand management as science and art (P.F.Drucker, A.D. Chandler, C.R. Hickman).
5. Quantitative Approaches - Methods to solve decision-making problems, which include a set of approaches and methods (mathematical) that serve to solve decision-making tasks and rely on system modeling of investigated phenomena and processes by modeling techniques (GB Dantzig, TC Koopmans, RL Ackoff, W. Churchman , ELArnoff, REBellman, TLSaaty) [10].

All these scientific approaches can be combined and they are supported by the decision-making process in practice [11]. Based on the use of scientific methods, companies achieve positive results in optimizing their processes. Operations research methods are used in all areas – education, health service, space research, transportation, military, urbanism and government management. Operations research methods are used in conjunction with logistic technologies. It is a way of optimization and simulation methods application [12]. The importance of quantitative methods means: to increase the efficiency, to improve production capacity, and to avoid time and profit losses [13].

These operations research methods are used in various areas of the economy [7]. Authors presented the utilization of optimizing methods by solving problem on how to increase unemployment in the Czech Republic [14], utilization of optimizing models as a potential instrument for the digital economy in smart cities [15]. Related information on optimal parameters for operations is required for the process improvement [16].

The mining industry is in constant development [17]. The reason is increasing demand for raw materials. The acquisition of mineral raw materials is the most important part of the mining industry. Mining industry promotes employment, it has an impact on wages and increases the value of the gross domestic product. Despite many positive aspects, there is a widespread concern from the general public about the negative effects of mining activities [18]. Those are barriers of business in mining companies. Economic and environmental problems in mining companies are possible to be solved by managerial instruments and optimize all processes, that influences the environment and for the health of the employees and general public. Business in the mining industry is challenging and represents technical, technological, economic, environmental, social, political barriers. It is very important for mining companies to use appropriate management tools in the decision-making process because the decision-making process is linked to financial investments that are very high [19].

Mining activity is often detrimental to the environment. For example for risk assessment of polluted soils, it is crucial to establish the speciation of the contaminants such as Zinc. Minkina et al. (2019) use quantitative and mathematical methods for this problem [20]. They identified the Zn species in the contaminated anthropogenic ally transformed soils known as 'spolic technosols'. The Zn speciation in techno sols was doing using a combined fractionation scheme and a set of X-ray synchrotron methods. Feng et al. (2017) used quantitative models of neural network modeling on rockburst risk assessment for deep gold mines in South Africa [21]. The establishment of a quantitative warning method for the location and intensity of different types of rockburst bring positive results for the mining company. Those examples point to the use of mathematical methods in mining processes. Present management cannot exist without significant use of quantitative methods during solving of economic problems of the firm [22]. Exact accesses during the decision and development of computer techniques have become decisive impulses and basis for the development of quantitative accesses in management. This contribution will be orientated mainly toward the use of models for maintenance and lifetime control of machines in mining companies.

3. Methodology

Mathematical modelling by solving mining problems needs to take into account the conditions in which the problem is solved and the risks that arise in solving economic problems, which are to be defined. The risk is a quantitative expression of the adverse consequences (loss) in decision-making in situations where the outcome is clearly known only after the relevant problem is realized. The risk is defined by the probability of failure to solve economic problems. It arises as a result of the variability of the economic activity of the company, its market position, changes in market conditions. It is influenced by a number of external and internal factors. The consequences of the risk are very important for the company, and the protection against risk can be realized in various ways:

1. Defining risk boundaries.
2. Creation of reserves.
3. Transfer of risk to other entities.
4. Eliminating risk.

When measuring and modeling risk, it is important to distinguish the type of risk. The magnitude of the risk depends on the absolute height of the individual risky conditions and the likelihood of these conditions occurring. If the risk is deviating from a given normal state the most appropriate measure of risk is dispersion - dispersion.

