Экономические науки
Economic sciences

UDC 622./ 53.045.2/ 338.45/ 338.314.053.4

http://doi.org/10.21440/2307-2091-2025-2-109-119

Optimization of development parameters of a mining enterprise based on the study of the economic efficiency function

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Abstract

Relevance. The key factor in the development of a mining enterprise is the volume and quality of the reserves of a mineral deposit expected to be extracted. They determine the possible level of efficiency and the area of rational production and economic parameters. Traditional methods for selecting the volume of effective reserves are based on determining the boundary coefficient of stripping and do not take into account the dynamics of the economic results obtained.

The aim of the study is to develop a methodological approach to optimizing the development parameters of a mining enterprise based on a study of the economic efficiency function.

Methods. The work uses a combination of methods of system, structural-functional, logical, factor, statistical analysis, economic-mathematical modeling, integral and differential calculus.

Results. A solution to the problem of optimizing the development parameters of a mining enterprise is proposed based on the analysis of the continuous function of economic efficiency. An economic and mathematical model for optimizing the development parameters of an enterprise based on this function is developed. The model allows assessing the sustainability of the achieved economic results by studying the relationship between external and internal factors of enterprise development using integral and differential calculus methods. The results obtained are of practical importance for making informed investment decisions at all stages of the life cycle of a mining enterprise, and contribute to the optimization of production and economic parameters of a designed and operating enterprise.

Conclusions. The proposed approach to optimizing the parameters of a mining enterprise, based on the formation and study of a continuous function of economic efficiency, allows taking into account the dynamics of results and costs. This ensures a multifactorial assessment of commercial and budgetary efficiency, taking into account the uncertainty of the external and internal environment. The key factors of economic efficiency of deposit development are substantiated, including mining and geological conditions, specific operating costs, the cost of financial resources and the level of investment costs.

***Keywords*:** mining enterprise, mineral reserves, function study, development model, parameter optimization, influencing factors, economic efficiency, economic development.

Introduction

In modern scientific literature, the concept of "development" is revealed primarily as a process of regular and purposeful change of an object with the emergence of new qualities and states (transition from simple to more complex, from lower to higher). The development of an industrial enterprise is a process of its qualitative changes aimed at increasing the reliability and efficiency of its functioning, as a result of which a previously non-existent set of elements and their interrelations arises [1, 2]. Development occurs continuously, but not linearly, including periods of growth and decline, positive and negative phenomena and trends from the point of view of the economy, as well as corresponding quantitative and qualitative changes in the parameters of the system itself.

The development of an enterprise is characterized by the presence of the following main features: the qualitative nature of changes, their irreversibility and direction. It should be noted that the development of an economic entity is determined not only by changes in technical and technological parameters, but also by achieving a certain level of economic efficiency in the context of a system of objective natural, market and legislative restrictions [3].

A mining enterprise is a specialized organization engaged in the extraction of minerals from the earth's interior. It has a number of unique features that distinguish it from other types of industrial enterprises:

– the specifics of the raw material base (exhaustibility of resources, as well as heterogeneity of the location and quality of mineral raw materials);

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Table 1. Stages of substantiation of parameters of the project for construction and reconstruction of a mining enterprise
Таблица1. Этапы обоснования параметров проекта строительства и реконструкции горнодобывающего предприятия

Stage name	The goal of the stage	Level of deviation in the assessment, %
Scoping study	Conceptual assessment of the feasibility and viability of the project	30–50
PreFeasibility study	Assessing the viability of the project, potential level of investment efficiency, critical limitations and the feasibility of further research	20–25
Feasibility Study	Determination of technical, environmental and economic conditions for investment decisions	15–20
Design basic	Justification of technical solutions, parameters and feasibility of the project in accordance with regulatory documents	10–15
Design detailed	A set of text and graphic documents required for construction and installation work	5–10

– territorial attachment (localization in remote areas, dependence on the impossibility of transferring to another place);

– high capital intensity (significant initial investment and long payback period); environmental impact (environmental risks and post-mining remediation obligations).

Based on the specifics, the choice of development directions for a mining enterprise is made on the basis of a number of consistently developed documents confirming the economic feasibility and economic necessity of the facility. Preparing a mineral deposit for development is complex, lengthy and expensive, so the customer must be confident that the enterprise creation project will not only be agreed upon and receive a construction permit, but will also be feasible and profitable. This is precisely what the pre-project study is aimed at, which is essentially a professional analysis of the construction conditions of the future facility [4, 5]. The composition of pre-project work is not regulated by law, but as a rule includes several standard stages (Table 1).

