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DEVELOPING AND IMPLEMENTATION A NEW MODEL OPTIMIZING THE PARAMETERS OF COAL MINES UNDER DIVERSIFICATION

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ABSTRACT

The purpose of this research is to propose methodological approach optimizing the parameters of a coal mine operation under diversification. Productive flows of coal mines have been considered as well as production functions. To solve the diversification problem, ratios between the types of the invested capital and output level in the form of raw material have been compared. Cobb-Douglas production function has been applied to develop a model supporting the coal mine activities; in this context, diversification potential of the activities is involved. For the first time, a model optimizing the mining parameters under diversification has been proposed. The model demonstrates the production functions-resources ratios. The developed model helps control temporally the efficiency of manufacturing resources, determine overall production, calculate the basic parameters of a coal mine operation, and define the resources helping increase its efficiency. In the first place, the diversification potential of mining production has been considered at the expense of changes in the productive flows. Methodological recommendations have been provided as for the production activities of mining industry. Innovatively, internal potential of the operation schedule has been examined to improve functioning efficiency of a mine; moreover, components of the potential have been analyzed. The abovementioned has made it possible to formulate managerial decisions being determination of output as well as ratios between the generated resources, required to support the output; constant monitoring of their use while determining adequate ratio between the fixed assets, labour force, and material resources; and determination of transposability of the productive flows within the total balance. To be used in practice, the paper proposes certain methods defining the rational output from the viewpoint of production activities as well as correlation of the operating resources to achieve the specified production scale. In such a way, return on assets is improved in terms of similar degree of the key assets, labour, and material use. To apply the technique properly and efficiently, a particular case has been considered determining an optimum production method for a coal producer.

Keywords: operation schedules, production potential, economic indices, optimization model, Pareto rule, coal mining.

INTRODUCTION

Currently, coal industry of the country is in a systemic crisis depending upon a number of reasons. The reasons are stipulated by the key asset aging, unsatisfactory infrastructure, and poor level of labour mechanization as well as by the underuse of raw materials resulting from mining. According to studies (Hrinov & Khorolskyi, 2018; Khorolskyi, Hrinov, Mamaikin & Fomychova, 2020; Salli, 2015), coal, methane, water, and waste are the productive flows of mines. However, coal is the only basic raw material of production and economic activities; and other productive flows are neglected. Turn our attention to the key problems following underground mining to form topicality as well as academic and research sense of the paper:

- first, the resources, extracted from the Earth, cannot be used integrally. However, the problem is that the unused accompanying productive flows affect unfavorably the procedure, i.e. methane nonuse creates unsafe underground labour conditions being potential of blast or methane outburst; water nonuse results in the necessity to have areas to be water segregators; and waste nonuse involves the necessity to have extra areas to be applied as dumps etc. Hence, the nonused productive flows impose technogenic environmental load, and worsen labour conditions (Mamaikin, Sotskov, Demchenko & Prykhorchuk, 2018; Sotskov, Podvyhina, Dereviahina, & Malashkevych, 2018);
- second, constant increase in mining cost takes place. The fact can be explained by the expanded net of mine workings as well as the expenditures connected with minimization of negative influence by water, gas, and dumps. Consequently, mining diversification is the potential for the improved production efficiency and integrated use of the Earth's interior (Fomichov, Pochepov, Sotskov & Mamaikin, 2018; Karabyn, Popovych, Shainoha & Lazaruk, 2019);
- third, decline in coal output takes place resulting in deterioration of situation within the regions where mines are the township-forming enterprises. Hence, social tension will become an inevitable scenario that can be prevented if only people are employed (Knysh & Karabyn, 2014; Inkin, Tishkov, Dereviahina, & Sotskov, 2018);
- fourth, there are no technical approaches evaluating the potential to diversify mining operations. The majority of papers rely upon general recommendations how to use methane or process rock dumps ignoring the economic output and connection between the productive flows

(Petlovanyi, 2016; Russkikh, Demchenko, Salli, & Shevchenko, 2016). That is why the study represents a complex tool concerning the problems of mining diversification;

- fifth, it is required to develop a model to evaluate the ratios of resources, needed for production, as well as complex recommendations (Khorolskyi, Mamaikin, Medianyk, Lapko & Sushkova, 2021; Yang, Hou & Zhang, 2018);
- sixth, there is a problem of insufficient use of production resources when investment volume to mine a ton of coal is overstated but in this context potential to increase the output is available (Fomychov, Fomychova, Khorolskyi, Mamaikin & Pochepov, 2020; Chen, Liu, Zhao & Liang, 2016; Khorolskyi, Hrinov, Mamaikin & Demchenko, 2019).