$$Rz = D(X) = \int_{-\infty}^{\infty} (x - E(X))^2 f(x)dx$$

D (X) - dispersion-scattering of a random variable, E (X) - mean value of a continuous random variable. The aim of the contribution was to point out the possibilities of optimizing the operation of mining machines through managerial tools - optimization quantitative mathematical models. Using of mathematical models in the recovery process of machines was applied in the ball mill of mining company, where we monitored equipment - ball mills and lifetime cycle control of ball mills. The lifetime of such a device is affected by the life of the segments that are located in the device and they are called plates. The life of these segments is reduced by the impact physical wear and mechanical action. Increasing the service life of these segments can be achieved by tightening the screws of the individual plates and replacing the damaged plates in the ball mill. In this paper was primarily focused on determining the optimal characteristics of this facility - the ball mill and its segments in the context of the use of mathematical modelling by the quantitative method with the name “Model of operation capability control of the machines”. We have used an optimization model to control the ball mill's performance, the essence of which is to determine the frequency of the ball mill control, which would guarantee the maximization of the amount of time associated with its operational capacity. The critical function of the model determines the time interval for performing the preventive control of the production facility. The optimal time interval is determined based on the maximum value of the critical function.

$$P_t = \frac{1 - p^t}{(1-p) * [t + t_1 + (t_2 * (1 - p^t))]} \quad (2)$$

Model of operation capability control of the machines consists of algorithm model and basis parameters of the model (table 1, table 2). This model monitors the functionality of the production equipment during its use in the mining process. This model is used in mining companies only in cases where the enterprise has a back-up source called a capacity reserve. This back-up source serves as a replacement for a non-functioning device. The need to maintain the machine in the capacity reserve in the functional state is based on the requirement of a smooth running of the mining process.

Table 1. Basic model parameters

t1	The time required to check the condition of the production facility
t2	The time required to remove the malfunction of the production facility
p	Probability of operating capability of the production facility at time (t)
t	Interval of operation of the production facility
P(t)- max	Criterion to determine the optimal interval of preventive control of the production facility

In the practical conditions of a mining enterprise and other manufacturing enterprises, there is a fixed capital of the enterprise for example machines, production facilities and their parts, respectively components whose functionality in the process of continuous use can be compromised, and these elements are referred to as critical elements. A critical element is a production facility or part of a production facility which, in the event of a breakdown, will result in the dismantling of the production plant's activities, resulting in major economic losses due to inaction or failure and stopping the production process. We also consider the critical device as a manufacturing device, the failure of which affects the health or life of the staff. In practice, the occurrence of machine failure can be monitored by a visual or instrumentation.

Table 2. Algorithm of model

Algorithm	Indicators
Time period	(t)
Statistical probability of reliability	(p^t)
Average time period	$t + t_1 + t_2(1 - p^t)$
Indicator of reliability P(t)	$P(t) = \dfrac{1 - p^t}{(1-p)*[t + t_1 + t_2 * (1 - p^t)]}$
Optimal time period t_{opt}	P(t)-max

A critical element is an equipment which, as part of a certain set of equipment, satisfies the following conditions:

- its value to the economic losses arising from its failure is very small,
- its disturbance causes a threat to the health or life of the staff,
- the occurrence of a fault within it can not be identified by preventive technical control,
- the cause of the malfunction is not incorrect operation and other interventions from the environment in which it works but the process of its gradual wear.

The "Model of a critical element" of fixed capital of an enterprise is a cost-oriented model aimed at determining the average cost per unit of time for the service ability of a critical element. The optimal time interval is determined and based on the minimum of average operating costs and this is a critical function for the model of a critical element. Optimal time (t opt) is time, where costs are minimum (Np=MIN).

$$Np = \frac{Ns\,(1 - P_{t-1}) + Nr * P_{t-1}}{O_t} \qquad (3)$$

Legend:

Np- average costs of failure of critical element

Ns-costs of losses of failure of critical element

Nr- costs for removal of failure of critical element

Ot- time of trouble – free operation

This model allows optimizing the time to exchange critical elements in mining machinery and equipment that is costly, the purchase of new mining machinery and equipment is a high financial investment. At the same time, this model draws attention to the negative consequences of failures. Malfunctions can be a threat to workers, endangering workers' health, cause material damage to the company, economic losses, stopping the mining process, failure of the fluently mining process, loss of good customers.

