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Optimizing the contours of open pit mining with the use of mining and geological information systems and technologies

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ABSTRACT
This article studies optimization of open pit mining using mining and geological information systems and technologies. The aim of the study is to develop an algorithm of optimizing the contour of an open pit using a mining and geological information system. The Lerch-Grossman algorithm has been applied using the Whittle program. Justification for changing the contour of an open pit based on the opening scheme, geometric characteristics and special technical and economic parameters of the blocks has been proposed. This proposal provides increasing the production efficiency and reducing capital and operating costs during the development of the deposit. The authors have come to the conclusion that the functionality of updated mining and geological information systems helps to take into account market conditions when designing the main parameters of an open pit and to make the right decision at the stage of preparing a deposit for development and while optimizing the existing open pit contour.
Keywords: open pit mining, iron ore, mining efficiency, open pit contour, mining operations, information technology, geotechnologies

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Introduction

With the development and improvement of information and computing equipment in the twentieth century, innovative technologies gradually began to be introduced into mining. Today, the largest part of narrow information technologies is used for certain enlarged areas: as mining and geological information systems (hereinafter MGIS), information resource bases, dispatch systems, etc [[1], [2]]. The advantages of informatization of the methods and tools used at a modern mining enterprise are obvious:

- accelerating the processes due to automation of routine operations;

- improving safety and control over mining operations;

- improving the accuracy of calculations in terms of estimating reserves, forecast and completed scope of work, establishing the boundaries of dangerous zones;

- optimizing business processes of a mining enterprise with increasing the economic efficiency [3].

The effectiveness of the open pit mining of a particular deposit depends on the decision made by the engineer at the open pit design stage. Here an important point establishing the contours of the operational excavation. Various indicators affect the boundaries of a pit, from the life of the mine and the productivity of the pit itself, to the economic parameters, including profitability of the project and return on direct investment [4]. A positive effect is achieved with involving balance reserves in the development and decreasing the volume of overburden.

Initially, optimization measures to identify open pit contours were carried out using highly specialized programs that helped establishing the parameters of the optimal excavation contour. With improving the existing deposit modeling technologies and design automation, the process of determining the boundaries of the open pit was supplemented by the use of a set of software. As a result, separate programs have been developed for planning mining operations and designing optimal pit boundaries.

Such programs have become the basis for the development and testing of mining and geological information systems focused on solving problems in terms of optimization and design measures [5, p. 81], as well as planning and comprehensively supporting all the mining cycles [6, p. 46].

Due to the volatility of overburden and minerals, the optimal contour of deep pits used for haulage berms changes periodically. This hypothesis is confirmed by such researchers of ore deposits, such as E. Appianing and D. Mireku-Gyimah, who substantiated that increasing the volume of overburden in the final contour by 16 % entailed decreasing the mass fraction of ore by 20 % depending on the contour. The result is a 26 % reduction in profits [[7], [8]].

Researchers have paid much attention to the issue of eliminating this shortcoming in mining planning. Thus, a number of researchers [[9], [10], [11], [12], [13]] believe that when optimizing, it is important to take into account the opening scheme, to introduce changes in the slope angle of the open-pit wall with haulage berms placed on it, into the calculations. Such a solution will make it possible to model the optimal open pit with its corners in accordance with the design contour. It should be noted that this technique has a number of disadvantages:

1. Minimizing the depth of the design contour. As a result, the obtained estimate will be 7-20 % lower than that of the contour modeled without taking into account the slope angle of the pit wall.

2. Absence of rationale for the optimality of the selected solution. The trajectory of the opening workings, that is, the places where the sites will be located in the future is not taken into account.

From the point of view of the scientific substantiation of the project's effectiveness, it should be taken into account that a high level of its implementation is assigned if there is a discrepancy between the values of the optimal and final contour of the deposit of no more than 10 % [14, p. 39].

In practice, the situation looks somewhat different. The design engineer seeks to find a compromise between leaving a part of the mineral reserves and cutting in additional volumes of overburden.

Optimization information systems allow calculating quickly and easily the optimal contours of an open pit. The economic justification for the use of MGIS is caused by the minimization of labor costs and identification of the open pit boundaries with maximum efficiency. The universality of this approach is characterized by the ability to take into account the time component when discounting cash flows using the software. All the tools meet the requirements of the present-day economy and can be used for a comprehensive assessment of the project investment attractiveness [[15], [16], [17]].

