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METHODOLOGICAL SUPPORT FOR ASSESSING THE IMPACT OF DRILLING AND BLASTING ON THE EFFECTIVENESS OF OPERATION OF THE MINING TRANSPORT COMPLEX OF THE BAKYRCHI MINING ENTERPRISE

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This article presents the results of a comprehensive scientific and technical research and technical and technological audit. The main goal of the study was to develop software and methodological support and analytical approaches to determine the nature of the dependence of the efficiency of operation of geotechnological complexes of quarries on the quality of preparation of rocks for excavation using drilling and blasting operations.

The research was based on the use of digital analogues, based on the method of simulation logical-statistical and object-oriented modeling. This approach made it possible to consider the events of the mining transport process operationally, taking into account the mining technical, mining-geological, mining-geometric, organizational and economic operating conditions.

As part of the study, an analysis of the existing software and methodological base was carried out and a technical, technological and energy audit of the efficiency of the geotechnological complex was carried out. Particular attention was paid to identifying promising areas and potential for increasing the efficiency of the complex, as well as analyzing energy consumption for individual machines and sections of intra-quarry roads. The study also included an assessment of the degree of congestion of intra-quarry roads and the development of proposals for improving their quality of coverage.

The article presents innovative approaches and methods that allow a deeper understanding and optimization of processes in geotechnological complexes, which is of great practical importance for the development of the mining industry.

Keywords: Geotechnological complexes, drilling and blasting operations, simulation modeling, technical and technological audit, mining transport processes, energy efficiency, optimization of mining activities, analysis of technical and economic indicators, logical and statistical modeling, increasing the efficiency of mining operations.

БАҚЫРШЫ ТӨК-КӨЛІК КЕШЕНІНІҢ ТАУ-КӨЛІК КЕШЕНІНІҢ ПАЙДАЛАНУ ТИІМДІЛІГІНЕ БҰРҒЫРУ ЖӘНЕ ЖАРЫЛУ ЖАСАУЛАРЫНЫҢ ӘСЕРІН БАҒАЛАУ БОЙЫНША ӘДІСТЕМЕЛІК ҚАМТАМАСЫЗ

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Бұл мақалада кешенді ғылыми-техникалық зерттеулер мен техникалық және технологиялық аудиттің нәтижелері берілген. Зерттеудің негізгі мақсаты бұрғылау-жару жұмыстарын қолдана отырып, тау жыныстарын қазуға дайындау сапасына карьерлердің геотехнологиялық кешендерін пайдалану тиімділігінің тәуелділігінің сипатын анықтау үшін бағдарламалық-әдістемелік қамтамасыз ету және аналитикалық тәсілдерді әзірлеу болды.

Зерттеу логикалық-статистикалық және объектілі-бағытталған модельдеудің имитациялық әдісіне негізделген цифрлық аналогтарды қолдануға негізделген. Бұл тәсіл тау-кен техникалық, тау-кен-

геологиялық, тау-кен-геометриялық, ұйымдық-экономикалық пайдалану жағдайларын ескере отырып, тау-кен тасымалдау процесінің оқиғаларын оперативті түрде қарастыруға мүмкіндік берді.

Зерттеу шеңберінде қолданыстағы бағдарламалық-әдістемелік базаға талдау жүргізілді және геотехнологиялық кешеннің тиімділігіне техникалық, технологиялық және энергетикалық аудит жүргізілді. Кешеннің тиімділігін арттырудың перспективалық бағыттары мен әлеуетін анықтауға, сондай-ақ жеке машиналар мен карьерішілік жол учаскелерінің энергия тұтынуын талдауға ерекше назар аударылды. Сондай-ақ зерттеу барысында карьерішілік жолдардың кептелу дәрежесін бағалау және олардың қамту сапасын арттыру бойынша ұсыныстар әзірлеу қамтылды.

Мақалада тау-кен өнеркәсібін дамыту үшін үлкен практикалық маңызы бар геотехнологиялық кешендердегі процестерді тереңірек түсінуге және оңтайландыруға мүмкіндік беретін инновациялық тәсілдер мен әдістер ұсынылған.

Түйін сөздер: Геотехнологиялық кешендер, бұрғылау-жару жұмыстары, имитациялық модельдеу, техникалық және технологиялық аудит, тау-кен көлік процестері, энергия тиімділігі, тау-кен жұмыстарын оңтайландыру, техникалық-экономикалық көрсеткіштерді талдау, логикалық және статистикалық модельдеу, тау-кен жұмыстарының тиімділігін арттыру.

МЕТОДИЧЕСКОЕ ОБЕСПЕЧЕНИЕ ОЦЕНКИ ВЛИЯНИЯ БУРОВЗРЫВНЫХ РАБОТ НА ЭФФЕКТИВНОСТЬ ФУНКЦИОНИРОВАНИЯ ГОРНОТРАНСПОРТНОГО КОМПЛЕКСА БАКЫРЧИНСКОГО ГОРНОГО ПРЕДПРИЯТИЯ

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В данной статье представлены результаты комплексного научно-технического исследования и технико-технологического аудита. Основная цель исследования заключалась в разработке программно-методического обеспечения и подходов к аналитике для определения характера зависимости эффективности работы геотехнологических комплексов карьеров от качества подготовки горных пород к выемке с использованием буровзрывных работ.