At the stages of the scoping study and the prefeasibility study in practice, when conducting the prefeasibility study, as a rule, the methods of reduced costs are used based on data on the actual operation of similar enterprises. The least formalized stage of substantiation of the parameters of the project for the construction and reconstruction of a mining enterprise is the feasibility study, where, taking into account the assessment of the level and interrelation of the influencing factors, options for solving general fundamental issues are developed: determining the boundaries of development and industrial reserves; capacity and service life of the enterprise; methods of opening and preparing the deposit, etc. With a sufficient level of study of the influencing factors, interrelations and limitations at the feasibility study stage, subsequent design is primarily technical in nature.

To optimize the parameters of a mining enterprise, it is necessary to take into account the features and patterns of the production process. The optimization problem cannot be solved using the experimental method in real conditions: such an event is expensive, difficult to implement in practice, and unsuccessful decisions in planning, organizing and managing mining production can lead to irreparable damage. Therefore, when solving complex issues that require the development of various options, it is necessary to use alternative methods, for example, an assessment of the consequences based on economic and mathematical modeling [6, 7].

The key factor in the development of a mining enterprise is the volume and quality of the reserves of a mineral deposit expected to be extracted, which determine the possible level of efficiency and the area of rational production and economic parameters. Traditional methods for selecting effective reserves are based on determining the boundary stripping coefficient, were predominantly static, not taking into account the dynamics of the economic results obtained, as well as the levels of commercial and budgetary efficiency of deposit development.

Theoretical foundations. The category of industrial enterprise development efficiency is complex and multifaceted, including not only economic but also environmental and social aspects, so it is not possible to determine all its aspects by one criterion. However, in some cases, taking into account a number of limitations and assumptions (including socio-economic, environmental, technical and technological and market factors), the assessment of economic efficiency can be reduced to a single target function.

Let us consider a mining enterprise as an economic system with an objective function of maximizing the effect, defined as the difference between income from the sale of the extracted mineral and production costs [8]:

$$\Pi_\Sigma = \int_0^Q \frac{\partial U}{\partial Q}\partial Q - \int_0^Q \frac{\partial S}{\partial Q}\partial Q \to \max, \quad (1)$$

where Q – volume of mineral extraction, t; $\frac{\partial U}{\partial Q}, \frac{\partial S}{\partial Q}$ – respectively, the income from sales and the costs of extraction of each unit of mineral resource, rub./t.

It should be noted that incomes and expenses are not constant values over time and depend primarily on the volumes of production and sales, which in turn are dynamic:

$$\begin{cases} \partial U = f(Q); \\ \partial S = f(Q); \\ Q = f(t), \end{cases} \quad (2)$$

where t – time.

In order to ensure the most complete extraction of mineral reserves from the subsoil, at the stage of pre-project work, options are considered when, as the most favorable reserves of mineral raw materials are developed, additional subsoil areas with worse mining conditions and, accordingly, a higher level of extraction costs can be successively connected to development. In practice, three options are usually considered, on the basis of which a choice is made: effective, moderate and conservative.

Expansion of production is only advisable until additional costs equal the additional gross economic effect, rub./t [9]:

$$\frac{\partial U - \partial S}{\partial Q} = 0. \quad (3)$$

The specific costs of open-pit mining of mineral raw materials, taking into account the volume of stripping operations, can be calculated using the formula of V. S. Khokhryakova, rub./t [10]:

$$S = \frac{\partial S}{\partial Q} = s_d + K_v s_v, \quad (4)$$

where s_d – costs of extracting 1 t of mineral directly (excluding stripping operations), rub./t; K_v – stripping coefficient (average volume required to extract 1 t of mineral), m^3/t; s_v – costs of drilling and blasting operations, excavation, transportation and dumping of overburden rocks, rub./m^3.

Let us assume that before the start of operation the final contour of the quarry is determined, and the development of the deposit is carried out with a constant level of production capacity Q_t and the volume of stripping operations $Q_t K_v$. This assumption cannot be fully implemented in practice, taking into account the rational schedule of mining operations based on mining, economic and market factors [11, 12]. However, the accepted averaging of parameters for the period of full development of a subsoil area does not lead to deviations in calculation errors exceeding those permissible at the feasibility study stage (15–20%).

Then, in a stable economic situation (consistency of specific costs and product prices), revenue from the sale of products for each interval of field exploitation is proportional to the volume of production, rub.:

$$U_t = pQ_t, \quad (5)$$

where p – average price per unit of output.

Then the income from operating activities in each period of exploitation of the mineral deposit will be, rub.:

$$\Phi_t = U_t - S_t\,(p - s_d - K_v s_v). \quad (6)$$

It should be noted that, under the accepted assumptions, the level of income from the operating activities of a mining enterprise is essentially determined by the reserves planned for extraction, taking into account the mining and technical conditions of the mineral deposit.