Rejection from mining within certain areas of a mine field depends upon various reasons: exhausted reserves of a seam being mined; desire to mine coal reserves under more favourable conditions in the near future, for instance, thicker seams are meant which are dimensioned and sized; seams occurring within more stable wall rocks etc. (Moldabayev, Sultanbekova, Adamchuk & Sarybayev, 2019; Moldabayev, Adamchuk, Toktarov, Aben, & Shustov, 2020; Krzak, 2013; Adamchuk, Shustov, Panchenko & Slyvenko, 2019; Pavlychenko, Adamchuk, Shustov & Anisimov, 2020). Such a transition is always followed by changes in various mine components; among other things, it concerns development operations, underground transport, and maintenance of mine workings. Probable, it will concern ventilation schemes. It is important fact that purposes of the forced output control may differ while involving different alternatives. Among other things, it is possible to consider alternatives of 10-30% decrease in a mine output or alternatives to apply various facilities in stopes etc. (Xu & Li, 2016). Different goals and approaches to achieve them always depend upon certain resource volumes and, hence, expenses, connected with coal extraction, i.e. its prime cost. It follows from the above-mentioned facts that any tendency of mine progress is a multivariant problem considering various initiatives with ensuing sequences and the necessity to find the perfect solution follows from it directly (Naghadehi, Mikaeil & Ataei, 2009; Balusa & Singam, 2018; Bakhtavar, Shahriar & Mirhassani, 2012).

It is common knowledge that the largest reserves to increase output are in loss reduction due to coal shearer and conveyor failure and in terms of a “seam” component particularly. The best approach is to shorten a period of failure removal. Several ways, being under the discussion now, are possible (Lozynskyi, Medianyk, Saik, Rysbekov & Demydov, 2020; Medianyk, Netecha & Demchenko, 2015). It is an increase in the thickness of seams, being mined, which anticipates the improvement of manufacturing process management, and more concentrated mining operations in time and in space. The above involves a possibility to accelerate significantly coal shearer feed with no increase in the failure intensity.

The study is intended to solve the problems.

MATERIALS AND METHODS

Primarily, it is necessary to consider the basic approaches and global trends as for the problematic of mining diversification (Table-1) which will help us identify the key tendencies of the research.

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Table-1. The basic studies concerning the world practices of mining diversification.

Researchers	Year	Originality
Lyu J., Lian X., Li P.	2018	The basic tendencies to diversify coal mines have been set forth; among other thing, operation of mines within the technological chains producing metal and generating electric power is considered
Li X.	2020	Industry progress has been analyzed in the context of engagement in the technological chains to produce ferrous metal
Jonek-Kowalska I.	2018	The basic factors, determining total efficiency of an enterprise have been studied as well as the mechanism forming production cost
Tabashnikova O.	2017	It has been determined that a cluster approach is the key diversification tendency when a one-type product is used for the needs of another type which favours formation of stable connections in the regions where industry is obsolete and outdated.
Jones S., Müller A.	1992	Changes in the basic tendencies of the activities of enterprises due to deterioration of the raw material quality.
Campbell S., Coenen L.	2017	The basic diversification tendencies have been singled out for the regions differing in high level of clusterization of enterprises, namely: improvement of innovations; removing barriers of inter-organization networks; making connections between the regional manufacturers; and transition from a single product to its several types in terms of one enterprise.
Gawlikowska-Fyk A.	2019	The keyways to improve competitiveness, reliability, and sustainable development of enterprises, belonging to fuel and energy sector, under diversification
Li C.M., Cui T., Nie R., Shan Y., Wang J. & Qian X.	2017	The main tendencies of coal industry re-orientation to manufacture other product types have been considered. Linear programming-based rational outputs of one or another production method have been proposed. The basic idea is to study a business capital; limitations as for the human resource introduction as well as production cooperation (first of all, extensive cooperation is meant); and political influence on the basis of a profit-maximization idea to develop a model of optimum industrial scale using a linear programming method.
Li C.M., Cui T., Nie R. & Yan X. Y.	2017	It has been defined that the diversified enterprise progress should involve harmonization of scales, managerial interaction, and market-based collaboration among industries. At the same time, the enterprise should get an opinion, simulate and assimilate profit-making partnership factors for secondary innovation. It is notable that the partnership factors should experience constant updating to be efficient for the industrial development.
Safarzynska K.	2017	To compare with other studies, attention is paid to increase in the assortment of new items (among other things, fuel types are meant which may be obtained as a result of mining) rather than the total output resulting from diversification.

