MANAGEMENT OF THE QUANTITY AND QUALITY OF THE RESERVES AND RESOURCES OF ORE DEPOSITS

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ABSTRACT. The paper presents methods for the effective management of the quantity and quality of the reserves and resources in the extraction and processing of deposits of ore minerals. Two approaches are proposed to optimise their management over the entire lifetime of the deposits. The first one is based on the methodology for carrying out feasibility study of the resources in ore deposits through the methods of the investment analysis of the annual net cash flows for the conditions of the Republic of Bulgaria.
The second one is based on operational methods for the efficient management of the extraction, processing and metallurgy processes using optimisation models of the indicators: extractable market value in extraction, processing and metallurgy processes; total profit from the extraction and processing of geological reserves for the entire period of extraction of the deposits; net present value of the profits from the mining extraction, mineral processing and metallurgical processes of the geological reserves of the deposits for the same period

Keywords: feasibility study, management of the quantity and quality of the reserves and resources, extracted market value

УПРАВЛЕНИЕ НА КОЛИЧЕСТВОТО И КАЧЕСТВОТО НА ЗАПАСИТЕ И РЕСУРСИТЕ НА НАХОДИЩАТА НА МЕТАЛНИ ПОДЗЕМНИ БОГАТСТВА

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РЕЗЮМЕ. В настоящия доклад са представени методи за ефективно управление на количеството и качеството на запасите и ресурсите при добива и преработката на рудни подземни богатства. Предложени са два подхода за извършване на оптимизация на управлението им за целия срок на експлоатация на находищата. Първият е основан на методиката за извършване на технико-икономическа оценка на запасите и ресурсите на находищата на метални подземни богатства чрез методите на инвестиционния анализ на годишните нетни парични потоци за условията на Р България.
Вторият подход е основан на оперативните методи за ефективно управление на добива, обогатяването и металургичната преработка с приложение на оптимизационни модели на показателите: извлекаема пазарна стойност при добива, обогатяването и металургичната преработка; общ финансов резултат от добива и преработката на геоложките запаси за целия срок на изземване на запасите; нетна осъвременена стойност на доходите от добива, обогатяването и металургичната преработка на геоложките запаси на находището за същия период.

Ключови думи: технико-икономическа оценка, управление на количеството и качеството на запасите и ресурсите, извлекаема пазарна стойност

Introduction

The effective management of the quantity and quality of the reserves and resources in the mining of ore deposits is based on economically substantiated conditions for contouring the reserves. These are based on the effective management of the quantitative and qualitative indicators of mining and processing processes along the entire technological chain beginning from the geological reserves, through the mined ore, to the produced concentrates, and to the final metals.

Under the conditions of strong dynamics of the supply, demand, and prices of metals on commodity exchanges, as well as of the strong dynamics of the development of mining and processing technologies, effective management of mining and processing has the following basic tools:

1. Change of the conditions and reassessment of the reserves and resources of the locality while keeping the mining extraction and mineral processing technologies and main technological indicators;
2. Modification of the technology or optimisation of the technological indicators of the mining and extraction of useful components from the conditional reserves, based on extraction events (decrease of quantitative and qualitative losses) in the mining, the mineral processing, and metallurgy.
3. Simultaneous change of the conditions, change of the technologies, and optimisation of the technological indicators.

The change in the prices of metals on the commodity markets leads to a change in the conditions regarding the quantitative and qualitative indicators of the reserves in the metal deposits. Some of the main condition indicators are the following:

- Cut-off grades and average grades of the content of useful components in geological blocks;
- The content of harmful components that reduce the quality of the extracted ores and of the produced concentrates and raise the price of the processing and metallurgical processes;
- Minimum spatial dimensions of the ore bodies, etc.

Based on these indicators, the geological reserves of the metal deposits are contoured.

The increase in the selling prices of extractable metals on the commodity exchanges increases the contour of reserves to include additional ore blocks with lower average content of useful components and units with smaller spatial dimensions. The lowering of prices of final metals on the commodity exchanges leads to the exclusion of contours of ore stocks with lower quantitative and qualitative indicators and spatial dimensions.