Исследования базировались на применении цифровых аналогов, опирающихся на метод имитационного логико-статистического и объектно-ориентированного моделирования. Данный подход позволил пооперационно рассматривать события горнотранспортного процесса, учитывая горнотехнические, горно-геологические, горно-геометрические, организационные и экономические условия функционирования.

В рамках исследования был осуществлен анализ существующей программно-методической базы и проведен технико-технологический и энерго-аудит эффективности функционирования геотехнологического комплекса. Особое внимание уделялось выявлению перспективных направлений и потенциала для повышения эффективности работы комплекса, а также анализу энергорасхода по отдельным машинам и участкам внутрикарьерных автодорог. Исследование также включало оценку степени загрузки внутрикарьерных дорог и разработку предложений по улучшению их качества покрытия.

В статье представлены новаторские подходы и методы, позволяющие глубже понять и оптимизировать процессы в геотехнологических комплексах, что имеет важное практическое значение для развития горнодобывающей отрасли.

Ключевые слова: Геотехнологические комплексы, буровзрывные работы, имитационное моделирование, технико-технологический аудит, горнотранспортные процессы, энергоэффективность,

оптимизация горнодобывающей деятельности, анализ технико-экономических показателей, логико-статистическое моделирование, повышение эффективности горных работ.

Introduction. In the modern mining industry, the importance of effective management and optimization of mining and transport processes is a key aspect for increasing productivity and reducing costs. In this context, drilling and blasting operations play a significant role in the preparation of rocks for extraction, directly affecting the overall efficiency of quarry geotechnological complexes. As part of this study, carried out by Qazaqstan Smart Technology LLP, in-depth analytics was carried out to develop advanced software and methodological solutions aimed at improving and optimizing these processes. The main objective of the study was to develop and test innovative approaches to analytics that allow for a detailed assessment of the relationship between the quality of rock preparation for extraction and the overall efficiency of geotechnological complexes. A special feature of this study was the use of modern methods of simulating logical-statistical and object-oriented modeling, which made it possible to conduct a comprehensive analysis of the mining and transport process taking into account many factors - mining engineering, mining and geological, mining and geometric, as well as organizational and economic. Additionally, the study included technical, technological and energy audits aimed at analyzing the current state and identifying potential areas for improving the efficiency of geotechnological complexes. These measures were implemented to not only improve operational characteristics, but also to reduce the cost of mining and transport operations.

The article covers complex aspects of the study, from an overview of the current state of geotechnological complexes to proposals for improving and optimizing processes. It represents a valuable contribution to the mining industry, offering new approaches and solutions to improve overall efficiency and reduce environmental impact.

Intervention in mining processes requires a deep understanding of both technological and economic aspects. Given the rapid changes in the global economy and increased demands on the sustainability of industrial enterprises, effective management of production processes is becoming a key success factor. In this context, optimization of loss and dilution management systems is a priority for mines.

One of the important aspects of optimization is the implementation of advanced technologies aimed at precise measurement and control of the content of useful components in ore. The use of modern analytical methods and automated data processing systems allows enterprises to significantly reduce losses and improve the accuracy of extraction.

The next important area of optimization is the development and implementation of a monitoring and control system based on the principles of artificial intelligence (AI) and machine learning (ML). These technologies are capable of analyzing data in real time, predicting possible losses and automatically adjusting production processes to maximize the extraction of useful components [1].

Attention should also be paid to the development of more effective resource management strategies aimed at reducing costs and optimizing the dilution of useful components, which may include the implementation of circular resource use models, waste recycling and improved planning of production cycles.

Solving the problem of optimizing loss and dilution management systems at a mine requires an integrated approach, including technological innovations, the implementation of modern data analysis methods, and the development of effective resource management strategies. This approach not only helps to increase mine productivity, but also ensures the sustainability of enterprises in a dynamically changing market and economic environment.

The economic approach to optimizing the loss and dilution management system at a mine is based on strategies aimed at maximizing the efficiency of resource use and increasing the profitability of p

roduction. The approach includes a number of key aspects (Table 1):

Table 1 - Key aspects of optimizing the loss and dilution management system at a mine