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Table-1 explains that the following can be considered as the basic diversification tendencies:

- multiply use of resources following coal mining, i.e. transition takes place from a mine determination as an enterprise mining coal to a mine as an enterprise being engaged in four minerals at minimum: coal, methane, waste (containing rare elements and noble metals), and mine water;
- managerial decisions being determination of the output as well as ratio between the generated resources required to provide the output; and
- constant monitoring of the resource use which needs identification of adequate ratio between the fixed capital, labour and material resources; if possible, it is also necessary to identify interchangeability of productive flows in the aggregate balance.

Consequently, the development of scientific foundations as for the mining diversification based upon the analysis of ratios between productive resources and outputs in terms of the generated additional productive flows is an urgent scientific and research problem. Specific feature of mining diversification is as follows. Increased impact per unit of the spent resources takes place; in this context, labour productivity of miners is preserved. It is correct to say that diversification is the key to improve economic performance as well as overcome crisis phenomena in the fuel and energy sector.

RESULTS

Generally, production functions are the ratios between material goods and resources used in production. In their aggregate, they are productive resources. According to the formulated problem, the productive resources are: *K* being capital assets. In our case, coal, methane, water, and waste are meant, i.e. the reserves prepared to be extracted and the facilities to extract them; *Q* being materials, i.e. reserves and intermediate goods; and *L* being labour resources, i.e. human work. In this context, the amount of the mined reserves *X* is the basic value. Consequently, a production function demonstrates the ratio between *K,Q,* and *L* resources used in production and *X* output. The abovementioned means that the production function is required to correlate a value of the production vector $\overline{X}$ with a value of the resource vector *Y*. Then,

$$F = \left(\vec{X}, \vec{Y}, \vec{A}\right) = 0 \tag{1}$$

where $\vec{A} = \{a_1, a_2, \ldots, a_p\}$ is vector of the production vector parameters.

Correlation (1) is nothing but a mathematical model for life support of production. Each of the listed input and output functions is a vector variable, i.e.

$$\vec{K} = \{k_1, k_2, \ldots, k_p\}; \vec{Q} = \{q_1, q_2, \ldots, q_p\};$$

$$\vec{L} = \{l_1, l_2, \ldots, l_p\}; \vec{X} = \{x_1, x_2, \ldots, x_p\}; \tag{2}$$

Solution of the problem of production diversification should involve comparison of the ratio between types of the spent resources and production level in the form of raw materials. (1)-(2) ratios are applied since the resource categories differ in their form and measurement types. Nevertheless, they have to be generalized. For the purpose, it is required to move from the vector form to the general one, i.e. monetary units should be used while data collecting. Then, a degree of raw material consumption Q may help understand consumption of reserves and intermediate goods in terms of time intervals (i.e. monthly, quarterly, annually). Consumption of capital assets *K* is understood owing to the amortization value as well as the fixed assets value. *L* is understood through the wages paid; and output *X* is understood through the profits.

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Determination of the specific type of a production function should involve identification of *X* change tendencies depending upon *K, Q,* and *L* amount and relying upon the obtained data. Earlier studies (Khorolskyi, Hrinov & Kaliushenko, 2019) have helped define that the function of production life support under diversification, based upon (1) and (2), is of a polynomial type. Hence, it is equal to the product of corresponding power functions of resources and a_0 coefficient

$$X^* = a_0 K^{a_1} Q^{a_2} L^{a_3} \tag{3}$$

where a_0, a_1, a_2, and a_3 are parameters (coefficients) of a production function.