Formation and maintenance of the operating activities of an enterprise is impossible without investment - long-term investment of resources, with the aim of obtaining benefits in the future. In foreign practice, to determine investment in projects for the development of mineral deposits, the empirical formulas of T. U. Kemm are widely used, obtained on the basis of regression analysis of statistical data on the design, construction and actual operation of various mining enterprises [13, 14]. To assess the scale of an enterprise and the level of investment, instead of the parameter "production capacity for extraction", the indicator "production capacity for rock mass" is usually used, m^3/year:

$$M_t = Q_t\left(\frac{1}{\rho} + K_v\right), \quad (7)$$

where ρ – density of extracted mineral raw materials, t/m^3.

In general, the amount of investment costs for a mining enterprise has a certain positive minimum level, and increases nonlinearly with the growth of production capacity. Then investment costs can be estimated based on the following formula, rub.:

$$IN = IN^0 + in_M M_t^b, \quad (8)$$

where IN^0 – investment costs associated with the formation of production and social infrastructure necessary for organizing the production process, rub.; in_M – specific investment costs that ensure the development and growth of the enterprise's production capacity, rub.-year/m^3; b – coefficient that determines the possibility of saving investment resources due to the effect of scale, $b \in [0,5; 1,0]$.

From the point of view of the overall economic efficiency of a mining enterprise over the entire life cycle, the costs associated with its subsequent liquidation can also be of the utmost importance [14]. Such costs for a mining enterprise are often quite significant and are usually incurred after the completion of the extraction of effective reserves of mineral raw materials of the deposit being developed. On the other hand, in some cases, additional income is received from the termination of a project (for example, from the sale of disposed assets). Therefore, it is advisable to consider the situation when the completion of the operation of a mining enterprise provides some (positive or negative) net liquidation income L (liquidation balance). In general, the liquidation balance is determined primarily by the production capacity of the enterprise for rock mass and can be assessed in the same way as investment costs are assessed, rub.:

$$L = L^0 + l_M M_t^b, \quad (9)$$

where L^0 – liquidation income associated with the advantage of the production and social infrastructure of the enterprise, rub.; l_M – specific liquidation income, rub.-year/m^3.

Specific liquidation income is determined by both the possibility of selling the released assets of the enterprise and the costs associated with the fulfillment of obligations for reclamation after the completion of production. In general, the level of liquidation income of a mining enterprise correlates with its production capacity.

The life cycle of a mining enterprise can be presented as an investment project, including the stages of investment, operation and liquidation. Then the assessment of the economic efficiency of development can be based on the principles of assessing the return on investments: determining the potential ability to increase the value of invested resources due to the regular economic effect obtained during the life cycle of the enterprise. The assessment of the return on investments is carried out based on the results of modeling cash flows over time, and when using net present value (NPV) as a criterion, the target function of deposit development can be written as:

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{(\Phi_t - IN_t - L_t)}{(1+E)^t} \to \max, \quad (10)$$

where Φ_t – operating effect (net operating income) for the t-th time interval; IN_t, L_t – respectively, investment and liquidation costs for the t-th time interval; E – discount rate (reflects the cost of financial resources for the project under consideration); T – the project life under consideration (the service life of the mineral deposit).

Mining enterprises are often city-forming or play a significant role in the regional economy. The state establishes regulatory rules that the enterprise must comply with and is interested in their implementation; ensuring social stability and budgetary efficiency of production. The key factor in the budgetary efficiency of a mining enterprise is the tax burden. A mining enterprise in Russia is obliged to pay all taxes in accordance with the law, as well as a number of specific taxes: payment for the use of natural resources, as well as for the reproduction and protection of natural resources. In general, the tax burden of a mining enterprise in Russia is 32–35% of sales revenue and its main components are proportional to the volume of extracted and sold mineral raw materials [15]. Accordingly, the state is interested in the most complete and intensive extraction of mineral reserves from the subsoil, i. e. maximizing the discounted budget effect (DBE):

$$\mathrm{DBE} = \sum_{t=0}^{T} \frac{Q_t}{(1+E)^t} p k_{\text{н.н}} \to \max, \quad (11)$$

where $k_{\text{н.н}}$ – tax burden ratio.

Thus, from the point of view of the interests of the state, the volume of recoverable reserves of the deposit should be maximum and does not require additional optimization.

Let us introduce the assumption that the costs of the mining enterprise not related to operating activities are made at one time:

– investment (related to the development of the field) at time $t = 0$ (before the start of the field operation);

– liquidation at the moment $t = (T + 1)$ (after completion of the field exploitation).