№	Key aspects of optimization	Description
1	Cost analysis at each stage of production to identify bottlenecks and opportunities for cost reduction. Implementation of effective cost management methods.	Cost analysis at each stage of production to identify bottlenecks and opportunities for cost reduction. Implementation of effective cost management methods.
2	Implementation of modern technologies and equipment for precise control and measurement of the content of useful components in ore. Automation of production processes using artificial intelligence and machine learning systems.	Implementation of modern technologies and equipment for precise control and measurement of the content of useful components in ore. Automation of production processes using artificial intelligence and machine learning systems.
3	Creation of a monitoring system that analyzes data on ore quality, losses and dilution of useful components in real time. Use of analytical tools to identify trends and make decisions.	Creation of a monitoring system that analyzes data on ore quality, losses and dilution of useful components in real time. Use of analytical tools to identify trends and make decisions.
4	Development and implementation of resource management strategies aimed at optimizing the use of material and energy resources. Minimization of waste and reuse of resources.	Development and implementation of resource management strategies aimed at optimizing the use of material and energy resources. Minimization of waste and reuse of resources.
5	Conducting economic assessments of each project taking into account investments, costs, potential profit and efficiency. Implementation of projects with the highest economic efficiency.	Conducting economic assessments of each project taking into account investments, costs, potential profit and efficiency. Implementation of projects with the highest economic efficiency.
6	Training personnel in modern management methods and technologies to improve professional competence and labor efficiency.	Training personnel in modern management methods and technologies to improve professional competence and labor efficiency.
Note: compiled by the authors based on the source [2]		

The economic approach to optimizing the management system in the mining industry is aimed at creating sustainable and competitive enterprises that are able to adapt to changes in market conditions and ensure maximum profitability while minimizing risks.

Literature review. The idea of integrating processes from mining to beneficiation in the mining industry is widely discussed. The ”Mine to Mill” concept emphasizes the relationship between the mining and beneficiation stages, which allows for the optimization of production processes. Authors such as **McCoy J.T. & Auret L.** [3] actively research and implement integrated strategies to maximize production efficiency. Theoretical aspects of cost optimization in the mining industry are actively discussed. Researchers pay attention to various methods such as linear programming and stochastic programming methods for optimizing cost parameters at various stages of the production process. Analysis of the effectiveness of these methods helps to solve problems with

minimizing costs while maintaining high quality of production [4].

Theoretical models and research in the field of accurate measurement and control of ore quality highlight the importance of using modern technologies such as sensorics and data processing to ensure high accuracy in measuring the composition and quality of useful components. These studies help develop effective strategies for raw material quality management. Theoretical models based on artificial intelligence (AI) methods such as machine learning and neural networks are actively considered for predicting and optimizing production processes. Researchers aim to create systems that can adapt to changes in mining conditions and provide accurate forecasts.

Theoretical foundations of management strategies ”Mine to Mill” is a strategic approach that aims to optimize the relationship and interaction between the stages of ore extraction and beneficiation. This concept goes beyond the traditional separation of mining operations and aims to create a unified and harmonious management system to maximize the yield of useful components.

Integration begins with the optimization of the physical characteristics of the ore, starting from its extraction, which includes the analysis of various parameters such as granulometry, hardness and flowability to better understand the characteristics of the raw material entering the beneficiation.

One of the key aspects is to improve the interaction between geologists, miners and beneficiation specialists. An integrated approach allows the exchange of data and experience between different disciplines, which contributes to a better understanding of the ore potential and its optimal processing. The ”Mine to Mill” concept is also aimed at optimizing the technological parameters of enrichment taking into account the characteristics of the raw material. This concept includes the selection of optimal methods of crushing, sorting and enrichment that are most effective for a specific ore composition. The main aspects of the ”Mine to Mill” concept are presented in Table 2.

Table 2 - Main aspects of the ”Mine to Mill” concept

№	Aspect	Description
1	Integration of mining and enrichment processes	The Mine to Mill concept emphasizes the interrelationship between the mining and beneficiation stages to optimize production processes.
2	Enrichment process parameters	Includes the selection of optimal methods for crushing, sorting and beneficiation of ore, taking into account its characteristics.
3	Integrated process monitoring	Provides continuous monitoring of product quality at each stage and a quick response to changes in ore composition.
4	Application of mathematical models	Allows for scenario analysis and selection of optimal parameters for each stage, taking into account technical and economic aspects.
5	Staff training	Extends integration to the level of personnel training to improve their understanding of the production cycle and the impact of their activities on the quality of the final product.
Note: compiled by the authors based on the source [5-7]		

Integrated process monitoring at each stage ensures continuous quality control of the product and allows for rapid response to changes in ore composition. Feedback between stages allows for real-time adjustments to beneficiation strategies.

The use of mathematical models and optimization methods allows for scenario analysis and selection of optimal parameters for each stage. This includes

not only technical aspects, but also economic ones, taking into account costs at each stage of the production cycle.

Extending integration to the level of personnel training to improve their understanding of the entire production cycle and the impact of their activities on the quality of the final product [8].

The Mine to Mill concept not only helps optimize production processes, but also promotes more sustainable and efficient mine management strategies. These strategies are also focused on the sustainable use of resources and the promotion of environmental sustainability [9].

Researchers such as Mutani G. et al. [10] highlight the importance of technological innovations in waste management at mining enterprises. They consider progressive methods aimed at reducing losses and optimizing waste disposal. Merouane Khammar et al. [11] raise the issue of applying artificial intelligence in mining engineering. Using AI in monitoring and control systems can provide significant benefits in process optimization and decision making.

Using sensor technologies such as IoT (Internet of Things) and sensors for continuous monitoring of waste. These devices provide real data on the quantity and characteristics of waste, which allows for more efficient management of its treatment and disposal.