Table 3. Algorithm of model

Algorithm of model	Indicator
Time period	*(t)*
Statistical probability of failure	*q(t)*
Probability of failure in time (t)	$p_{11} = P_{11-1} * q_{11}$
Probability of failure after work of more time period	$P_{11} = 1 - (p_0 + p_1 + ... + p_{11})$
The number of time units of single-device trouble-free operation	$O_{11} = \sum_{t=0}^{10} P_t = P_0 + P_1 + ... + P_{11-1}$
Average operating cost of production facility in failure (loss costs and repair costs)	$Np = N_s(1 - P_{t-1}) + N_r * P_{t-1}$
Average operating cost	$Np(11) = \dfrac{N_{11}}{O_{11}}$
Determining the optimal time interval for critical element recovery	t_{opt} = *Np(t) minimal* ***MIN*** ⇨ **t opt**

Most existing research focus on waiting time, travel time, headway distribution, in-vehicle time, etc., but neglecting the maintenance performance [23], therefore these mathematical models aim to optimize equipment status and reduce maintenance and repair costs. An appropriate preventive maintenance policy can improve the operation efficiency of the product, extend the service life and reduce enormous losses brought by failures [23]. Part of the mathematical modelling is a comprehensive information system that allows us to process information and create a mathematical model. Optimization function is the basis of the models, and it is cost-orientated for equipment reliability. An important key factor in modelling is determining the correct mathematical model and calculating its parameters. At the same time, it is important to monitor the impact of external factors that affect equipment and machines.

4. Results

Model of operation capability control of the machines – this model we used to solve problem in mining company. The use of mathematical models in the renewal process was applied in the mill of mining company (figure 1), where we monitored equipment - ball mills and control of their lifetime. The lifetime of such a device is affected by the life of the segments that are located in the device, and they are called plates. The lifetime of these segments is reduced by the influence of physical wear and mechanical action. Increasing the service life of these segments can be achieved by tightening the screws of the individual plates and replacing the damaged plates in the ball mill. Our project was primarily focused on determining the optimal characteristics of this facility - the ball mill and its segments in the context of the use of mathematical modelling. Ball mills are used to crush and grind different materials. A ball mill is a horizontal cylinder filled with steel balls or similar objects. This roller rotates around its axis, bringing a ball-tipping effect. The material guided by the mill breaks up with shocks and breaks between the balls. The drive system can be either a central drive or a toothed rim and pinion gearbox.

The segments of the mill are replaceable. The performance of the mill depends on the physic-mechanical properties, the input grain size of the ground material, and the desired fineness of grinding. Basic types of ball mills and their characteristics are presented in table 4. The performance of ball mills is valid for medium-hard ore, 20 mm inlet grain size and about 80% inlet size below 0.074 mm.

Table 4. Internal information for ball mills

Type	Performance	Mass	Motor	Max of ore	Mass of mill material
	t/h	kg	kW	мм	kg
GM 12/12	1,0-1,5	8 300	40	25	1 600
GM 15/15	1,5-3,0	14 800	55	25	5 000
GM 20/20	6,0-10,0	23 700	130	25	8 500
GM 20/30	11,0-15,0	33 400	200	25	12 000
GM 27	28,0-35,0	78 000	400	25	35 000
TM 12/20	6,0-8,0	9 800	35	50	4 600
TM 20/30	30,0-40,0	33 400	130	50	15 000
TM 27	70,0-90,0	73 700	400	50	50 000

Working condition of the ball mill uses the quantitative model of optimization. Time interval (t) presents one month of using of the ball mill , we will ball mill at time t=9-13 months, average time (t_1) control of ball mill 2 hours = 0,0028 month, average time (t_2) time for removal of failures of critical element (damaged discs)- t2= 48 hours=0,07 month, statistical probability (p)- at ground of statistical measurements in mining company. According to the predetermined criteria and the probability of occurrence of a fault on a ball mill, we have determined the base model´s parameter by formula 2 and algorithm in table 2. The results are given in Table 5 and Figure 2.