Then the operating effect, investment and liquidation costs are values determined by the mining parameters of the deposit, production capacity and general economic parameters. The target function of deposit development can be written as:

$$\mathrm{NPV} = \sum_{t=0}^{T} \frac{\Phi}{(1+E)^t} - \left(IN + \frac{L}{(1+E)^{(T+1)}} \right) \to \max. \quad (12)$$

It should be noted that the result of operating activities, as well as the level of investment and liquidation costs, are determined primarily by production capacity, which in turn depends on the volume of reserves of the deposit planned for development. Optimization of the parameters of economic development of a mining enterprise should take into account the time factor, including not only the intensity, but also the total duration of development of reserves of raw materials of a specific deposit. The planned period of development of a deposit as a whole increases with the growth of reserves of mineral raw materials planned for development. The rational service life of a deposit can be determined analytically using the empirical Taylor formula, years [15]:

$$T = 0,2\, Q_\Sigma^{0,25}, \quad (13)$$

where Q_Σ – balance (planned for development) reserves of mineral raw materials, t.

Accordingly, the optimal production capacity of the future enterprise is determined as the quotient of the volume of extractable reserves of mineral raw materials divided by the service life of the deposit, mln t/year:

$$Q_t = \frac{Q_\Sigma}{T} = 5 Q_\Sigma^{0,75}. \quad (14)$$

The operation of any production enterprises is subject to the law of diminishing returns, which for mining enterprises is caused, first of all, by the uneven occurrence o f minerals in the subsoil [16, 17]. Taking into account the principle of economic feasibility, the most rational areas for priority extraction are those with the best mining and geological conditions. The consistent involvement of additional subsoil areas in the development leads to a deterioration in the extraction conditions: an accelerated growth in the volume of stripping operations, an increase in specific costs, and in some cases a decrease in the quality of mineral raw materials. At the same time, the relationship between the volume of stripping operations in relation to the volume of mineral reserves planned for extraction can be represented by a power function reflecting the growth of the average stripping coefficient with an increase in the volume of reserves of the deposit planned for involvement in the development, m³/t:

$$K_v = N Q_\Sigma^R + K_0, \quad (15)$$

where N – proportionality coefficient reflecting the change in the specific volume of overburden operations with the increase in the planned reserves of the deposit, m³/t²; R – coefficient determining the growth rate of the stripping ratio; K_0 – stripping coefficient that ensures the extraction of the most favorable mineral reserves of a deposit, m³/t.

Proportionality coefficient N, reflecting the change in the specific weight of overburden operations with the increase in reserves planned for development, for most known deposits has a positive value. For horizontal and gently dipping bedded mineral deposits, the relationship between the stripping coefficient and the volume of recoverable reserves can be reflected with high accuracy as a linear ($R \approx 1,0$). For most complex structure deposits, it is possible to use a power law dependence with satisfactory accuracy $R \in [0,5; 1,5]$.

The use of the above dependencies allows a mining enterprise to take into account the relationship between the production capacity for mining and rock mass and the volume of reserves involved in the development of the deposit. Accordingly, it is the volume of reserves involved in the development that becomes the key factor in the formation of cash flows and net present value.

The presentation of cash flows in discrete form is made in the form of tables, which significantly simplifies the calculations and ensures clarity. At the same time, such a calculation limits the possibilities of analyzing the essential properties and features of the investment process. The search for rational solutions with a discrete approach is carried out on the basis of a comparison of alternative options, the number of which for determining the optimal parameters and ratios of significant factors may be unlimited.

An alternative representation of cash flows as a continuous and smooth function allows the use of mathematical analysis tools to find the area of rational project parameters, taking into account the uncertainty of external and internal influencing factors.

Methods of mathematical analysis have not yet found wide practical application in assessing the commercial efficiency of projects. This may be due to the peculiarities of the classical direct costing approach, in which the enterprise is considered as a linear system with constant and variable costs. This method provides sufficient accuracy only for enterprises producing homogeneous products with a simple technological chain and a minimum number of stages of raw materials. In more complex production systems, this approach may give significant distortions in efficiency calculations.