According to the Underground Resources Act, the assessment of the reserves and the resources of the exploited deposits is carried out annually. With a sustained trend of changes in metal stock prices, a reassessment of the reserves and resources of the deposits is required. The reassessment may be based on the existing mining and processing technologies, or on optimised or new technologies with increasing extraction in mining, processing, and metallurgy, and lowered single investment and operational costs. When the expected revenue grows faster than the total cost, the expected economic effect is positive, and in the opposite case it is negative.

According to Velev and Mitov (2013), in the economic assessment of the utilisation of technogenic deposits, it is advisable to take into account the technogenic waste accumulated as a result of the long-term exploitation of ore deposits.

The extremely favourable metals prices on international markets currently provide highly efficient mining of metallic ores and favour investment in: exploration, construction and exploitation of new or expanding old deposits and sections; extraction and processing of poorer-quality ores; replacement of the technologies and equipment for extraction and processing. In other words, invest now to get more, to reduce cost, or both at the same time. The goal is to accumulate earnings to secure your future, even with unfavourable developments in metal price on the commodity markets in future periods.

Effective management of the mining and processing of metal ores can be provided in two ways. The first way is based on a thorough reassessment of reserves and resources of mineral deposits using the methods of investment analysis. This is the only feasible way in case of a substantial modification of the overall design work for mining and processing, in case of changes in the end price of the products, or of the prices of used resources. The second way is based on the use of operational methods of effective management of mining and processing based on the application of optimisation models.

Reassessment of the reserves and resources of deposits of metal ores

Reassessment of the reserves and resources at the stage of operation of the deposits or of separated sections of them is a method of effectively managing the mining works. It requires a feasibility study which includes economic assessment and risk analysis. An example flow chart of the stages of leading a feasibility study of the reserves and resources of the deposits of polymetallic ores, according to Mitev (2005), is presented in Fig. 1.

The method of analogy with existing similar sites (or deposits) is mainly used in developing the geological study of the deposits at the stages of reconnaissance and feasibility study. In this case, the development of partial design variants and the formation of complete design variants, i.e. steps (2) and (3) of the methodology, are skipped.

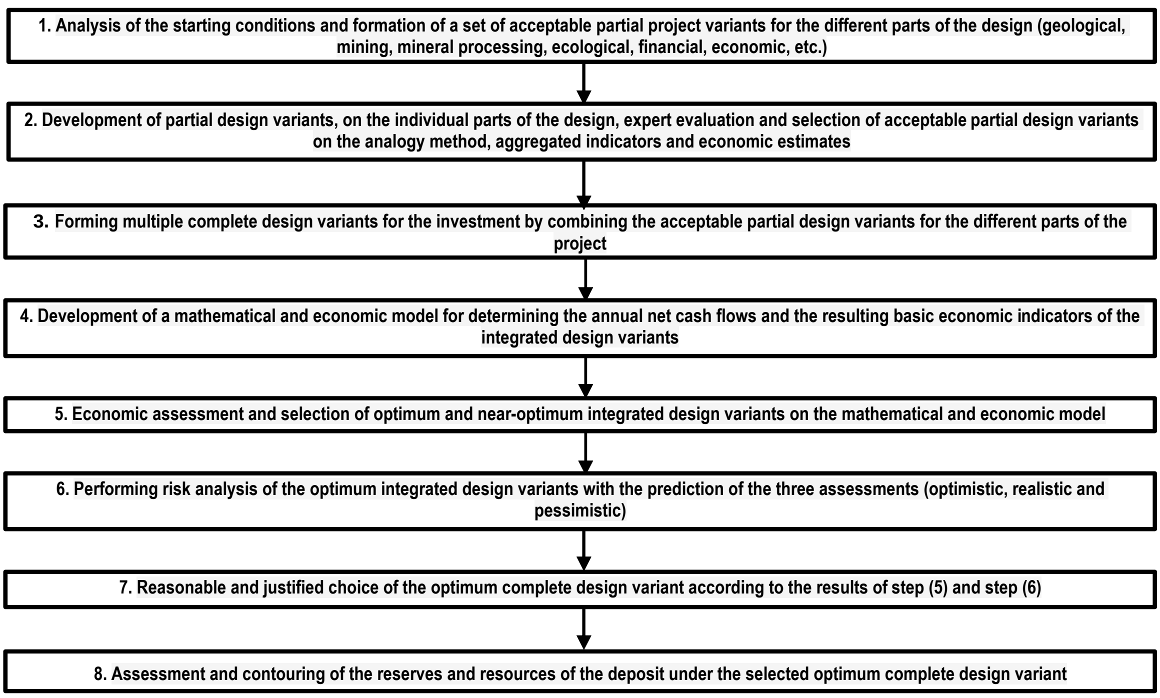

Fig. 1. Flow chart of the methodology for the assessment of the reserves and resources of deposits of metal ores