Figure 1. Ball mill in mining company

Table 5. Calculation of the basic indicators for the determination of the critical function

t_1	0,0028				
t_2	0,07				
p	1	0,99	0,98	0,88	0,6
1-p	0	0,01	0,02	0,12	0,4
t	0	1	2	3	4
p^t	1	0,99	0,9604	0,681472	0,1296
$1-p^t$	0	0,01	0,0396	0,318528	0,8704
$t+t_1+t_2(1-p^t)$	0,0028	1,0035	2,005572	3,025097	4,063728
P(t)- max	0	**0,996512**	0,98725	0,877459	0,535469

In the time interval in which the function P(t) (figure 2) takes the maximum value, it will be necessary to carry out a preventive control of the ball mill. Based on the calculated characteristics, the optimal solution to this problem is the most advantageous interval for performing the preventive control of the ball mill on the tenth month of its operation. From the view of preventive control, it should be noted that every 10 months of ball mill operation, it is necessary to check it for physical wear and tear life of the plates (segments) that are part of the ball mill and that may cause malfunction and operability.

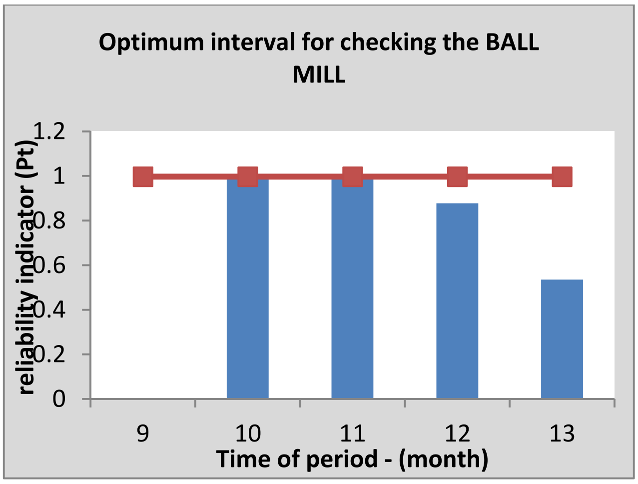

Figure 2. Function of optimizing – indicator of reliability

The "Model of a critical element" we used in the second problem in the mining process of the mining company. A belt conveyor is a facility used by a mining company to transport extracted raw material. When the conveyor belt breaks (figure 3), a loss in the company occurs, and the transport of the extracted raw material is stopped. With the mathematical model of operational research, we want to find out when it is necessary to replace the material on the conveyor belt so that the process of transporting the raw material is continuous and no economic losses occur. The mining company transports the extracted coal by a belt conveyor. The transport of loose materials is one of the important links, which connect the various technological nodes in the production process. In the field of bulk material transport, conveyors such as continuous working machines have their irreplaceable position, the advantage of which is to ensure a continuous and continuous flow of material. The belt conveyor has the state of the most popular mechanism to move almost any material. Modern electronics and automation many times increase the ability of a conveyor belt. In the event of the conveyor belt breaking; there are downtimes that result in losses. Losses reduce 1/8 change in output. We have found out what the optimal time interval for conveyor belt replacement is, which ensures smooth running during work change.

Figure 3. Belt conveyor in mining company

The belt is the basic part of the belt conveyor. The belt is a critical element of the device. An important role is also played by the tensioning device, which secures the belt tension. A second function is provided by the drive station with a belt cleaner. When transporting the material, the extracted raw material, the belt is contaminated and thus the wear is increased. Soft rubber belt cleaners pressed against the drum serve the cleaning process. The basic requirements on the belt are: abrasion resistance, high longitudinal stiffness, low weight, high strength, long life. For the mining process, these belt conveyor requirements are the basis for the belt conveyor's functionality. The belt for the belt conveyor can be purchased from various suppliers e.g. GUMEX Ltd., and it is needed to account the requirements. The belt on the belt conveyor can be made of a textile skeleton covered with protective rubber layers. The skeleton is composed of textile inserts. The upper protective layer protects the belt from the abrasive effects of the transported material, against the weather; the lower layer protects the belt from the effects of the supporting rollers and drums. The composition of the belt points to the importance of its replacement, and therefore it is necessary to keep the belt in working order. The model of a critical element can be used to analyse the optimal time interval for replacing the conveyor belt or repairing the material-rubber on the conveyor belt. For the calculation of the model, we have ascertained the following data: the average change power is 600 t of coal, the average cost per tonne of extracted coal is 5 €/ ton, the average cost of repairing the strip at break is 183 €. The statistical probability of failure is being monitored in the mining company. We used an algorithm by table 3. The results are illustrated in Table 6 and 7.

