Models and algorithms of choice of development technology of deposits when selecting the composition of the backfilling mixture

Ch. Kongar-Syuryun¹, A. Ubysz², V. Faradzhov¹
¹National University of Science and Technology MISIS, Leninsky Av. 4, 119991, Moscow, Russia
²Wroclaw University of Science and Technology, Wyb. Wyspianskiego 27, 50-370 Wroclaw, Poland

*Corresponding author: cheyneshkongarsyuryun@gmail.com

Abstract: The analysis of the applied development systems in the extraction of minerals is carried out. The main problems arising during the development of mineral deposits are formulated. A method is proposed that allows solving the problem of choosing a technology for developing a mineral deposit and selecting a rational composition of a filling mixture for given filling parameters. The structure of the methodology includes fuzzy models and algorithms that ensure the processing of large amounts of information, form the significance of environmental factors (organizational, mining and geological, production, technical and economic indicators), design and technological parameters of the development system and allow to establish the main interdependencies between them, which, in contrast to the existing ones, allow assessing the integral indicators of the project already at the first stages of selecting the composition of the filling mixture. A structural representation of a design solution model for the development of a mineral deposit is formulated, built on the basis of a system analysis and formalization of mining, geological, technological and external conditions of the deposit, which makes it possible to provide a comparative assessment of the integral indicators of projects. The information structure of the project variant is also recommended. To consider the influence of each factor in the algorithm, it is proposed to apply the coefficient of significance of technical and economic performance indicators.

1. Introduction – the scope of the study
The development of society is a natural process of civilization. Moreover, since the middle of the twentieth century, this process has been proceeding at an accelerated pace. This is confirmed by the increase in consumed raw materials against the background of more than doubling the population of the Earth: from 3 billion people in 1960 to 7.7 billion people today. The large consumption of extracted resources predetermines the high rates of development of geotechnology, respectively, the use of safer and more productive technologies for extracting minerals and faster decision-making when choosing a technological solution. Extraction of minerals from the subsoil is a complex multi-stage process involving: the state represented by various regulatory bodies and ministries, private investors or business owners, design, survey, construction and regulatory organizations.
During the development of design solutions, modern information technologies are actively used. At the same time, extraction technologies should be as safe as possible, have a minimum impact on the environment and as cost-effective as possible.

When choosing options for developing deposits and making design decisions, as a rule, the benchmarks are the following criteria: the cost of building a mine; mine construction time; mine service life; economic efficiency. However, the various risks that arise when choosing any technological solution are not taken into account. The complexity of the choice of development methods and systems for the development of mineral deposits, methods for constructing technological schemes, calculating technological cycles and in general everything that is included in the concept of mineral extraction technology creates the need to create models and algorithms when selecting the compositions of the filling mixture. These algorithms will subsequently allow to create a self-learning program. At the initial stage, it is assumed that the created program will select the technology for developing a mineral deposit and create an “ideal” mine design. The designer will rely on the "ideal" production, technical and economic and environmental indicators obtained by the program in calculating his project. Due to the fact that the program is self-learning and accumulates a large amount of database, the program will be able to independently design mines up to the choice of the composition of the filling mixture.

2. Selection of a development system
When choosing the method and systems of mining, only technical and economic indicators of production are considered while the environmental impact is neglected [1]. It is preferred to combine the open-pit mining method with the prevailing underground mining method of stopping with caving. The use of these technologies is connected with ground surface disturbance and lacks environmental safety [2].

In case of using mining systems with natural support of stopping space to ensure ground surface preservation, the problems connected with waste rock dumps and tailings ponds remain unsolved [2–4]. The environmental impact and additional costs of waste management are widely discussed in [5], and the ecological and economic costs of storage and haulage of waste are analysed in [6]. Mining systems with natural support of stopping space are characterized by high losses of mineral reserves— up to 70–75%. Sometimes, as a result of mistakes made during mine operation, or as a result of secondary mining (completion) of abandoned mineral reserves, induced disasters take place in the form of roof falls or flooding in mines (Silvinit and Uralkali mines, Perm Region), water breakthrough from open pit to underground mine (Mir mine, Republic of Sakha, Yakutia) and rock bursts which invoke earthquakes (Umbozero mine, Murmansk Region, etc.) et al. [1-4] and high dynamic and vibration impacts on the buildings of the surface complex, underground workings and hydraulic structures are manifested [7-10].

