OPTIMIZING THE DESIGN CAPACITY OF A MINE UNDER CONDITIONS OF INVESTMENT RISK

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The problem of optimizing the parameters of mines is formulated on the basis of the criterion of maximizing discounted net income in an investment with a risk. Possible solutions to the problem are proposed, and results are presented from optimization of the design capacity and dimensions of a panel in the "Kotinskaya" mine.

The high degree of uncertainty and risk in mining is largely related to the long time interval between the beginning of planning and the beginning of operation of the mine, as well as to the incomplete and imprecise nature of prospecting data on the bedding conditions of mineral deposits.

By risk, we mean the uncertainty connected with the possibility of unforeseen problems, accidents, and disasters in mines and the difficulty of reliably predicting and optimizing the parameters of mines over a long period of time, given the unstable development of the market economy in Russia [1]. The importance of the problem of accounting for these factors in investment projects (IPs) involving mines increased in connection with the Federal law passed in 1997 on the safety of industrial facilities that pose a hazard [2]. In accordance with this law, mines prepare declarations of industrial safety that include a mandatory comprehensive risk assessment, analyze the effects of measures that have been implemented to prevent and eliminate accidents, and devise ways of mitigating the consequences of accidents and the attendant losses.

At present, mine investment projects are often evaluated by using integral criteria of efficiency, such as current net cost or discounted net profit, a profitability index, or an internal norm of profitability.

These criteria are based on the discounting of projected costs and profits over future years. Thus, the integral value of a given mineral deposit includes annual discounted cash flows, which depend mainly on the rate of the mine's development or the capacity of the mine. The latter is one of the main technical-economic indices that determine the efficiency with which a mineral deposit as a whole is exploited.

Mines in Russia and abroad are planned by using the expression derived by P. Z. Zvyagin [3] to determine the dependence of the optimum capacity of a mine $A_0$ on the coal reserves $Q$ within the field of the mine

$$A_0 = \varphi \sqrt{Q} = \sqrt{\frac{cQ}{k}},$$

where $c$ and $k$ are the components of production cost and capital investment, respectively.

*Zvyagin's relation is known abroad as Taylor's formula.
The Mining Institute of the Siberian Branch of the Russian Academy of Sciences has proposed a new approach to solving the problem of optimizing the design capacity of a mine. The solution of this problem is based on economic principles which we have found to govern the optimization of the capacity of a mine. The optimization is done by determining the maxima of integral criteria of optimality with the use of logging data [4]. In particular, it has been found that \( A_0 \) depends asymptotically on \( Q \) and that this dependence can be approximately represented by a hyperbola

\[
A_0 = \frac{K}{k \ln(1 + E)} + \frac{c}{ru - c_0} - \frac{K}{KaQ + k \ln(1 + E)},
\]

where \( K \) represents the resources of the organization that is building the mine and is measured in terms of the annual volume of investments; \( u \) is the market price of coal; \( r \) is a coefficient expressing the capital gains tax; \( E \) is the discount rate (annual bank rate); \( a \) is an empirical coefficient.

The main difference between this relation and Zvyagin’s formula is that for infinitely large coal reserves (\( Q \to \infty \)), the optimum mine capacity determined from Eq. (2) has a finite asymptotic or limitingly optimum value

\[
A_0 = \frac{K}{k \ln(1 + E)} + \frac{c}{ru - c_0},
\]

while mine capacity approaches infinity in this case according to the Zvyagin’s formula.

One consequence of this relationship is that the increment of growth of the mine \( A_0 \) decreases with a uniform increase in the reserves of minerals that are brought under development. This provides grounds for the establishment of a general law, which states that the maximum efficiency of the exploitation of mineral deposits necessarily decreases over time.

At the same time, until now it has not been clear how the optimum capacity of a mine depends on the degree of investment risk. Should the planned size of a mine be increased or decrease as the probability of mine accidents and disasters increases?

We will examine two possible approaches to solving this problem.

One of the most frequent types of disasters at mines in the Kuznetsk Basin (Kuzbass) is a sudden release of coal and gas. The probability of such outbursts is greatest in shortwalls and stopes. On the average, the probability of one outburst in one face can be determined from a formula that sums the probabilities of non-simultaneous events

\[
P_s = \sum_{i=1}^{N_p(A)} p_i^p + \sum_{i=1}^{N_o(A)} p_i^o = N_p(A) p_s^p + N_o(A) p_s^o,
\]

where \( p_i^p \) and \( p_i^o \) are the probabilities of an outburst in the \( i \)th shortwall and \( i \)th stope, respectively; \( p_s^p \) and \( p_s^o \) are the average probabilities of an outburst in shortwalls and stopes of the mine; \( N_p(A) \) and \( N_o(A) \) are the number of shortwalls and stopes being mined simultaneously, this number depending on the size of the mine. If we consider that \( N_o(A) = A/As \), we can obtain the following formula to calculate the average probability of an outburst in the faces of a mine

\[
P_s = k_s N_o(A) p_s^p + N_o(A) p_s^o = \frac{A}{As} (k_s p_s^p + p_s^o),
\]

where \( k_s \) is the average number of shortwalls per stope; \( As \) is the load on the stope.

Thus, the average probability of a sudden release of coal and gas increases linearly with an increase in the productive capacity of the mine.