Ratio (3) is nothing but general function of Cobb-Douglas. However, its implementation should involve dynamics of the temporal changes since time is also important resource *I(t)*. Introduction of time resource into the ratio helps take into consideration a tendency of production changes. Thus, (3) can be expressed as

$$X(t) = a_0 K^{a_1}(t) Q^{a_2}(t) L^{a_3}(t) e^{\alpha t} \tag{4}$$

where *e* is basis of natural logarithms;
α is parameter characterizing production change; and

t is time (months, quarters, years).

Hence, taking into consideration dynamics of the changes in reserves, the simplified version of (4) ratio will be represented as follows

$$X = F(K, L) = a_0 K^{a_1} L^{a_3} \quad (5)$$

To identify dynamics of changes in one raw material type elimination in terms of the increase in one resource type when other resource involvement value is unknown, changes in the output should be equal to

$$\frac{\partial F(K,L)}{\partial K} \succ 0 \quad (6)$$

$$\frac{\partial F(K,L)}{\partial L} \succ 0 \quad (7)$$

Expression (6) is the boundary asset efficiency; and expression (7) is the boundary labour efficiency. Message of ratios (5)-(7) is as follows: gradual increase in one resource type and permanence of another one result in gradual decrease of raw material X extraction. It is quite important aspect in the context of solving a problem of mining diversification since switch to one raw material type extraction (for instance, methane or coal) as well as changes in capital asset structure will initiate constant efficiency loss. Consequently, all types of resources should be seen from a holistic perspective. In view of the fact that diversification involves integrity of mineral mining (i.e. asset cost increases), the production function may be expressed through $\beta(t)$ multiplier evaluating the improved efficiency of reserve use. Thus,

$$X = F[\beta(t)K, L] \quad (8)$$

Assume that the increased return on investment ($k_0 > k_1$) factors into the increase in labour productivity x and average return on investment as well as boundary one remains invariable. If so, then (8) may be transformed into a following form

$$x = f[\beta(t)k] \quad (9)$$

Important observation follows from expression (9) that under mining diversification, less use of the capital assets labour efficiency remains unchangeable but both average and maximum return on the investment increase. Hence, output per unit of the capital assets experiences its growth. Consequently, it is possible to consider the associate resources, being mining products of the basic mineral, as the additional production functions, i.e. a production function for the diversified mining operations will be as follows

$$X^* = a_0 K^{a_1} Q^{a_2} L^{a_3} I^{a_4} \quad (10)$$

The point of expression (10) is: a life support model of the diversified mining X^* is focused on the utmost use of associate resources $I(t)$ to maximize production and economic performance in terms of constant value of K,Q, and L, resources required to mine X mineral. Thus, $I(t)$ components describes the increase of return on investment in the absence of average and boundary labour productivity. For instance, if the activities to demineralize mine water and use the water as extra operating return are made (Salli & Mamaikin, 2012), there is no labour productivity increase on coal. Nevertheless, the enterprise generates extra revenues owing to the service water sales for the community need. In such a way, return on investment increases in terms of similar degree of use of the capital assets, labour, and materials.

The proposed model (10) is quite important; moreover, it may be implemented.

First, values of a_1, a_2, a_3, and a_4 components of equation (10) help indicate the quality production parameters, i.e. monitor its development tendency which will help to take timely action. Mathematical meaning of the ratio between a_1, a_2, a_3, and a_4 demonstrates elasticity of X enterprise life support model as for the resource flows. It means they are used to identify the averaged value of the resource flows at the enterprise

$$\varepsilon_K = \frac{dX}{X} \Big/ \frac{dK}{K} \quad (11)$$

$$\varepsilon_Q = \frac{dX}{X} \Big/ \frac{dQ}{Q} \quad (12)$$

$$\varepsilon_L = \frac{dX}{X} \Big/ \frac{dL}{L} \quad (13)$$

$$\varepsilon_I = \frac{dX}{X} \Big/ \frac{dI}{I} \quad (14)$$

In terms of equation (10), elasticity indices are equal to the equation components

$$\varepsilon_K = a_1;\ \varepsilon_Q = a_2; \varepsilon_L = a_3; \varepsilon_I = a_4 \quad (15)$$

Each of (11)-(14) equations demonstrate a tendency of change in mineral X extraction depending upon 1% increase in the generated resource type. For instance, suppose that 1% increase in the consumption of Q materials takes place then the increase in coal mining X is considered, if ε_Q=a_2>0 argument in equation (10) is positive. If the argument is $\varepsilon_Q = a_2 < 0$ then expansion in the number of additional materials cannot result in the production increase. Consequently, measures should be taken to reduce metal intensity of the production. The abovementioned helps indicate the mine life support model and what should be mentioned first while optimizing the operating parameters.