The feasibility study of the reserves and resource of deposits at the stage of design, construction, operation, liquidation or conservation of mining sites can be done alternatively, i.e. by completing all the steps of the above methodology (to design, assess, and select a leading design variant in conformity with which to perform reserve and resource assessment). Such assessments may also be made based on existing and functioning mining sites without developing and forming different partial and complete design variants. In this case, step (1) of the methodology is limited only to the analysis of the initial conditions, steps (2) and (3) are skipped, and it is passed directly to step (4) and the next steps.

The analysis of the starting conditions is based on a diagnostic analysis of the external and internal environment of the mining investment, i.e. the external and internal factors of mining and the subsequent processing of the reserves. The results of the investment analysis depend directly on the quality of this analysis.

Figure 2 presents the methodology, published by Mitev (2005), for the development of a mathematical and economic model for determining the annual net cash flows and the resulting basic economic indicators of the mining and processing of metallic underground minerals, with the inclusion of inflation (or the cost of the investor's capital) and the investment risk expressed by the discount rate of discounting annual net cash flows as a result of the investment. The figure is made for the conditions of the Republic of Bulgaria. Usually, the so-called minimum acceptable risk rate for the investor company is adopted as the value of the discount rate.

Methods for economic assessment of the reserves and resources of the metal ore deposits

The defined annual net cash flows of the complex project variants are assessed using the main methods of economic assessment of investment projects, namely Net Present Value (NPV) and Internal Rate of Return (IRR), and the additional methods used are Discounted Payback Period (DPBP) and Profitability Index (PI). When the results of these methods are similar, the conclusions regarding the profitability and the return on the project are confirmed. When the results are conflicting, we should apply the practical methods that are most frequently used to find the cause of ~~a~~ conflict between the methods, the so-called “Fischer point”.

An increase in the number of the observed economic and feasibility indicators based on the annual net cash flows brings about an insignificant raise in the timing of the assessment, but the amount and quality of the resulting information available to financial experts increase. This also leads to the possibility of evaluating long-term project variants from different aspects, which enhances the quality of such assessments and provides good reasons for the decisions taken.

When the investor is also the user of the mining and processing output, then the benefits to them, in addition to the expected income from the investment project, will also include the benefits of: gaining independence from suppliers and customers, increasing the assets they manage, vertical and horizontal activity diversification, and others. In other words, these kinds of investors consider the efficiency of the investment project, which is determined on the basis of the change in the efficiency of their total economic activity.

From the point of view of the mining of minerals, efficiency has different priorities for the owner of the mineral resources (the state - the grantor/concedent) and the investor (the concessioner/concessionaire). For the concedent, the efficiency of the exploitation of the deposits is measured in maximizing the extraction of the useful components from the deposit reserves, obtaining the maximum concession fee (royalties) from the concessionaire as a total sum or as a present value, increasing the revenues in the national and local budgets, limiting the import, accomplishing mineral and raw material independence, social impact of the investment for the population in the region, and many other non-monetary benefits. The measurement of the direct economic effect for the grantor is done using the Total Value of Royalties ($TV_{Royalties}$) and the Present Value of Royalties ($PV_{Royalties}$) as of the end of the concession period. According to Mitev (2006), non-monetary benefits to the state from the implementation of investment projects for the extraction and processing of minerals can be assessed through the Benefit - Costs Analysis, which is used for assessing public investment projects.