For a natural system, reliable optimization of key parameters (volume of recoverable reserves, period of field development, production capacity and potential income level) cannot be performed as for a linear system. At the same time, the obtained dependencies allow nonlinear optimization using mathematical analysis methods. This is carried out through the study of function (12), transformed to a continuous form by replacing discrete time $t = 1, 2, 3,\ldots, n$ to the continuous $\tau \geq 0$:

$$\mathrm{NPV}(\tau) = \Phi\int_0^T \frac{d\tau}{(1+E)^{\tau}} - \left(IN + \frac{L}{(1+E)^{(T+1)}}\right). \quad (16)$$

Note that:

$$\int_0^{\tau} \frac{d\tau}{(1+E)^{\tau}} = \frac{1-(1+E)^{-\tau}}{\ln(1+E)}. \quad (17)$$

Thus:

$$\mathrm{NPV}(\tau) = \Phi\frac{1-(1+E)^{-\tau}}{\ln(1+E)} - \left(IN + \frac{L}{(1+E)^{(T+1)}}\right). \quad (18)$$

When the deposit is fully developed $\tau = T$. Thus, we can use a system of substitutions (formulas (6), (7), (8), (9), (13), (14), (15)) that predetermine the function of dependence of the level of net present value income generated by a mining enterprise on the planned mineral reserves for involvement in development:

$$\begin{cases} \Phi_t = Q_t\left(p - s_d - K_v s_v\right); \\ IN = IN^0 + in_M Q_t\left(\frac{1}{\rho} + K_v\right)^b; \\ L = L^0 + l_M Q_t\left(\frac{1}{\rho} + K_v\right)^b; \end{cases} \quad \begin{cases} Q_t = 5Q_{\Sigma}^{0,75}; \\ T = 0,2\,Q_{\Sigma}^{0,25}; \\ K_v = NQ_{\Sigma}^{R} + K_0. \end{cases} \quad (19)$$

The resulting function reflects the dependence of the net present value on the volume of mineral reserves involved in exploitation and allows modeling the parameters of economic development of a mining enterprise. The approach to studying a continuous function, in contrast to the principle of developing scenarios (characteristic of the traditional discrete approach), ensures optimization of parameters under conditions of significant uncertainty in combinations of key influencing factors (cost level; cost of financial resources; mining and geological conditions, etc.).

Research results

Let us consider the application of the above theoretical assumptions to the conditions of one of the sections of a mineral

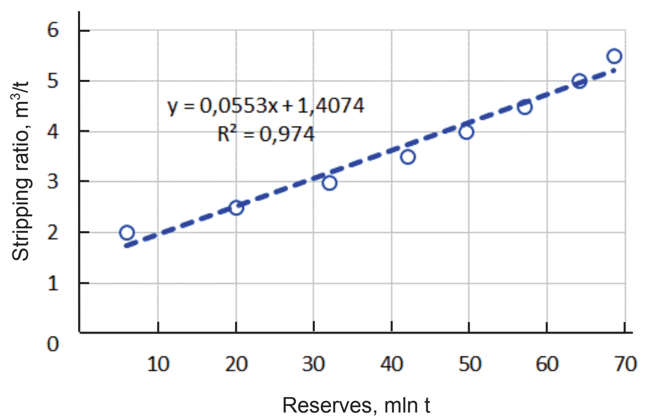

Figure 1. Dependence of the stripping ratio on the volume of reserves of the deposit planned for extraction

Рисунок 1. Зависимость коэффициента вскрыши от объема планируемых к извлечению запасов месторождения

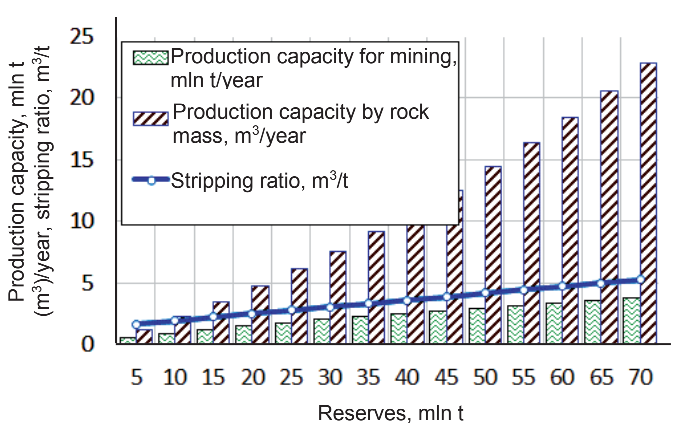

Figure 2. Dependence of production capacity and stripping ratio on the volume of reserves planned for extraction

Рисунок 2. Зависимость производственной мощности и коэффициента вскрыши от объема планируемых к извлечению запасов месторождения

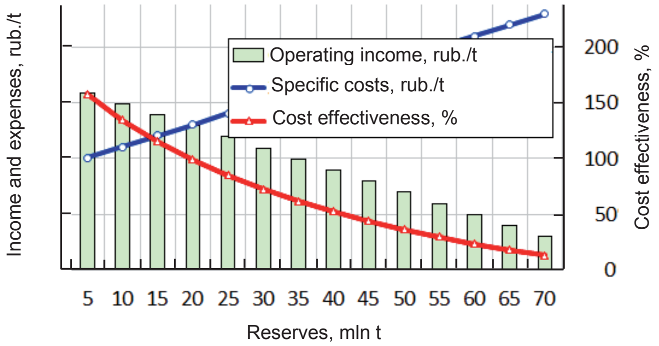

Figure 3. Dependence of income and expenses on the volume of reserves planned for extraction