Using robotic systems equipped with artificial intelligence for automated waste sorting, which increases the accuracy of separation of different materials, reducing the amount of waste sent to landfill. Developing more efficient waste processing technologies to extract valuable materials. Processes such as pyrolysis, hydrometallurgy and biotechnology can increase the percentage of waste recycling and reduce its environmental impact.

Implementing digital platforms and management systems to monitor, analyze and optimize waste management processes. Platforms provide centralized management, allowing for informed data-driven decisions and reduced losses.

Using machine learning algorithms to analyze waste generation and processing data. These technologies help identify trends, predict waste volumes and optimize waste management processes. Using biotechnologies such as biodegradation and composting to process organic waste. Biotechnologies help minimize waste volumes and create environmentally friendly methods of disposal.

Developing encapsulation technologies that stabilize hazardous substances in waste. Encapsulation technologies reduce the risk of environmental pollution and improve processing safety. Research into new methods and technologies for the reuse of sludge and waste from mining processes includes the creation of building materials adapted for use in construction or even the production of new materials.

Technological innovations in waste management in the mining industry aim to create more efficient, sustainable and smart waste management systems that reduce negative environmental impacts and increase the efficiency of use.

Circular economy is a concept that aims to optimize resource use by eliminating the principle of “take, make, throw away” and replacing it with “take, make, reuse” (Figure 1).

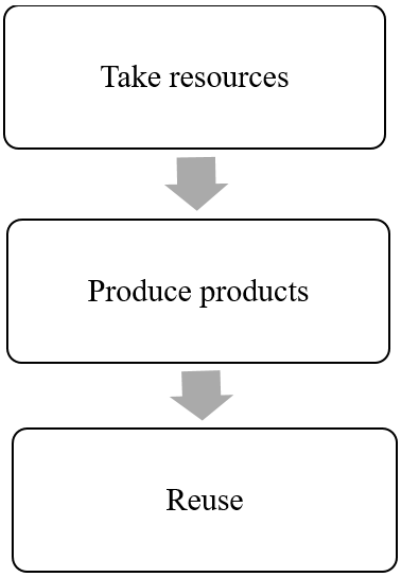


Fig.1 - Circular Economy Principle

Note: compiled by the authors

In the context of the mining industry, the application of the circular economy includes a

number of key aspects:

One of the main principles of the circular economy in the mining industry is the maximum recycling of materials, which includes the development and implementation of waste processing technologies in order to extract valuable materials for reuse in production processes.

The circular economy implies the efficient use of resources, which means reducing losses during the extraction and processing of minerals. Innovations in mining, enrichment and processing technologies are aimed at maximizing the extraction of valuable components and minimizing waste.

The principle of the circular economy includes the management of the product life cycle - from resource extraction to end use. The principle of the circular economy includes extending the service life of products, facilitating their repair, upgrade and, ultimately, disposal with minimal impact on the environment.

The use of monitoring technologies and feedback systems that allow for continuous assessment and improvement of environmental and economic indicators of production. This allows for a more effective response to changes in processes and optimizes the use of resources.

Developing and implementing sustainable resource extraction methods that minimise impacts on nature and include the use of technologies such as zero-waste mining or processing methods and the introduction of energy-efficient technologies.

Promoting circular ecosystems in which mining companies interact and exchange resources and materials to maximise their reuse and minimise waste [12].

Encouraging innovation and research into technologies and methods that support a circular economy in mining. This includes funding research into improved processing technologies, resource efficiency and reduced impacts [13]

A circular economy in mining not only contributes to environmental sustainability, but can also be a key element in ensuring the long-term sustainability of the industry and reducing negative environmental impacts.

Materials and methods. Based on the relevance and socio-economic significance of this topic, especially in light of the desire of the Republic of Kazakhstan to form a new scientific and technological policy and aspirations for low-carbon development, we have defined an integrated approach to the study, which includes not only traditional methods of analysis and evaluation, but also the use of advanced digitalization and automation technologies for a deeper understanding and optimization of processes at the enterprise [14].

The authors consider in detail each stage of the study, from the initial collection of data to their analysis and interpretation. This approach will identify potential areas for improving the efficiency and reducing the cost of mining and transport operations and assess the environmental aspects and carbon intensity of the technologies used. This approach is important to ensure sustainable development of the mining industry and its compliance with modern environmental standards and requirements.

Research question: The study is aimed at establishing a real relationship between mining and transport and drilling and blasting operations in the context of the efficiency of the geotechnological complex of the Bakyrchy mining enterprise. Hypothesis put forward: The hypothesis suggests that optimization of drilling and blasting and mining and transport operations can significantly increase the efficiency of geotechnological complexes, which in turn will improve the profitability and environmental safety of field development.

Research stages. Research in the field of low-carbon development strategy is important for achieving sustainable economic and environmental growth. For successful implementation of such a strategy, it is necessary to conduct a systematic scientific and practical study, which would include a number of stages. The first stage is the analysis of the relevance and socio-economic significance of the proposed research in the context of the low-carbon development strategy of the Republic of Kazakhstan. Then the object, subject, goals and objectives of the study are determined. After this, the primary data on the current situation at the

enterprise is studied. Finally, new methods and approaches for the analysis and optimization of processes are developed and applied (Figure 2).