Table 6. Statistical probability of failure in mining company

Time period	10	11	12	13	14	15	16	17	18	19	20
statistical probability of failure (%)	0	5	9	**20**	**27**	**38**	**43**	**55**	**61**	**87**	**10**

Based on the operational research models used, we found that the ball mill in the capacity reserve positions should be monitored within its life cycle in 10 months of its operation and conducted a comprehensive control focusing on the functionality of the ball mill. On the belt conveyor, it is necessary to carry out a belt check after each working shift, since this interval represents the minimum operating costs and at the same time it is the time when the belt conveyor can be repaired.

Table 7. Results of model of a critical element in mining company

t	10	12	14	15	17	18	19	20
q_t	0	0,09	0,27	0,38	0,55	0,61	0,87	1
p_t	0	0,09	0,19	0,19	0,1	0,05	0,03	0
Pt	1	0,86	0,5	0,31	0,08	0,03	0	0
Ot	10	11,95	13,51	14,01	14,5	14,58	14,61	14,62
Np	183	201,75	298,65	368,67	491,09	527,9	546,3	556,47
Npt	18,3	16,88	22,11	26,31	33,86	36,2	37,38	38,07

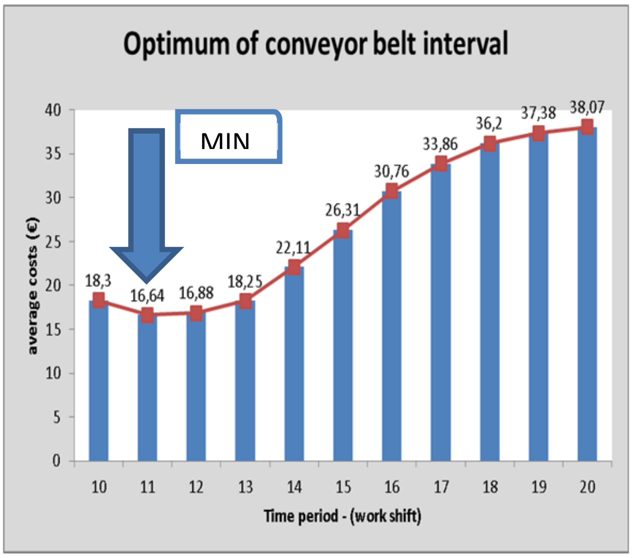

Figure 4. Optimal time interval of raw material exchange of belt conveyor

5. Discussions and conclusion

A number of authors use quantitative mathematical models to solve business process problems and to achieve positive benefits form an economic, technical, social, environmental, technological perspective. These facts on the use of mathematical models in decision making processes point out their importance and importance. Renovation models enable management to decide about the fixed capital renovation and to plan necessary financial means for securing of fixed capital renovation, that means machinery and production equipment that is necessary for securing of fluent production [24]. Quantitative methods are today most important tool of management for every firm that has to decide about risk conditions, indefinite or definite, it has to choose proper alternatives for the economic problem solving and to apply the economic problem solving in practice as well. Modeling serves for such situations that means illustration of reality through mathematical expressions and its economical interpretation.

Today's management of mining and other industrial enterprises makes full use of operational research methods to address stock-related decision-making issues, production processes, technical equipment for production, mining, raw material transport, and raw material storage. It focuses on optimizing (maximizing, minimizing) indicators that characterize various economic phenomena and processes and the use of mathematical apparatus.

The prosperity of businesses in advanced economies depends on timely and correct business management decisions, which are about how to obtain and size financial, raw material, material flows, from the efficiency of workplaces and workers in production, from inventory management and sales, to the efficient use of fixed capital, for example machinery and equipment, from the location of customers and transport, from the environment in which the business is located, as well as from other factors [25]. Through quantitative models of operational research, we were able to solve the problems of the mining company. The use of operations models results from the fact that competitiveness is not only about economic performance, but also about the social performance, environment of the company, etc. The synergy between them could create sustainable competitiveness of the company. The results from the present study may be very encouraging and useful for managers as well as investors to plan investment and operational activities to achieve profitability objectives more efficiently and effectively. The use of these models is very wide and operational research is applied in various fields of industry, transport, agriculture and also in services, health, education, etc. The task remains to increase using of these models in the mining sector with the aim to increase competitiveness.

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