Рисунок 3. Зависимость доходов и затрат от объема планируемых к извлечению запасов месторождения

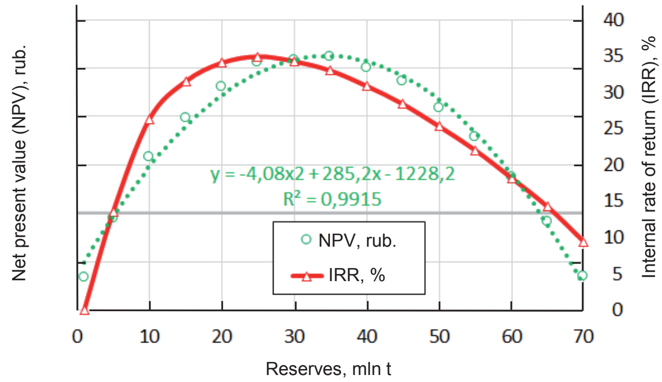

Figure 4. Dependence of the level of net present value and internal rate of return on the volume of reserves of the field planned for extraction

Рисунок 4. Зависимость уровня чистого дисконтированного дохода и внутренней нормы доходности от объема планируемых к извлечению запасов месторождения

deposit located in Kuzbass. The mining and geometric analysis conducted allowed us to confirm that the relationship between the stripping ratio and the volume of reserves planned for extraction of the deposit can be represented with sufficient reliability by a linear function (Fig. 1).

It should be noted that the initial data for modeling are the predicted values of economic, mining and organizational factors:

– price of products p, as well as the specific cost of extraction and transportation of mineral raw materials and stripping operations s_d, s_v;

– the cash flow in relation to the project under consideration E.

– physical properties of mineral raw materials and mining conditions of the deposit area proposed for development (ρ, A, K_0, B);

– level of investment and liquidation costs IN^0, L^0, in_M, L_M.

Depending on the volume of reserves planned for extraction, the following can be determined: rational level of production capacity for extraction; stripping ratio; productivity by rock mass (Fig. 2).

Determining rational parameters for deposit development, in turn, allows us to assess the levels of specific costs, operating income and profitability (Fig. 3).

The parameters found do not allow us to directly determine the optimal level of recoverable reserves, but they provide the necessary information for assessing investment and liquidation costs. This, in turn, allows us to establish the dependence of the project's commercial efficiency indicators on the expected volume of field reserves development (Fig. 3).

It should be noted that the found relationship has significant differences when assessing the optimal reserves for extraction using different criteria [18, 19, 20]:

– according to the internal rate of return (IRR) criterion – about 25 million tons (37.5% of the volume of explored reserves of the deposit);

– according to the net present value criterion – about 35 million tons (50.0% of the volume of explored reserves of the deposit).

It is obvious that for optimizing the volume of recoverable reserves of a deposit, the criterion of net present value has great potential: it is aimed at more complete development of the deposit reserves and, accordingly, satisfies the interests of the state to a greater extent.

Based on the study of the obtained continuous function of net present value (18) for the deposit under consideration, it was established that an increase in the level of operating and investment costs, the stripping ratio and the discount rate significantly reduces the optimal value of the reserves involved in development and the potential level of net present value (curve AB, fig. 5).

The conducted study of the sustainability of the achieved economic results showed that the following factors have the greatest influence on the rational level of development of the deposit reserves (Table 2):

– mining and geological conditions – up to 25% per 1% change in factor;

– operating costs – up to 15% per 1% change in factor;

– cost of financial resources – up to 14% per 1% change in cost;

– investment costs – up to 10% per 1% change in factor.

The study of the continuous function of economic efficiency allows to evaluate and optimize such parameters of development of a mining enterprise as production capacity, mining period and profitability for conditions of variability of external and internal environmental factors; to evaluate the economic sustainability of the project in various conditions.

Conclusion

The paper examines the issues of optimizing the development parameters of a mining enterprise based on the analysis of the economic efficiency function. The study was conducted using economic and mathematical modeling methods to assess the impact of external and internal factors on the rationality of the parameters for developing mineral deposits.