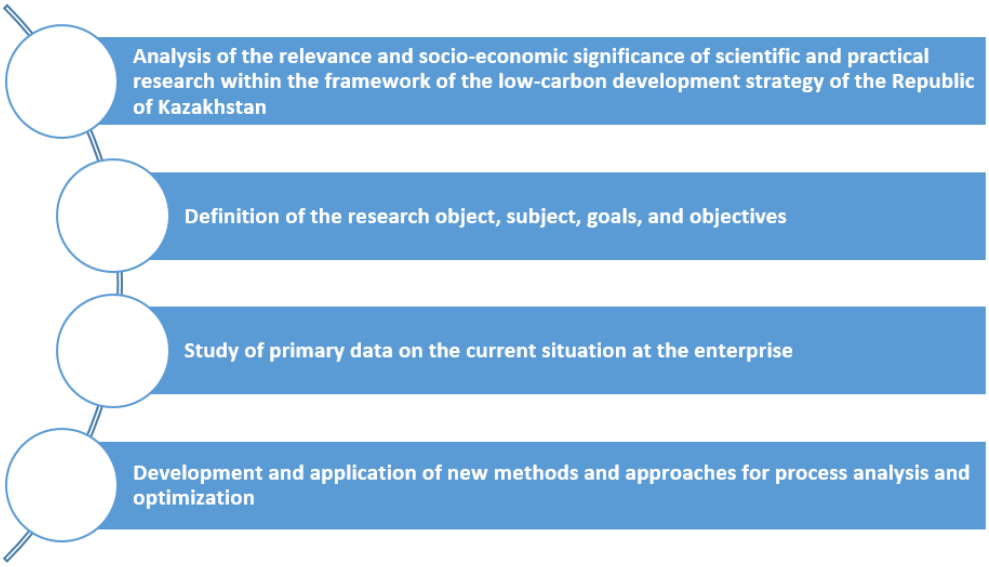


Fig.2 - Research stages

Note: compiled by the authors

These stages represent a sequence of steps necessary to carry out a successful study within the framework of a low-carbon development strategy, thereby providing a basis for developing effective strategies and solutions.

Research methods:

- Simulation modeling to assess various scenarios of mining and transport and drilling and blasting operations.

- Technical and economic analysis to assess the efficiency and potential for reducing the cost of work.

- Methods of digitalization and information analytical support for process management and automation.

- Environmental audit to assess the carbon intensity and environmental efficiency of technological processes [15].

Research results:

- Proposal of specific measures to improve the efficiency of the geotechnological complex.

- Analysis of the potential and directions for process optimization, including assessment of the quality of the road surface, organization of blasting operations, preparation of rocks and optimization of the structure of intra-quarry rock flows.

- Development of methods for the environmental assessment of geotechnological complexes in open-pit mining [16].

The research is due to its relevance and socio-economic feasibility in the context of modern tasks in the formation of a new scientific and technological policy in the Republic of Kazakhstan, including aspects of low-carbon economic development and modernization of the mining industry.

One of the leading areas determining the efficiency of the mining industry is the optimization of the fleet of the main mining and transport equipment. Numerous studies and technical and technological audits confirm the importance of this aspect not only in terms of updating the model range and numerical ratio, but also in the context of the constant emergence of new equipment modifications on the world market. This observation

emphasizes the need to adapt and modernize equipment in accordance with current requirements and market trends [17].

Optimization of the depreciation policy of equipment, taking into account its technical condition and service life. Adequate consideration of these factors is often overlooked when planning mining and transport complexes, which leads to significant discrepancies between the actual and design efficiency of the equipment.

An important component of an integrated approach to managing mining processes is the analysis of the quality of the road surface in quarry areas. The quality of the road surface directly affects the speed modes of transport, the time of trips of dump trucks and, as a result, the overall productivity of the complex and the volume of environmental emissions during the work. Particular attention is paid to the optimization of drilling and blasting operations, especially when developing hard rocks. The efficiency of organizing these operations plays a key role in increasing the overall efficiency of the geotechnical complex. Thoughtful planning and organization of drilling and blasting operations contribute not only to increased productivity, but also to reduced costs [18].

Results and Discussions. The research of the influence of the quality of rock preparation for excavation and drilling and blasting methods opens up new opportunities for increasing the overall efficiency and reducing the cost of mining and transport operations. An important factor here is the degree of loosening of rocks, which affects the overall efficiency of the process.

The use of simulation modeling made it possible to evaluate various scenarios for mining and transport and drilling and blasting operations, which helps to improve the efficiency of these processes. Conducting a technical and economic analysis made it possible to evaluate the efficiency and potential for reducing the cost of work, which is an important aspect when making management decisions. The use of digitalization methods and information analytical support contributes to the management and automation of processes in the mining industry, which increases their efficiency. Conducting an environmental audit allows you to assess the carbon intensity and environmental efficiency of technological processes in the mining industry, which is important from the point of view of compliance with environmental norms and standards.