As part of the use of this software product, high accuracy and reliability of models are ensured, which allows considering the calculated volume values as universal parameters for the statistical analysis of the obtained mathematical models [18].

Methods

Block models of deposits form the basis of innovative programs with optimization tools for establishing the boundaries of an open pit [[19], [20]]. To form their layout, the entire area is divided into specific blocks, the size of which depends on many factors: geometric characteristics of the ore body, dispersion of qualitative values in the contours of the mineralization area, the ledge predicted height, special parameters of the exploration system, the mining unit used. For each block, its own economically justified estimate is calculated.

Thus, the economic performance of a particular block is determined by subtracting from the income received from the sale of minerals in this sector all the costs of extraction and dressing. This formula also takes into account the volumetric characteristics of a particular block, the physical and mechanical components of the rock, the volume of the useful component, the percentage of loss during production, and others. The economic assessment can take both positive and negative values, which are determined by the content of the useful component and the amount of overburden in the block.

In the classic version, the formula for calculating the economic valuation is the difference between non-operating income and total production costs until the end product is received. To calculate such costs (Rj), the following formula is used:

$$Rj = \sum_{i=1}^{i} Wi * ki * (Zi + (1 - Qi) * Pi * (Ri + Z^0_i)), \quad (1)$$

where Zi is the total costs for the extraction of the i-material in the block (characterized by variability for different types of ores and host rocks);

Ri is the total costs for mining and processing of the i-material;

ki is the specific weight of the i-material;

Pi is diluting the material of the i-th type;

Qi is losses of the i-type material in the course of the block mining;

Wi is the material volume in the block;

Z^0_i is the cost for processing the material of the specific i-th type.

The formula can be upgraded by adding additional variables to account for costs, such as logistics costs, the sale of a useful component, and production tax.

In addition to the above factors, updated software products can take into account other parameters, including mining conditions, restrictions, and additional features for calculating the most accurate results.

In the course of optimization measures, it is necessary to take into account the general slope angle of the pit wall reflecting or not reflecting the ramps in the pit. Software packages are endowed with wide functionality that allows setting different values for different areas both in-depth and in the plan, for example, local zones with different slope angles can be effectively distinguished using wireframe models of lithological differences or coordinates of this area. The use of such methods is justified by taking into account the geomechanical and hydrogeological conditions of mining operations.

Additional functionality of the MGIS is to assess the sensitivity of the investment project to changes in cost parameters, such as prices for mineral resources and their forecast. This goal is achieved by applying a yield adjustment factor. This indicator should be multiplied by the price of each useful component that is set during optimization. For forecasting, a range of coefficient values and an increment step for performing calculations are determined.

It is also possible to set limiters to include or conversely exclude specific areas from optimization. So, if there are industrial and administrative buildings on the surface, as well as mining facilities, these areas can be removed from the calculation of the optimal contour of the pit. There also can be set boundaries of the allotment to form the optimal pit shell.

The calculated optimal contour is the surface reflecting the outer boundaries of the blocks in each section. Despite the fact that the general angles of the pit walls are taken into account in their formation, the slope angle on each ledge is not taken into account. To identify the general angle, there is practiced introducing additional blocks in the corresponding area.

The proposed algorithm for forming the contour of a pit includes a number of successive stages:

1. Identifying the optimal open pit shell using a block model of deposit design. The result is a digital model of the open pit surface and the establishment of economic estimates for each block by analyzing the technical and economic characteristics. To improve the position of the trench route, both the optimal contour of the pit and the block model are used simultaneously.

2. Pit tracing is carried out taking into account the specified coordinates (beginning and exit to the daylight surface) of the opening workings. When calculating, many factors are taken into account: the direction of the cargo flow, the productivity, the presence of mining facilities on the surface, the terrain, and others. Then, the optimal location of the opening workings in relation to the contour of the quarry is revealed.

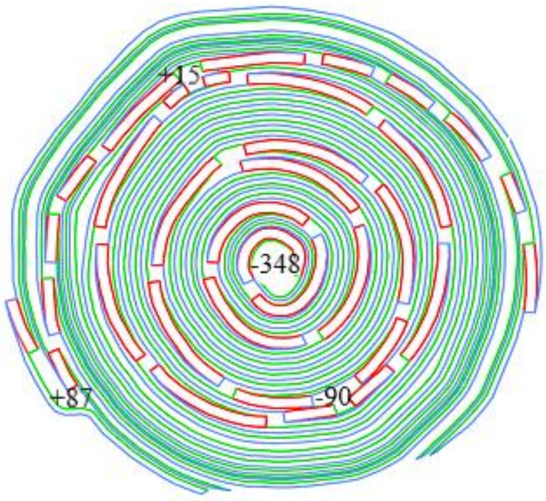
3. Modeling the final contour of the site with a system of opening workings. To display the ledge edge line on horizontal plans, the economic estimates of the model blocks and their sizes, as well as the established boundaries within the optimal open-pit shell are taken into account. In this situation, the key design goal is to obtain the maximum economic evaluation of the blocks included in the block model within the final contour of the open pit.

