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RESULTS OF STUDIES TO DETERMINE THE OPTIMAL RATIO OF PRODUCTIVE FLOWS OF COAL, GAS, WATER, ROCK IN THE CONDITIONS OF DIVERSIFICATION

Andrii Khorolskyi[1]

[1]Doctor of Philosophy, Head of the Department of Field Development Problems, Branch for Physics of Mining Processes of the M.S. Poliakov Institute of Geotechnical Mechanics the NAS of Ukraine, Dnipro, Ukraine, e-mail: andreykh918@gmail.com

Abstract. 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: productive flow, production function, technology, efficiency, criterion.

РЕЗУЛЬТАТИ ДОСЛІДЖЕНЬ ЩОДО ВИЗНАЧЕННЯ ОПТИМАЛЬНОГО СПІВВІДНОШЕННЯ ПРОДУКТИВНИХ ПОТОКІВ ВУГІЛЛЯ, ГАЗУ, ВОДИ, ПОРОДИ В УМОВАХ ДИВЕРСИФІКАЦІЇ

А.О. Хорольський[1]

[1]кандидат технічних наук, в.о. завідувача лабораторії проблем розробки родовищ, e-mail: andreykh918@gmail.com

[1]Відділення фізики гірничих процесів Інституту геотехнічної механіки ім. М.С. Полякова Національної академії наук України, Дніпро, Україна

Анотація. Запропоновано підходи, які можуть бути застосовані для комплексної оцінки вугільних шахт, що дозволить визначити рівень підтримки з боку держави, а також спрогнозувати рівень розвитку та концентрації гірничих робіт у просторі. Все це дозволить здійснювати ефективне управління основними виробничими ресурсами для підвищення потенціалу технологічних схем вуглевидобутку та зниження рівня збитковості державних вугільних шахт.

Ключові слова: продуктивний потік, виробнича функція, ефективність, критерій.

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 labor mechanization as well as by the underuse of raw materials resulting from mining. According to studies [1, 2], coal, methane, water, and waste are the productive flows of mines [3, 4]. 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 labor 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 labor conditions [5, 6, 7];
- second, constant increase in mining cost takes place;
- third, decline in coal output takes place resulting in deterioration of situation within the regions where mines are the township-forming enterprises [8];
- 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 [9, 10].

Key trends identified based on research [1, 9, 11–20] 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 [21].

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 [22].

Purpose 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.

The main part. 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 *X* with a value of the resource vector *Y*. Then,

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

where $\vec{A} = \{a_1, a_2, \dots, a_p\}$ 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.

$$\begin{gathered} \vec{K} = \{k_1, k_2, \dots, k_p\}; \vec{Q} = \{q_1, q_2, \dots, q_p\}; \\ \vec{L} = \{l_1, l_2, \dots, l_p\}; \vec{X} = \{x_1, x_2, \dots, x_p\}; \end{gathered} \tag{2}$$

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.

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 [2, 23, 24] 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 [25]. 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

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

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

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

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

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 β(t) multiplier evaluating the improved efficiency of reserve use. Thus,

$$X = F[\beta(t)K, L] \tag{8}$$

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

$$x = f[\beta(t)k] \tag{9}$$

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

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

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 [26], there is no labour productivity increase on coal.

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 demonstrates 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 $\varepsilon_Q=a_2>0$ 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.

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

$$X = a_0 K^{a_1} L^{a_3} \to max; S = p_1 K + p_3 L \quad (16)$$

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

$$X = a_0 Y_1^{a_1} Y_2^{a_2} \dots Y_n^{a_n} \to max; \quad (17)$$

$$S = p_1 Y_1 + p_2 Y_2 + \dots + p_n Y_n \quad (18)$$

(17)-(18) expressions help set down the resource consumption

$$Y_i = \frac{X^k}{a_0 \prod_{i=2}^{n} Y_i^{a_i}} \quad (19)$$

$$Y_i = \frac{S}{p_1} - \sum_{i=2}^{n} \frac{p_i}{p_1} Y_i \quad (20)$$

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 (17) is solved relative to Y_i, (i=1,2,…,n) variables to be solved according to equation (19). Define the total resource costs in terms of the specified alternate solution

$$S^k = \sum_{i=1}^{n} p_i Y_i; k = 0,1,2, \dots, m \quad (21)$$

After that, cost variance *d* is identified

$$d = S - S^k \quad (22)$$

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

$$X = a_0 K^{a_1} Q^{a_2} L^{a_3} \rightarrow max$$
$$S = p_1 K + p_2 Q + p_3 L.$$

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 [27], 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 1 explains the procedure of optimum decision making.

Table 1 – 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	121484
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
5	425000	337875.4	69326.2	108821	516022.4	500000	-16022
6	412500	329037.2	67509.6	105946	502492.8	500000	-2492.8
7	406250	324598	66598.8	104517	495713.6	500000	4286.4

It follows from Table 1 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 1). 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 [28]. 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 1 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).

Conclusion. 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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РОЛЬ ЦИРКУЛЯРНОЇ ЕКОНОМІКИ В УПРАВЛІННІ ВІДХОДАМИ ГІРНИЧОДОБУВНИХ ПІДПРИЄМСТВ

І.І. Чоботько[1]
[1]провідний інженер відділу фізики вугілля та гірничих порід, e-mail: efilonov79@gmail.com
[1]Відділення фізики гірничих процесів Інституту геотехнічної механіки ім. М.С. Полякова НАН України, Дніпро, Україна

Анотація. У роботі розглянуто застосування принципів циркулярної економіки до управління відходами гірничодобувних підприємств, розглянуто основні ідеї зменшення впливу на навколишнє середовище відходів гірничодобувних підприємств за рахунок використання циркулярної економіки, що сприятиме економічному розвитку гірничодобувних регіонів.

Ключові слова: циркулярна економіка, відходи, гірничодобувні підприємства, навколишнє середовище.

THE CIRCULAR ECONOMY ROLE IN MINING WASTE MANAGEMENT

Ihor Chobotko[1]
[1]Leading Engineer of the Department of Coal and Rock Physics, e-mail: efilonov79@gmail.com