Classical methods of assessing rational development parameters based on static assessment of the boundary stripping ratio do not take into account the time value of money, market dynamics and scale effect. The developed model eliminates these limitations, providing a comprehensive analysis of the enterprise life cycle. The model is based on the classical discrete function of net present value and takes into account the following key factors:

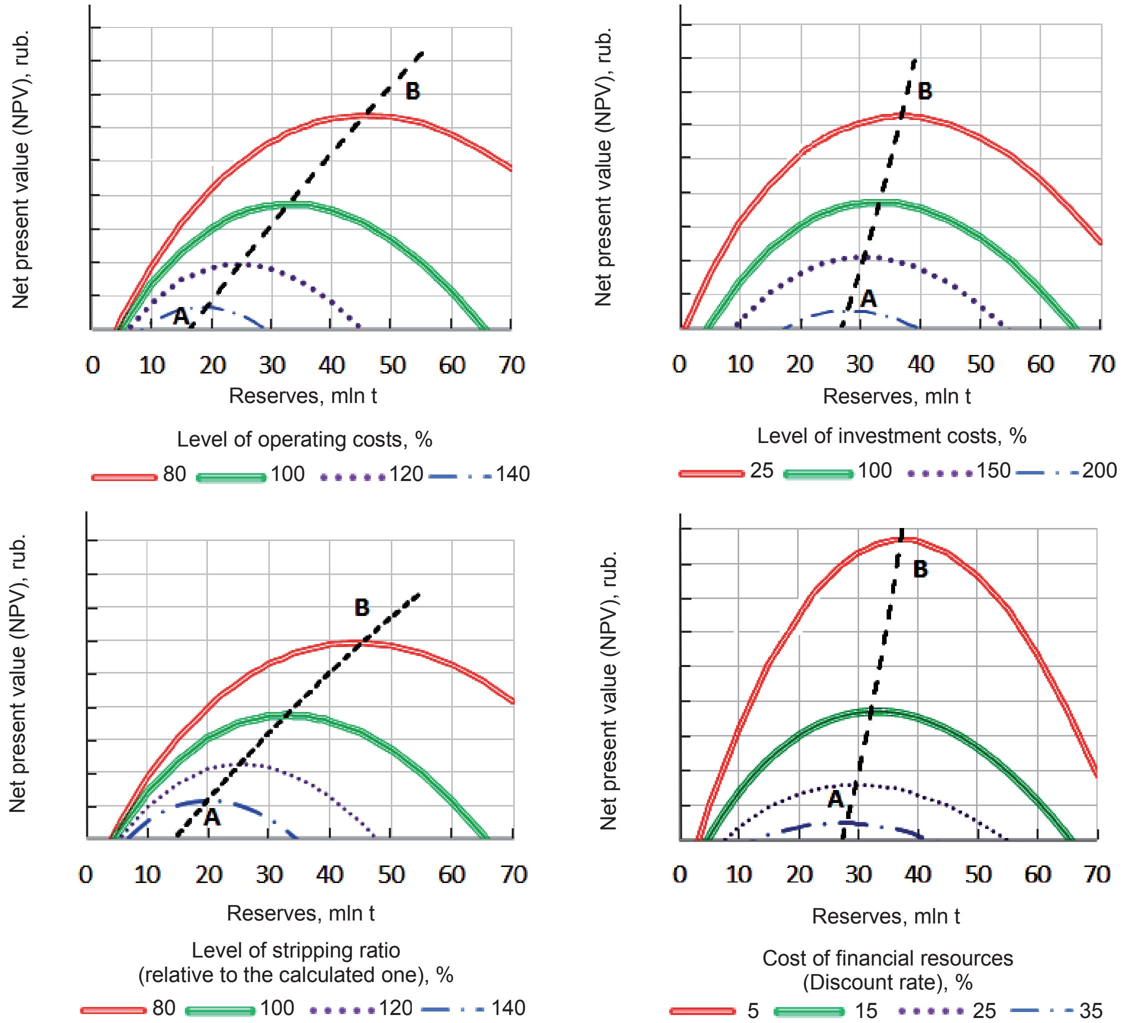

Figure 5. Study of the efficiency function

Рисунок 5. Исследование функции эффективности

Table 2. Evaluation of the impact of key factors in the development of a mining enterprise: percent change in result per 1% change in factor

Таблица 2. Оценка влияния ключевых факторов развития горнодобывающего предприятия: процент изменения результата на 1 % изменения фактора

Factor	Impact on the level of achievable NPV, %	Impact on the oprimal level of reserves, %
Investment costs	0,9–1,1	1,0–10,0
Cost of financial resources	1,7–3,3	1,0–14,0
Operating costs	2,0–4,0	1,0–15,0
Mining and geological conditions	4,0–20,0	5,0–25,0

– mining and geological conditions of the mineral deposit;
– specific operating costs;
– cost of financial resources;
– level of investment and liquidation costs.