The results of the research include proposals for specific measures to improve the efficiency of the geotechnological complex, an analysis of the potential and directions for optimizing processes, and the development of methods for the environmental assessment of geotechnological complexes in open pit mines.

An important area is the optimization of the organization of food for drivers of mining and transport equipment, which, despite its seeming secondary importance, has a significant impact on the productivity and efficiency of the complex.

Optimization of the structure of intra-quarry rock flows and the location of ore handling warehouses is also an important aspect that allows increasing the efficiency of the geotechnological complex and reducing costs.

The final stage is the development of methods for assessing the environmental efficiency of the complexes, the introduction of digital technologies and automation of management decisions, which helps to increase the economic efficiency of the geotechnological complex and reduce the costs of mining and transport operations, while improving the profitability of deposit development [19].

One of the important points in the economic assessment of the efficiency of the geotechnological complex, as well as the impact of its work on the efficiency of the enterprise as a whole. In this regard, it is fundamentally important to establish the relationship between the main economic indicators at the levels of the enterprise, quarry and the geotechnological complex under consideration.

According to the presented data, the total cost of the enterprise is 102493545.67 tenge. Of these, the mining part accounts for 82260256.7 tenge or 80.26% of the total volume. At the same time, with a given volume of rock mass extracted at the quarry, the specific cost of m3 of rock mass is 2481.3 tenge

or $ 5.45 (at the exchange rate of 1 US dollar = 455 tenge). For the geotechnological complex, similar indicators have values of 55,745,052.0 (54.3% of total costs) and 1,683.6 tenge/m3, respectively.

One of the main cost items for maintaining the functioning of the quarry geotechnological complex are operating costs for the main mining and transport equipment - depreciation charges and material costs. In this regard, in the process of forming an economic and mathematical model of the functioning of the geotechnological complex, take into account the fact that the enterprise has established depreciation periods for the main mining and transport equipment purchased in 2016 and later, in particular dump trucks: BelAZ-75139 - 84 months and Komatsu HD785 - 60 months. The purchase prices of dump trucks are as follows: BelAZ 75139 - 594.2 million tenge (2021) and Komatsu HD785 - 410.7 million tenge (2021). In 2016, 6 Komatsu HD 785-7 dump trucks were purchased, with a service life of 60 months.

Another important item of operating costs taken into account is the monthly salary of drivers and operators of the main process equipment. Based on the adopted mode of organizing the main technological processes, similar shift indicators are established, which participate in the operational calculation of the cost of mining and transport operations, based on the actual production volumes of the main product of the functioning geotechnological complex. For 2023, according to the enterprise, the salary of excavator drivers is set at 639,002.2 tenge / month for drivers and 498,273.4 for assistant drivers. The salary of dump truck drivers at the enterprise is set at 591,476.0 tenge for the main workers and 532,377.0 for those who go on to replace them during lunch breaks (Table 3).

Table 3 - Calculation of costs for the extraction and processing of one m3 of rock mass for 2022-2023

Name of works and expenses	Cost Amount.	Mining Part		Geotechnological complex	
				Fact	
Share in total cost, %	100%	80,25%		54,39%	
Volume of rock mass, thousand m3.	**2022 г. -33 111, 87 /2023 г. – 30770,0**				
Total wages of workers, thousand tenge	7 946 581,0	5 221 194,0	157,7	5 221 194,0	157,7
Depreciation, thousand tenge.	24 154 670,1	19 494 675,7	588,8	19 494 675,7	588,8
Materials, thousand tenge	805 559,3	750 617,6	22,7	750 617,6	22,7
Fuels and lubricants	13 155 053,3	12 405 334,7	374,6	16 330 487,6	493,2
Energy tenge/kW.	2 031 750,7	438 098,9	13,2	438 098,9	13,2
rent	216 022,0	211 427,8	6,4		
spare parts	12 065 947,7	4 164 599,5	125,8	17 450,1	0,5
travel expenses	21 638,4	14 448,8	0,4		
utilities	250 845,1	172 056,6	5,2		
Taxes (fee for emissions)	1 301 628,5	1 152 575,0	34,8	1 152 575,0	34,8
Occupational safety	90 554,3	87 226,3	2,6		

Food	638 543,9	397 603,2	12,0		
Other (unaccounted for + personnel delivery)	326 812,4	243 241,1	7,3	243 241,1	7,3
Sn	453 281,7	303 186,8	9,2	303 186,8	9,2
So	187 067,9	118 795,8	3,6	118 795,8	3,6
OSMS + OPPV	472 324,6	327 115,8	6,9	327 115,8	9,9
MET	16 418 696,0	16 417 273,3	495,8		
Tires, thousand tenge				6419071,8	193,9
Repair and service	5 531 716,9	4 300 606,7	129,9	4 928 541,8	148,8
Services	39 244,1	37 891,1	1,1		
Contractor (drilling and blasting operations)	14 966 230,8	14 966 195,8	452,0		
Training	27 918,5	17 985,7	0,5		
Insurance	286 707,2	189 192,2	5,7		
Expert and analytical services	342 910,1	286 273,6	8,6		
Transport services	761 844,5	542 625,9	16,4		
TOTAL expenses tenge	**102 493 548,7**	**82 260 256,7**	**2 481,3**	**55 745 052,0**	**1 683,6**
Dollar (at the rate of $1 = 455 tenge)			**5,45**		**3,70**