Sales Quantity x Net Selling Price	= Sales Revenues
- Cash Deductions	- Operating Costs - Transportation Costs - Commercial Cost - Royalties - Administrative and Managerial Costs - Local taxes, Fees - Loan Interests
- Non-Cash Deductions	- Depreciation
	= Profit before Tax (Taxable Income)
- Tax	- Corporation Tax
+ Tax Credits from Government	+ Tax Credits
	= Profit after Tax
- Capital Expenditures	- Investment
+ Non-Cash Deductions made for Tax Purposes	+ Depreciation
+ Cash Deductions made for Tax Purposes	+ Loan Interest
+ Cash proceeds from the residual value of fixed assets	+ Residual value of fixed assets at the end of the investment period
	= **Annual Net Project Cash Flow**

Fig. 2. Methodology for determining the annual net cash flows of the complex design variants for the contouring, mining, and mineral processing of polymetallic ores

Concession contracts recognise and measure the priorities and benefits for both parties. Concession contracts are agreements based on a mutual compromise on priorities and finding a balance in the distribution of project benefits between the grantor and the concessionaire.

The accounting of inflation in the evaluation of reserves and resources is based on its incorporation into the annual net cash flows. This is done through the detailed incorporation of inflation effects into the factors determining cash flows, namely: production prices; resources costs (labour, tangible, intangible) (Oresharski, 1997). Annual net cash flows are discounted at a discount rate, taking into account the investor's cost of capital and the risk for the project using the Risk Discount method.

Risk analysis of the mining investment projects

The high degree of variation in engineering decisions and the low degree of definition of incoming information involves high levels of risk for the mining investment projects. Risk analysis is performed based on a quantitative assessment by experts. This requires the risk to be quantified and included in the discount rate at the stage of the economic assessment and choice of optimum and near-optimum complex project variants based on the of the Risk Discount Factor method. Project variants should be assessed according to the risk-based prognosis of two or more scenarios for the development of the investment project. For this purpose, it is recommended to use the Sensitivity Analysis method or the Monte Carlo Simulation method employing the so-called risk-free discount rate at which the annual net cash flows of the investment project are discounted.

The high variability in the design and operation of mining and processing sites is due to the variety of engineering and management solutions at the stages of exploration, design, construction, operation and liquidation (or conservation) of mining sites. On the other hand, a large part of the input parameters for the assessment of the investment project are defined with varying degrees of definition of the input information; the latter is the result of the following factors:

- Limited geological information on the quantity and quality of the proven reserves on the accepted geological model of the deposit and variance in determining the cut-off grades and the average grades of the useful and harmful components, the minimum sizes of the orebodies subject to mining, and the subsequent contouring of geological reserves;
- Variation in the choice of the overall technology of the development of the deposit - mining methods, opening-out methods, system of reserve preparation, mining technology and equipment, mining transport, water drainage, ventilation, energy supply, etc., and their inherent degree of definition of incoming parameters in the mathematical and economic model for determining the annual net cash flows and the technical and economic assessment of the reserves;
- Variation in the order of mining of the separate sections of the deposit - in terms of minimising the payback period of the investments, maximising the net present value and reducing the risk for the investor;
- Variation for the production programme (annual produce volume), respectively the lifetime of the mine, investment and operating costs in order to maximise the profit and return for the lifetime of the investment;
- Variation regarding the choice of a complete mineral processing technology for the extracted ore - value of the investments; extraction of useful components; extraction of concentrates; content of useful and harmful components in the concentrates; variable and constant costs of the mineral processing process and waste disposal costs and reduction of the harmful effects of the mineral processing on the environmental components;
- Variation in terms of the adopted mining and processing stage - investment up to a certain stage of completion of the final product (ore, concentrate, final metal or products of the final metal);
- Risk in determining the estimated end-product prices over a long period of time (10 to 35 years);
- The risk of changing the prices of the resources used (labour, tangible, intangible, and financial);
- Risk in determining the discount rate - taking into consideration the time factor;
- Risk of changing the innovation, investment, industry, social, environmental, and fiscal policies of the government.

A sensitivity analysis of the assessment aims to quantify the risk with respect to input variables in the mathematical and economic model to determine the annual net cash flows of the investment. Through it, the so-called “Strategic” or “Sensitive” variables are identified that affect the economic indicators for the assessment of investment projects. Starting from the priority of the economic goals, the risk must be assessed primarily in terms of the main and additional economic indicators of a synthetic nature (NPV, IRR, DPBP, PI, $PV_{Royalties}$, etc.). They are set at a discount rate which takes into account the cost of capital of the investor or of the investment, not including the risk component.