Second, coefficients of equation (10) allow making a judgment on the productive efficiency in terms of 1% simultaneous increase in each resource use, i.e. if $a_1+a_2+a_3+a_4>1$ then the efficiency results from the production scaling-up being its concentration. If $a_1+a_2+a_3+a_4<1$ then there is a tendency towards decrease in the productive efficiency; hence, reduce in the scale is required.

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Third, it is possible to set standards to replace one resource by another through the ratio of elasticity indices

$$N_{K/L} = \varepsilon_K/\varepsilon_L = a_1/a_3 \tag{16}$$

$$N_{Q/L} = \varepsilon_Q/\varepsilon_L = a_2/a_3 \tag{17}$$

where $N_{K/L}$ is rate of comprehensive mechanization replacement by muscle labour; and $N_{Q/L}$ is rate of material use replacement by muscle labour.

Based upon (10)-(17) expressions, the abovementioned helps forecast the basic indices characterizing the life support of a mine under diversification (Table 2).

Table-2. Basic indices of the life support indices of a mine under diversification.

Index	Expression
Labour productivity	$\Pi = X/L = a_0K^{a_1}Q^{a_2}L^{a_3-1}I^{a_4}$
Return on assets	$\Phi = X/K = a_0K^{1/a_1}Q^{a_2}L^{a_3}I^{a_4}$
Rate of mining growth	$T_x = \frac{X_i - X_{i-1}}{X_{i-1}} \cdot 100$
Rate of labour productivity growth	$T_\Pi = \frac{\Pi_i - \Pi_{i-1}}{\Pi_{i-1}} \cdot 100$
Rates of return on assets increase (decrease)	$\Phi = \frac{\Phi_i - \Phi_{i-1}}{\Phi_i} \cdot 100$
Measures for reliability growth	$I = \frac{I_i - I_{i-1}}{I_i} \cdot 100$

The abovementioned has helped us develop a mining model under diversification. The optimization problem may be formulated as follows: it is required to increase the funds raised by sales while minimizing the amount of the spent resources *S*. The problem may be termed as the optimization of a production method, and expressed as follows:

$$X = a_0K^{a_1}L^{a_3} \to max; S = p_1K + p_3L \tag{18}$$

Hence, if *n* resources have been applied to mine a mineral then the initial problem is formulated as follows

$$X = a_0Y_1^{a_1}Y_2^{a_2} \dots Y_n^{a_n} \to max; \tag{19}$$

$$S = p_1Y_1 + p_2Y_2 + \dots + p_nY_n \tag{20}$$

(19)-(20) expressions help set down the resource consumption

$$Y_i = \frac{X^k}{a_0\prod_{i=2}^{n}Y_i^{a_i}} \tag{21}$$

$$Y_i = \frac{S}{p_1} - \sum_{i=2}^{n}\frac{p_i}{p_1}Y_i \tag{22}$$

Optimum solution determination is reduced to a procedure of one-dimensional search of output *X*. For the purpose, random initial value of coal mining $X^{(0)}$ is assumed, for which equation system (19) is solved relative to Y_i, (i=1,2,…,n) variables to be solved according to equation (21). Define the total resource costs in terms of the specified alternate solution

$$S^k = \sum_{i=1}^{n}p_iY_i; k = 0,1,2,\dots,m \tag{23}$$

After that, cost variance *d* is identified

$$d = S - S^k \tag{24}$$

where *k* is step number; and *m* is total number of steps.

If d>0 then there are additional reserves; the output may be increased. If d<0 then the resources are not sufficient for the output; thus, it is required to decrease output. If d=0 then the multiple use of resources takes place; hence, the production method is optimal.

Optimum decision is made as follows.