To exclude the influence of mining on the Earth's ecosystem, it is proposed to begin the development of the mineral resource base of celestial bodies [2,11]. The lack of a regulated legal framework [12] and technologies that allow starting the extraction of minerals from celestial bodies, this idea is not feasible in the near future.

3. System of mining with backfill
Analysing the world experience [1, 13], it can be concluded that about 35% of mines use systems with backfilling of stopping space using when extracting minerals. This is predetermined by the constant increase the depth of mining, complication and constant change in mining and geological conditions, and in addition to everything, an increase in the completeness of extraction of minerals is required [5].

At present, when creating backfill mixtures, the development of fundamentally new materials [14] with a certain structure or properties are being studied, which has a positive effect on the indicators of reliability [15] and safety of mining operations. But at this stage, the simplest and cheapest method are mixtures based on cement binder. At deposits with a high ore value, systems with a cemented backfill based on a cement binder are used, which makes it possible to ensure the maximum completeness of
extraction [1, 13, 14]. One of the main advantages of the system of mining with backfill is reliability and safety [16].

At coal deposits, dry or hydraulic backfilling was used with coarse rock from drilling or specially mined sand. The cemented backfill was used in coal deposits in exceptional cases: when extracting thick, steeply dipping seams; if necessary to reduce endogenous fire hazard; when mining seams under security facilities [13, 16]. Due to the low cost of the extracted raw materials and the high cost of mining operations, the use of backfilling in the development of coal deposits was abandoned.

The use of system of mining with backfill allows:

- manage rock pressure;
- improve the safety of mining operations;
- conduct simultaneous development of the deposits by underground and open pit methods;
- increase the rate of extraction;
- reduce the negative impact of mining on the environment;

In addition, the use of a backfill in the extraction of minerals allows to extract reserves previously considered off-balance or left in pillars. This, in addition to reducing losses and improving the quality of extraction, leads to an increase the life of the mine, which in addition to the economic aspect, solves the social issue in the regions where the mining enterprise is a city-forming [1-5], [13-16].

To create a high-quality filling mass, it is necessary to control the granulometric composition of the inert filler. In order to stabilize the size of the aggregate, equipment has been created that makes it possible to more carefully separate it into fractions [17]. In view of the presence of useful components in mining waste, it is necessary to introduce technologies that allow their additional processing [18], before being included in the filling mixture.

4. Factors of constructive and technological solutions for the development of mineral deposits

The complexity and laboriousness of the process of selecting the backfill parameters and the composition of the backfill mixture does not allow detailed elaboration of several variants and compositions, which does not guarantee an optimal decision. Consequently, there is a need for the development and implementation of a mechanism that makes it possible to quickly perform a comparative assessment of many options from the proposed design and technological solutions. For the procedure of analysing the parameters of the backfill and the composition of the backfill mixture, the concept of "project" was generalized and a general formalized model was created for making a decision [19].

It is necessary to take into account all sufficiently significant technical and economic indicators when creating a method for the integral assessment of design solutions. This is a prerequisite for the widespread use of methodological, algorithmic and mathematical methods in geotechnology, with no bias, made without the subjective opinion of one person or design organization, assessing the quality of the completed project.

The conclusion of the design solution must be highly reliable and objective, which seems to be a very difficult task in terms of expertise of the technological and economic component of this project. All this requires the identification and establishment of relationships between economic, technological and mining-geological summary parameters and characteristics of the compared project with an ideal (reference) project or with operating mining enterprises that have the best performance. This methodology is intended to provide assistance in finding discrepancies from the generally accepted systematic and consistent rules for calculating technological and economic provisions. It is impossible to assess the economic potential and long-term progressive prospects of design solutions without comparing them with ideal (reference) mining enterprises.

There is no need to demand from the compared objects a sufficiently clear similarity of their mining and geological conditions. But at the same time, for a more accurate and detailed disclosure of the true advantages of technical and economic indicators and technological solutions, it is necessary to consider and compare moderately similar mining enterprises.