All input parameters in the mathematical and economic model for determining the annual net cash flows of the overall design variants cannot be distinctively determined, they are random variables. This requires that they be expertly predicted on the basis of expert assessment, by determining their most probable (expected) values and by defining conditional intervals for their variation. It is advisable to determine their probability distribution within the range of their variation, but this leads to complications in the risk assessment of the projects for the mining and mineral processing of the deposits because of the impossibility to objectively prognosticate their probability distribution within the range of their variation.

Reasonable choice of project variant grounded on the results of the economic assessment and risk analysis

The choice of an overall project variant for mining and mineral processing that will help contour the reserves and resources of the deposit is based on the analysis and rating of the results of the economic assessment and the risk analysis. The values obtained for the monitored economic indicators (NPV, IRR, DPBP, PI, $PV_{Royalties}$, etc.) are ranked in the so-called Payment matrices and the decision-making criteria under the conditions of risk and uncertainty are applied (Velev, 1988). The following criteria are most commonly used and of sufficient information importance:

- Extreme Pessimism (the Wald Criteria) - of the utmost importance for the so-called “Mature industries”, as is the mining industry. The managers in the mining industry are people who are not willing to take high levels of risk;

- The Bayesian Criterion - optimum mathematical expectation for the main economic indicator;
- The Savage Criterion - under the conditions of risk and uncertainty, the option is chosen that is characterised by the lowest risk value (the variance of the economic indicators between the realistic and the pessimistic scenarios).

By decision of the investor, additional criteria may be used for decision-making under the conditions of risk and uncertainty. It is also possible to scale these criteria by placing great value on the individual criteria and obtaining a generalised summary, presented by summary criteria similar to the Belyaev Criterion.

Assessment of reserves and resources of the deposit based on the selected design variant

The assessment of the reserves and resources of the polymetallic ore deposits is based on the selected complete design variant. It will represent the expected most efficient opportunity for mining and processing of the reserves of the estimated deposit in view of the geological and technological information collected, the development of the mining and processing technologies, the expected mining, geological, technological, economic, and market conditions. On this basis, the final contouring of the reserves and resources of the particular deposit is made.

Operational method for the efficient management of the mining and mineral processing with the application of optimisation models

Many operational methods exist that optimise the quantity and quality of mining and mineral processing. This report discusses an operational method for optimising the average content, based on the theory of natural and market value. According to Mitev (2011), for this purpose, the indicator of the recoverable market value of the useful components in the geological reserves during the mining, mineral and metallurgical processing is used. This indicator has the following form:

$$EC_{GR} = \sum_t \sum_i \Pr_{ti} .Q_t^{GR} .\frac{c_{ti}}{100} .\frac{\varepsilon_{t_i}^{mining} .\varepsilon_{t_i}^{proc.} .\varepsilon_{t_i}^{met.}}{10^6} = \sum_t \sum_i \Pr_{ti} M_{t_i}^{GR} .\frac{\varepsilon_{t_i}^{mining} .\varepsilon_{t_i}^{proc.} .\varepsilon_{t_i}^{met.}}{10^6}, USD, \quad (1)$$

where:

$\Pr_{t_i}$ is the average selling price of the i-th metal in the year "t" of the operation of the reserves, USD/t;

c_{t_i} is the average content of the i-th number of metal or non-metal component in the geological reserves, envisaged for mining during the year "t" of the operation, %;

$M_{t_i}^{GR}$ is the quantity of the i-th number of metal or non-metal component in the geological reserves, envisaged for mining during the year "t" of the operation, t;

Q_t^{GR} is the quantity of geological reserves, envisaged for mining during the year "t" of the operation, t;

$\varepsilon_{t_i}^{mining}, \varepsilon_{t_i}^{proc.}$ и $\varepsilon_{t_i}^{met.}$ are respectively the parameters of extraction of the i-th number of metal or non-metal component during mining, during processing, and during metallurgical or other activities during the year "t", %.