Results

Figure 1 shows the optimal contour of the open pit of the Benkala iron ore deposit obtained as part of the design using information systems based on the optimal shell and the concept of substantiating the final contours. As part of the design, the Whittle MGIS has been used (Figure 1).

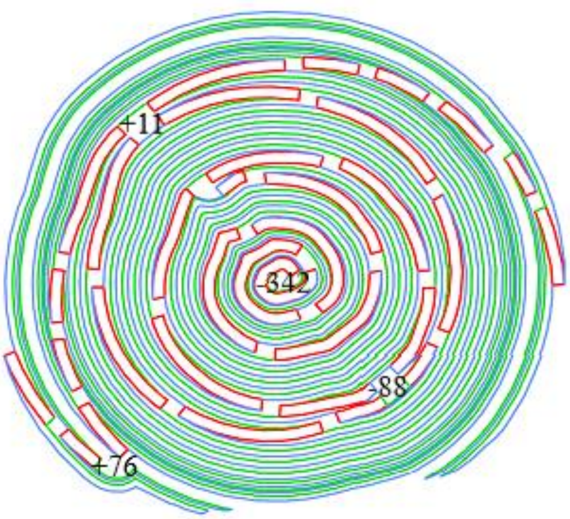
The ledge crest lines have been made using the developed technique based on the optimal pit contour. To do this, the starting point of the route has been set and the position of the opening workings has been optimized with further calculations of the value of the blocks involved in the construction of this trajectory. As a result, the track moved to the surface due to the variability of the pit horizons at the endpoint of the exit. Despite ensuring the track structure's safety, the entry point to the lower horizon had to be moved. This is a forced measure to preserve the designed exit points from the open pit. These measures made it possible to reduce the depth of the contour by 6 meters compared to the initial data.

a)



a) the open pit contour option from Benkala

b)



b) the open pit contour from the authors

Figure 1 – Modeling the contour of the open pit at the Benkala deposit

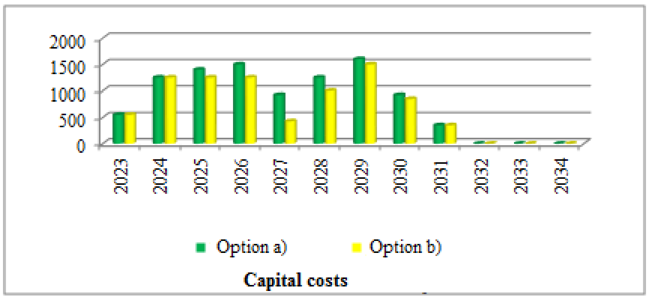
Discussion of results

The comparative analysis according to the parameters of the design contour of option a), presented by Benkala, and option b) modeled by the authors showed decreasing the volume of overburden by 9.59 %, and the volume of ore by 4.01 %. The average content of the useful component increased by 0.7 %. It should be noted that characteristics of the general angle of the open pit remained unchanged, and its final depth became less by 6 meters, which is also a positive characteristic.

Decreasing the overburden and ore volumes relative to option a) caused reducing the deposit mining period by 6 months. In general, decreasing the volume of overburden led to decreasing the volume of related work after reaching the design capacity, which made it possible to reduce the vehicle fleet for mining the deposit.

Figure 2 shows the comparative cost analysis for both options.

a)



b)

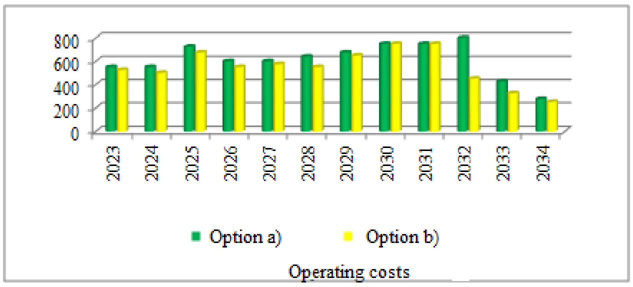


Figure 2 – Costs for the deposit development by the options of the open pit contours, mln.tg.