It has been proven that the state is interested in the most complete and intensive extraction of mineral reserves from the subsoil, that is, in maximizing the discounted budget effect. From the point of view of the interests of the state, the volume of recoverable reserves of the deposit should be maximum and does not require additional optimization.

Using the example of one of the subsoil areas of the deposit in Kuzbass, it was shown that the optimal volume of recoverable reserves differs significantly depending on the chosen criterion for assessing commercial efficiency and is from the volume of explored reserves:

– on the internal rate of return criterion – 37.5%;
– on the net present value criterion – about 50.0%.

The task of optimizing the parameters of a mining enterprise can be solved on the basis of determining the rational level of mineral reserves extracted from the deposit, and, accordingly, the production capacity and the period of operation, ensuring the maximization of net present value. Rational parameters for the development of a deposit by an analytical method are formed on the basis of determining the derivative function of net present value, which can be reduced to a continuous form. The study of this function provides an assessment of the influence of external and internal environmental factors and the level of economic sustainability of the planned enterprise.

The study of the obtained continuous function allowed us to assess the sustainability of the achieved economic results and identify the most significant factors influencing the optimal level of reserves development (in % per 1% change in the factor): mining and geological conditions – up to 25%; operating costs – up to 15%; cost of financial resources – up to 14%; investment costs – up to 10%.

The proposed approach allows us to optimize the development parameters of a mining enterprise, including production capacity, development period and profitability, taking into account the variability of external and internal factors. This is especially relevant for decision-making at the stages of pre-project development and investment planning.

The model used is based on a number of assumptions, such as the constancy of production capacity, specific costs and product prices. In real conditions, these parameters may change, which requires additional adaptation of the model for specific projects. The results obtained open up opportunities for further improvement of the methodology for assessing the economic efficiency of mining enterprises. In particular, it is possible to consider the application of the proposed approach to study a wider range of constraints and goals, including environmental risks and social responsibility. In addition, the issue of taking into account fluctuations in prices for mineral raw materials and changes in regulatory requirements remains relevant.

Thus, the presented study is an important contribution to the development of theoretical and practical approaches to optimizing the parameters of mining enterprises development, providing a reliable basis for making informed investment decisions. The results of the study can be used in the formation of technical and economic justifications, strategic planning and assessment of the investment attractiveness of projects in the mining industry.

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The article was received on March 14, 2025

УДК 622./ 53.045.2/ 338.45/ 338.314.053.4 http://doi.org/10.21440/2307-2091-2025-2-109-119

Оптимизация параметров развития горнодобывающего предприятия на основе исследования функции экономической эффективности

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Аннотация

Актуальность. Ключевыми факторами развития горнодобывающего предприятия являются объем и качество планируемых к извлечению запасов месторождения минерального сырья. Они определяют возможный уровень эффективности и область рациональных производственно-экономических параметров. Традиционные методы выбора объема эффективных запасов основаны на определении граничного коэффициента вскрыши и не учитывают динамику получаемых экономических результатов.

Цель исследования – разработка методологического подхода к оптимизации параметров развития горнодобывающего предприятия на основе исследования функции экономической эффективности.

Методы. В работе использовано сочетание методов системного, структурно-функционального, логического, факторного, статистического анализа, экономико-математического моделирования, интегрального и дифференциального исчисления.

Результаты. Предложено решение задачи оптимизации параметров развития горнодобывающего предприятия на основе анализа непрерывной функции экономической эффективности. Разработана экономико-математическая модель оптимизации параметров развития предприятия, основанная на этой функции. Модель позволяет оценивать устойчивость достигаемых экономических результатов путем исследования взаимосвязи внешних и внутренних факторов развития предприятия с использованием методов интегрального и дифференциального исчисления. Полученные результаты имеют практическую значимость для принятия обоснованных инвестиционных решений на всех этапах жизненного цикла ГДП, способствуют оптимизации производственных и экономических параметров проектируемого и действующего предприятия.

Выводы. Предложенный подход к оптимизации параметров горнодобывающего предприятия, основанный на формировании и исследовании непрерывной функции экономической эффективности, позволяет учитывать динамику результатов и затрат. Это обеспечивает многофакторную оценку коммерческой и бюджетной эффективности с учетом неопределенности внешней и внутренней среды. Обоснованы ключевые факторы экономической эффективности отработки месторождения, включая горно-геологические условия, удельные операционные затраты, стоимость финансовых ресурсов и уровень инвестиционных затрат.

***Ключевые слова*:** горнодобывающее предприятие, запасы минерального сырья, исследование функции, модель развития, оптимизация параметров, факторы воздействия, экономическая эффективность, экономическое развитие.

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Статья поступила в редакцию 14 марта 2025 года