Input data are: *n* being the number of the specified production resources; $a_0, a_1, a_2, \dots, a_n$ being the coefficients of Cobb-Douglas production function; *S* being the allowable expenditures connected with the resources; X_0 being the initial coal output; d_g being the allowable variances of the estimated total expenditures *S* from the assumed ones; *g* being the initial decision making step; and $p_1 \dots p_n$ being the proportionality factor if each resource is set in money terms, i.e. p_i=1.

Additional variables required for the decision making are: *F* being the indicator of the decision procedure with the initial step *g*; l being the indicator of the step measurement direction; and t_1,t_2 being the indicators of *d* context (i.e. positive or negative).

The fact of change in *d* means that redistribution of the production structure has taken place, i.e. either resource amount is insufficient (if the value is negative) or the resources are not applied completely (if the value is positive). *d* index is the sum of t_1 and t_2. Dichotomous search takes place until *d* becomes equal to 0. Direction index *l* denotes a path to move (step increase or decrease). For instance, it is required to calculate optimum output $X^{(k)}$ for a mine as well as cost ratio between *K,Q,* and *L* resources in terms of the specified resource total *S*.

Following equation system can describe the problem solution

$$X = a_0K^{a_1}Q^{a_2}L^{a_3} \to max$$
$$S = p_1K + p_2Q + p_3L.$$

Represent *X, P, Q, L,* and *S* in the form of conditional units (c.u.). Consequently, a proportionality factor is p_1=p_2=p_3=1.

Following data are the input ones: *S*=50000 c.u. being the total cost of three resource types; X_0=300 thousand tons being the initial output; *g*= 50 thousand tons being a step of changes in the output; and d_g= 5 thousand tons being the allowable output variance from the design overall production. According to the data by (Salli, Mamaikin & Smolanov, 2013), in the context of Western Donbas, coefficients of Cobb-Douglas production function are a_0=1.250; a_1=0.237; a_2=0.151; and a_3=0.736.

Table-3 explains the procedure of optimum decision making.

Table-3. Optimization results of the production method.

	$X^{(k)}$	*L*	*Q*	*K*	S^k	*S*	*d*
1	300000	247856.6	50853.6	79806.4	378516.6	500000	121483.4
2	350000	284285	58327.6	91543.6	434156.2	500000	65843.8
3	400000	320140	65680	103080	488900	500000	11100
4	450000	355518.4	72943	114476	542937.4	500000	-42937.4
5	425000	337875.4	69326.2	108820.8	516022.4	500000	-16022.4
6	412500	329037.2	67509.6	105946	502492.8	500000	-2492.8
7	406250	324598	66598.8	104516.8	495713.6	500000	4286.4

It follows from Table-3 analysis that 406 thousand tons will be the optimum annual amount in terms of the specified ratio of *K,Q,* and *L* resources (line 7 of Table 3). To make the solution more accurate, it is required to decrease a step of output change. In terms of each d<0 value, the problem solving is inexpedient since the use of the resources is not efficient.

Logic of the calculations is simple. We specify *X* value of coal output and determine the required amount of *K, Q*, and *L* resources for the production volume. After that, the amount of the resources is calculated (Fomychov, Pochepov, Fomychova & Lapko, 2017; Inkin & Dereviahina, 2018). Following step is to deduct the amount of three S^k resources from the cumulative sum of S resources. If $S - S^k$ is more than zero, then it is required to increase the annual output by g value. Increase the annual output until $S - S^k < 0$. Next, make a decision concerning d_g accuracy. Table 2 explains that the output being 300-400 thousand tons has a reserve for the output increase (lines 1-3 of the Table). A resolve is made to increase the output by 50 thousand tons, i.e. up to 450 thousand tons (line 4). It is understood that the resources are not sufficient; hence, the optimum decision is within 400…450 thousand tons. Determine the optimum decision using the ordinal calculations (lines 5-7).

CONCLUSIONS

The paper is the first one proposing a model optimizing the mining parameters under diversification. Specific feature of the study is the consideration of the potential to apply each of four productive flows of coal mines as well as interchangeability of the flows within the total production balance of a mine. In addition, practical recommendations have been represented concerning the ways of model application, determination of the performance indicators, and identification of the optimum production structure.

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