The reduction of the rock mass in the developed open pit and the distribution of the released volumes made it possible to reduce the company's vehicle fleet by 3 vehicles. This optimization measure led to reducing the capital costs in the authors' option b) compared to the Benkala option a).

There is an observed slight decreasing the volume of operating costs after the field reaches its design capacity. As a result, the volumes of rock mass were redistributed over the years. During the pit completion period, which should take place in 2032-2034, there is predicted the maximum difference between the operating costs of the two options for the pit contours (the peak falls in 2032).

The investment attractiveness of the proposed option is evidenced by the indicators of net discounted income (+7.48 % compared to the Benkala option), net profit (+1.81 %), and internal rate of return (+4.81 %).

Conclusions

The results of technical and economic calculations allow drawing the following conclusions:

1. When using the pit contour option proposed by the authors, the investment attractiveness of the project increases, it is evidenced by higher rates of the net present value.

2. Current financial ratios and indicators are higher for the proposed option, which also ensures stable resistance to possible risks.

The results obtained and the economic justification allows stating that the proposed method using the Whittle MGIS is effective for the development of iron ore deposits with deep open pits.

Mining and geological information systems based on optimization tools for determining the contour of an open pit are actively used by mining enterprises in designing the work for reconstructing and open pit mining. In the absence of techniques for optimizing the boundaries of open pits, the gross profit from the extraction of rocks is reduced.

The developed method of identifying open pit boundaries takes into account the opening scheme and allows designing the contour in advance, which is especially important for maintaining high technical and economic indicators of the mining enterprise.

Conflict of interest. On behalf of all authors, the corresponding author declares that there is no conflict of interest.

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Тау-кен-геологиялық ақпараттық жүйелер мен технологиялардың көмегімен ашық тау-кен жұмыстарының контурларын оңтайландыру

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ТҮЙІНДЕМЕ
Бұл мақалада тау-кен-геологиялық ақпараттық жүйелер мен технологиялардың көмегімен ашық тау-кен жұмыстарын оңтайландыру зерттелді. Зерттеудің мақсаты – тау-кен геологиялық ақпараттық жүйесін қолдана отырып, карьер контурын оңтайландыру алгоритмін жасау. Whittle бағдарламасының көмегімен Лерч-Гроссман алгоритмі қолданылды. Карьер контурын ашу схемасына, геометриялық сипаттамаларға және блоктардың арнайы техникалық-экономикалық параметрлеріне сүйене отырып өзгерту негіздемесі ұсынылған. Бұл ұсыныс кен орнын игеру кезінде өндіру тиімділігін арттырады және күрделі және пайдалану шығындарын қысқартады. Авторлар, қазіргі заманғы ТКГАЖ функционалдығы карьердің негізгі параметрлерін жобалау кезінде нарықтық жағдайларды ескеруге және кен орнын игеруге дайындау кезеңінде және қолданыстағы карьер контурын оңтайландыру кезінде дұрыс шешім қабылдауға көмектеседі деген қорытындыға келді.

Түйін сөздер: ашық тау-кен өндірісі, темір кені, өндіру тиімділігі, карьер контуры, тау-кен жұмыстары, ақпараттық технологиялар, геотехнологиялар.

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Оптимизация контуров открытых горных работ с помощью горно-геологических информационных систем, технологий

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АННОТАЦИЯ
В настоящей статье исследуется оптимизация открытых горных работ с помощью горно-геологических информационных систем и технологий. Целью исследования является разработка алгоритма оптимизации контура карьера с помощью горно-геологической информационной системы. Применен алгоритм Лерча-Гроссмана с помощью программы Whittle. Предложено обоснование изменения контура карьера исходя из схемы вскрытия, геометрических характеристик и специальных технико-экономических параметров блоков. Данное предложение обеспечивает повышение эффективности добычи и сокращение капитальных и эксплуатационных затрат при отработке месторождения. Авторы пришли к выводу, что функционал современных ГГИС помогает учитывать рыночные условия при проектировании основных параметров карьера и принять правильное решение на этапе подготовке месторождения к разработке и при и оптимизации имеющегося контура карьера.

Ключевые слова: открытая добыча, железная руда, эффективность добычи, контур карьера, горные работы, информационные технологии, геотехнологии.

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