Based on the assessment of the applied technologies, an analysis was made of the filling parameters and the applied compositions of the filling mixture, as well as the influence of the conditions of
occurrence of ore bodies and development of deposits on the parameters of filling and the composition of the filling mixture.

As a result, 13 parameters (factors) of the conditions of occurrence and development of deposits were identified, which have the greatest impact on the choice of design and technological values, filling parameters and the choice of the filling mixture composition: mining and geological conditions ($U_1$) - fortress of ore ($P_1$), fortress of enclosing rocks ($P_2$), value of ore (percentage of the useful component in ore) ($P_3$), presence of an aquifer ($P_4$), water saturation of soils ($P_5$), average angle fall of the ore body ($P_6$), average thickness of the ore body ($P_7$), reserves of the deposit ($P_8$); underground conditions ($U_2$) - the number of horizons in simultaneous development ($P_9$), the depth of development ($P_{10}$); ground conditions ($U_3$) - the presence of ground structures ($P_{11}$), the presence of a quarry ($P_{12}$), the presence of protected objects ($P_{13}$).

The most important integral indicators of the application of a certain extraction technology are traditionally considered to be the service life of a deposit ($T$) and the cost of extracting a mineral resource ($C$). Recently, in connection with the increased requirements for the environmental component of mineral extraction, the reliability and safety (technological and environmental) of the applied technology ($E$) at a particular deposit is the most important indicator.

The content of the design solution is presented by the structural model of the project in figure 1.

![Figure 1. Structural representation of the project model for the development of mineral deposits.](image)

Thus, each design option ($D$) can be represented as the following information structure:

$$D_t \{ U_{1i}, U_{2i}, U_{3i}, S_i, Z_i, G_i, C_i, T_i, E_i \}$$  \hspace{1cm} (1)  

where: $U_{1i}, U_{2i}, U_{3i}$ – a set of parameter values characterizing a specific technology for the development of mineral deposits; $S_i$ – development system parameters; $Z_i$ – backfill mixture composition; $G_i$ – technology or technologies that form the basis of the applied system; $C_i, T_i, E_i$ - integral indicators of the project: the cost of mining, mine life, reliability and safety of the applied technology [20].
The created models and algorithms will make it possible to develop a software product that makes it possible to select a technology and method for developing a mineral deposit, and subsequently carry out a project for developing a mineral deposit. With such a program, an important task is resolved - an objective assessment of the quality of the completed project [21].

Despite the accurate choice of filling parameters and filling mixture compositions and correctly selected "in theory" technologies for developing mineral deposits, in practice there is a deviation from the design recommendations, which leads to a decrease in the assessment of the reliability of integral indicators of filling. This situation is due to the complex nature of these projects, the presence of complex interrelationships of technological processes with infrastructure facilities, which cannot be fully taken into account without a deep preliminary analysis, as well as the impact during the implementation of the development of mineral deposits of many technogenic and social factors that affect the work schedules and consumed resources. The proposed method for assessing the most important development indicators (mine life, production costs, safety), based on the integration of expert knowledge and factual information about previously implemented projects, is mainly based on building a model of the dependence of integral parameters on the parameters of external conditions, design parameters of the project and the technology used. [22,23].

In the algorithms, it is necessary to express the existing relationships between mining and geological, technical, economic, environmental parameters and the functionality of the project with the "standard" [24].

Inconsistency is a significant difference between the compared technical and economic indicators. An ordinary decision is made in the presence of all technical and economic indicators that are higher or lower than the "standard". Often, some of the indicators exceed the "standard", some are below. In this case, the methodology must present alternative compared groups in a uniform assessment system. The experience, intuition or authoritative opinion of scientists and specialists may not correspond to the real dependencies in the compared project with the "standard". Comparison with the existing mines is impossible, as there is no exact analogy. Consequently, it is difficult to understand which of the factors of the established mining and geological conditions to a greater or lesser extent affects the technical and economic indicators.

Based on the existing theories for solving a complex problem based on the method of multicriteria efficiency, a method of integrative assessment, called the method of total root-mean-square weighted deviations, is proposed [25]. It is also proposed to enter a coefficient of relative importance for each factor. The coefficient of relative importance is needed to increase or decrease the influence of this factor in the algorithm.