General practice and experience in researching the efficiency of quarry geotechnological complexes, traditionally, areas related to compliance with the depreciation policy in relation to dump trucks and optimization of their loading mode, by optimizing the equipment replacement schedule and maintaining the workshop profitability of the mining and transport complex at an optimal level, have significant potential in this regard. In this case, due to the insignificance of the term of open-pit mining, this direction can be implemented only in a small part of the existing total potential. A full-fledged economic assessment of the efficiency of the geotechnological complex from the quality of rock preparation for extraction at the stage of drilling and blasting operations requires adequate consideration of the corresponding change in the traction forces of excavators during the process of rock extraction with subsequent reliable identification of energy costs, as well as the corresponding volumes of costs for drilling and blasting operations. In this direction, additional studies are also required with the corresponding variation in the volumes of buckets and dump truck bodies.

The most valuable thing in conducting a set of researches is identifying the economic effect realized by the enterprise from the deviation from the design solution adopted at the enterprise for opening the quarry and organizing the transportation

of overburden rock mass to the dump. This economic effect is about 6263.60 million tenge per year with a significant decrease in the indicator of optimal productivity of the geotechnological complex [20].

Analysis of other economic effects shows that the greatest potential for reducing the cost of mining and transport operations in the established mining-technical, mining-geometric, mining-geological, organizational and economic conditions are in the areas of improving the quality of the road surface of intra-quarry roads, as well as optimizing the structure and number of the listed fleet of the main technological equipment.

Table 2 - Potential economic effect, thousand tenge per year

Optimization direction	Potential economic effect (thousand tenge per year)
Improving the quality of road surfaces of quarry roads	Approximately 1268.27
Optimization of the structure and number of the list of the main technological equipment	Approximately 1035.42
Note: compiled by the authors	

The total potential economic effect is about 1268.27 thousand tenge per year. Taking into account the lack of practical possibility of replacing the diesel fleet of excavators with electric ones with the corresponding technological parameters, the real potential for obtaining an economic effect will be 1035.42 million tenge per year.

Conclusion. The conducted research considered the efficiency of the quarry geotechnological complex with varying various factors of mining engineering, mining-geometric, mining-geological, organizational and economic nature.

In the course of research using the method of simulation logical-statistical and object-oriented modeling, the current state and economic efficiency of the functioning of the Bakyrchik quarry geotechnological complex were analyzed and assessed with a set of studies of its operation under various qualitative characteristics of the extracted rock mass.

As a result of the work carried out, the dependences of the economic efficiency of the geotechnological complex on the preparation of rocks for excavation were determined; the potential for increasing efficiency and directions for its implementation with the development of a set of appropriate measures were determined; software and methodological support for the formation of digital twins of quarry geotechnological complexes were improved using the simulation modeling method; directions were determined and a set of specific measures were developed to increase efficiency and reduce the cost of mining and transport operations in the Bakyrchik quarry of Bykyrchik Mining Enterprise LLP.

The maximum possible planned productivity of the quarry geotechnological complex in terms of rock mass is ensured by the high organization of mining and transport operations, high-quality operational management of the involved mining and transport equipment. The identified potential for increasing the efficiency of the geotechnological complex and reducing the cost of mining and transport operations is associated with the use of a process approach in management and can be most effectively implemented with the appropriate adaptation of the automated management system for mining and transport operations used in the quarry, providing operational accounting and operational economic assessment of the operation of elements and subsystems of the quarry geotechnological system. It is advisable to implement modules for monitoring the loading of sections of the quarry motor transport system, operational accounting and control of environmental emissions and dust in the

quarry space, and the introduction of a dynamic approach to accounting and control of energy consumption by motor transport.

The conclusions and proposals resulting from the conducted research work may be of interest to a wide range of specialists and managers of the enterprise on technical and mining-production issues, on digital transformations and automated control systems, the energy service and the environmental protection department, as well as specialists in the planning and economic direction in terms of the formation of the economy of process management at the enterprise.

References

1. Naugol' nova I.A. Processnyj podhod k upravleniju: jevoljucija, sovremennye vyzovy, innovacii // Kreativnaja jekonomika.- 2023.-T.17(6).- S.2143–2164. DOI 10.18334/ce.17.6.117951[in Russian].

2. Kaplan A.V., Galiev S.Zh. Processnoe upravlenie gornotransportnym kompleksom v kar' ere na osnove jekonomicheskih kriteriev // Gornyj zhurnal.-2017.- № 6.- S.28–32. DOI 10.17580/gzh.2017.06.05 [in Russian].

3. McCoy J.T., Auret L. Machine learning applications in minerals processing: A review // Minerals Engineering.- 2019.- Vol.132.- P. 95-109. DOI 10.1016/j.mineng.2018.12.004.