When the sum of the estimated annual total costs is deducted from the above indicator, we will obtain the total gross financial result of the exploitation of the geological reserves from the deposit for the entire assessment period. The indicator is then transformed into the following:

$$TP_{GR} = \sum_t \sum_i \Pr_{ti} .Q_t^{GR} .\frac{c_{ti}}{100} .\frac{\varepsilon_{t_i}^{mining} .\varepsilon_{t_i}^{proc.} .\varepsilon_{t_i}^{met.}}{10^6} - \sum_t TC_t - \sum_t In_t = \sum_t \sum_i \Pr_{ti} M_{t_i}^{GR} .\frac{\varepsilon_{t_i}^{mining} .\varepsilon_{t_i}^{proc.} .\varepsilon_{t_i}^{met.}}{10^6} - \sum_t TC_t, USD, \quad (2)$$

where:

TC_t are the estimated annual total costs of mining, mineral processing, and metallurgical or other activities during the year "t"; USD;

In_t are investments in the year "t", USD.

To count the time value of money, we can convert the previous indicator by including the discount factor. In this case, the indicator will have the character of a net present value of the income from the exploitation of geological reserves (NPV_{GR}) and will have the following form:

$$NPV_{GR} = \sum_t \frac{\sum_i \Pr_{ti} .Q_t^{GR} .\frac{c_{ti}}{100} .\frac{\varepsilon_{t_i}^{mining} .\varepsilon_{t_i}^{proc.} .\varepsilon_{t_i}^{met.}}{10^6} - TC_t - In_t}{(1+r)^t} = \sum_t \frac{\sum_i \Pr_{ti} M_{t_i}^{GR} .\frac{\varepsilon_{t_i}^{mining} .\varepsilon_{t_i}^{proc.} .\varepsilon_{t_i}^{met.}}{10^6} - TC_t - In_t}{(1+r)^t}, USD, \quad (3)$$

where: r is the discounted rate of annual cash flows, determined as part of a unit.

As can be seen from the above equations, the expected gross incomes from the mining and mineral processing of ore deposits are directly proportional to the following variables: the expected average annual net prices of the final metals; the annual mining yield; the annual average content of the i-th number of the useful components in ores and the extraction of the individual useful components during the mining, the mineral processing, and the metallurgical activities or other processing in individual years. They also directly determine the total costs and investments necessary to carry out these processes.

If we consider several project variants characterised by variant combinations of the participating magnitudes in the above expressions, we will prefer the one that provides the highest income for the entire lifetime of the deposit. Taking into consideration the time value of the money, we will select the project option that has the highest net present value of the income from the operation and processing of the geological reserves of the deposit, i.e. the optimisation function looks like this:

$$TP_{GR} \rightarrow \max. \; or \; NPV_{GR} \rightarrow \max. \quad (4)$$

Conclusion

The efficiency of mining management is higher when methods of investment analysis are used than through the operational methods of management of the mining and mineral processing. Investment analyses make it possible to completely cover the economic activity of a company or a particular investment project, while operational methods are appropriate for partial optimisation and often cannot assess the aggregate effect on the profitability for the duration of the investment.

The essence of the assessment of reserves and resources in complex ore deposits is in the prediction of annual net cash flows, based on the specifics and uniqueness of the deposits, as well as on the basic engineering and management decisions adopted in the design, construction, exploitation, processing and realisation of the mineral resources.

The main economic indicators (NPV, IRR, DPBP, and PI) provide sufficient information to make a grounded choice of the preferred project options for the investment. This information will be used to assess the reserves and resources of the ore deposit.

Input variables in the mathematical and economic model for the assessment of reserves and resources in ore deposits are dynamic variables, and some of them are subject to optimisation. During partial or complete optimisation of engineering and management decisions, it is necessary to determine the variation in the economic indicators of the project. Thus, the optimisation of a parameter or of a project or management decision can be taken into account, as well as what impact it has on the change in efficiency and profitability of the investment project. It is, therefore, advisable to assess the efficiency of the partial optimisation (optimisation of the individual parts of the project) with the methods of investment analysis.

The economic indicators of the investment analysis performed are strictly specific. The formation of aggregate criteria for choosing an optimum design variant based on the scaling of economic criteria and on the decision-making criteria under the conditions of risk and uncertainty, integrated assessments or other approaches to mining investments is only appropriate when an investor's opportunities and priorities, as well as their attitude to risk, are precisely defined.

Observing the dynamics of the identified "strategic" or "sensitive" variables of the mining investment projects during their economic life is particularly important for their future efficiency and return.

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