5. Discussion of findings
To exclude the subordination of the range-point value judgment, it is necessary to calculate the reliable values of the coefficients of significance of technical and economic performance indicators. They can be used with reference to the unequal relative importance of the conditional value of deviations for the most appropriate solution of an extremely important task: selection of the most effective design solution.

Consequently, the probabilistic discrepancies of design solutions with the indicators of "standard" acquire mutually distinctive weight, significance and usefulness. Significance coefficients of technical and economic performance indicators are calculated once, and the obtained values can be used for a rather long time, until the moment: changes in the evaluation criteria; new technological changes in geotechnology, and as a consequence, to the replenishment and acquisition of new knowledge and experience by experts.

6. Conclusion
The use of the developed methodology and algorithms will make it possible to create a software product that, at the initial stages, will be able to provide significant assistance in the design, and subsequently, it may be able to independently carry out the design of mining enterprises.
The implemented software tool, which will make a comparative assessment of the integral indicators of the filling parameters and the composition of the mixture, will allow already at the initial stages of the selection of the composition of the filling mixture to evaluate and select the variant that improves the efficiency and safety of the development of a mineral deposit.

References
[1] Khayrutdinov M M 2007 Gornyi Zhurnal 11 pp 40-43 [In Russ]
[2] Khayrutdinov A M and Tyulyaeva Yu V 2019 Problems of subsoil development in the 21st century through the eyes of young people: materials of the 14th International Scientific School of Young Scientists and Specialists, Moscow, October 28 – November 1 2019 pp 280-283
[3] Ivannikov A L, Kongar-Syuryun C, Rybak J, Tyulyaeva Yu V 2019 IOP Conf. Ser.: Earth Environ. Sci. 362 012130
[4] Tyulyaeva Y S and Khayrutdinov A M 2019 Problems of subsoil development in the 21st century through the eyes of young people: materials of the 14th International Scientific School of Young Scientists and Specialists Moscow, October 28 – November 1 2019 pp 283-286
[5] Khayrutdinov M M 2009 Gornyi Zhurnal 2 pp 64-66 [In Russ]
[6] Pashkevich M A, Petrova T A, Moiseeva K A 2008 Mining Information and Analytical Bulletin 83 pp 302-306 [In Russ]
[7] Wyjadłowski M 2017 Studia Geotechnica et Mechanica 39(4) pp 121-129
[8] Herbut A, Khairutdinov M M, Kongar-Syuryun C, Rybak J 2019 IOP Conf. Ser.: Earth Environ. Sci. 362 012131
[9] Dobrzynski P, Kongar-Syuryun C, Khairutdinov A 2019 Journal of Physics: Conf. Ser. 1425 012202
[10] Lohunova O and Wyjadłowski M 2018 MATEC Web of Conf. 151 03063
[11] Khayrutdinov M M, Kongar-Syuryun C, Tyulyaeva Yu, Khayrutdinov A M 2020 Russian Mining Industry 3 pp 113-120
[12] Gugunskiy D, Chernykh I, Khairutdinov A 2020 Artificial Intelligence: Anthropogenic Nature vs. Social Origin 1100 pp 657-664
[13] Khayrutdinov M M and Shaimerdyanov E K 2009 Mining Information and Analytical Bulletin 1 pp 240-250
[14] Khayrutdinov M M and Votyakov M V 2007 Mining Information and Analytical Bulletin 10 pp 220-222 [In Russ]
[15] Kongar-Syuryun C, Tyulyaeva Yu, Khairutdinov A, Kowalik T 2020 IOP Conf. Ser.: Mat. Sci. Eng. 869 032004
[16] Vasyuchkov Yu F and Mel'nik V V 2016 Industrial Safety 8 pp 51-54 [In Russ]
[17] Gorbatyuk S M, Zarapin A Y, Chichenev N A 2018 Mining Informational and Analytical Bulletin 1 pp 143-149
[18] Eronko S P, Gorbatyuk S M, Oshovskaya E V, Starodubtsev B I 2018 IOP Conf. Ser.: Mat. Sci. Eng. 287(1) 012004