4. Ayoub R., Baïna S., Mhada F.Z., El Bachari E. Predictive maintenance in mining industry: Grinding mill case study // Procedia Computer Science.-2022.-Vol.207.-P.2483–2492.DOI 10.1016/j.procs.2022.09.306.

5. Salem K., AbdelGwad E., Kouta H. Predicting forced blower failures using machine learning algorithms and vibration data for effective maintenance strategies // Journal of Failure Analysis and Prevention.-2023.- Vol.23.- P.2191–2203. DOI 10.1007/s11668-023-01765-x.

6. Restrepo O. Exploring new sustainable horizons in the mining industry: Circular economy, sustainability, and technological development // Material Science Research India.-2024.- Vol.21(2). - P.72-73. DOI 10.13005/msri/210202.

7. Gilligan R., Aleksandar N. The extraction of vanadium from titanomagnetites and other sources // Minerals Engineering. - 2020. -Vol.146. -P.106. DOI 10.1016/j.mineng.2019.106106.

8. Ghorbani B., Saharkhiz M., Li J. A novel integrated system for sustainable generation of hydrogen and liquid hydrocarbon fuels using the five-step ZnSI thermochemical cycle, biogas upgrading process, and solar collectors//Journal of Cleaner Production.-2021.-Vol.312. DOI 10.1016/j.jclepro.2021.127715.

9. Koyama K., Krane J. Energy security through FDI: The legacy of Early Japanese Investment in the Oil Sectors of the Persian Gulf // Resources Policy.-2021.-Vol.74:102165. DOI 10.1016/j.resourpol.2021.102165. 2021.

10. Mutani G., Todeschi V., Beltramino S. Energy Consumption Models at Urban Scale to Measure Energy Resilience // Sustainability. - 2020. - Vol.12.- № 14. DOI 10.3390/su12145678.

11. Khammar M., Zhu Y., Xu Y. Centrifugal recovery of solvent-diluted bitumen from oil sands // Minerals Engineering. - 2019. - Vol.136. – P.8-17. DOI 10.1016/j.mineng.2019.03.005.

12. Munagala V., Thudumu S., Logothetis I., Bhandari S., Vasa R., Mouzakis K. A comprehensive survey on machine learning applications for drilling and blasting in surface mining // Machine Learning with Applications. - 2024. - Vol.15. DOI 10.1016/j.mlwa.2023.100517.

13. Kaplan A. V. Upravlenie social' no-jekonomicheskim razvitiem gornodobyvajushhego predprijatija.- M.: Jekonomika, 2015. - 270 s. ISBN 978-5-282-03409-7 [in Russian].

14. Galiev S.Zh., Samenov G.K. Avtomatizirovannaja sistema korporativnogo upravlenija geotehnologicheskim kompleksom/ Sbornik dokladov i katalog VII Mezhotraslevoj konferencii

«Avtomatizacija proizvodstva - 2016»,-M.-2016.-S.38-41 URL: https://official.satbayev.university Data obrashhenija: 05.02.25). [in Russian].

15. Galiev S.Zh., Galiev D.A., Sejtaev E.N., Uteshov E.N. O edinoj metodologii upravlenija geotehnologicheskim kompleksom na otkrytyh gornyh rabotah/ Gornyj zhurnal.- 2019.- №12 S.70-75. DOI 10.17580/gzh.2019.12.15. [in Russian].

16. Rakishev B.R., Shubin I.L., Alenichev I.A. i dr. Snizhenie poter' i razubozhivanija pri otrabotke rudnyh blokov slozhnoj konfiguracii i bol' shoj doli malomoshhnyh rudnyh tel. /Otchjot o nauchno-issledovatel' skoj rabote TOO «Qazaqstan Smart Technology» ot 27.12.2022 g. Almaty.: 2023.-41s. IRN123PKH003. URL: https://official.satbayev.university/download/document/42896/МАГ_2024 .- Data obrashhenija: 05.02.25). [in Russian].

17. Galiyev S.Zh., Samenov G.K., Zhusupov K.K., Galiyev D.A. Conception of automated management of geotechnological complex on an innovative base / 24th World Mining Congress Proceedings / Innovation / Instituto Brasileiro de Mineracio. IBRAM. - 2016. - 2555p.

18. Galiev D.A., Uteshov E.T., Tekenova A.T. Digitalization of Technological and Organizational Processes in Mining Operations through the Implementation of a Key Performance Indicators Installation and Monitoring System // Bulletin of the National Academy of Sciences of the Republic of Kazakhstan. Series of Geology and Technical Sciences.- 2020. - Vol.5 (443).- P.47-53. DOI 10.32014/2020.2518-170x.103

19. Zarubin M., Statsenko L., Spiridonov P., Zarubina V., Melkumyan N., Salykova O.GIS Module for Environmental Impact Assessment of Open-Pit Mining Projects for Small-Scale Mining Operators in Kazakhstan // Sustainability. - 2021. - Vol.13(12): 6971. DOI 10.3390/su13126971.

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