The object of research relates to the field of control systems for mining and transport machines in the development of deposits of solid minerals in an open way. The problem of reducing the cost of transporting 1 ton of rock mass and increasing the efficiency of these machines is being solved. The article develops an expert system for dispatching mining vehicles with a subsystem for selecting their innovative appearance with the ability to control their operational parameters, taking into account the stochastic conditions of the developed sections of the rock mass. The mathematical model for constructing the prospective appearance of a mining and transport machine, based on its functional and economic assessment, is reduced to solving the problem of optimizing the generalized criterion of the required efficiency. As an example of private indicators of their effectiveness in operation, there is an expert analysis of the evaluation of solution options, for example, structural-kinematic and operational parameters of these machines, etc. Innovative designs of a skip body of any size of its carrying capacity of single-rope and multi-rope steeply inclined skip hoists for highly profitable mining in quarries are substantiated. unlimited values of their depth and annual productivity. In the proposed study, the values of the forces of resistance to the destruction of a section of a rock mass, obtained by analytical and experimental methods, are refined by finding the optimal Kalman coefficient, which increases the efficiency of using mining and transport machines. The proposed methods provide the creation of innovative mining and transport machines with the ability to control their operational parameters, taking into account the stochastic conditions of the developed section of the rock mass

Keywords: open pit mining, dispatching system, rock mass, skip hoist, counterweight

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DEVELOPMENT OF INTELLIGENT AND EXPERT SYSTEM FOR AUTOMATION OF PROCESSES OF MINING AND TRANSPORT WORKS ON THE BASIS OF SATELLITE NAVIGATION

Suleimen Kaimov
Corresponding author
PhD, Researcher of Mechanics*
E-mail: kayim.suleimen@gmail.com

Aidarkhan Kaimov
PhD, Information Technology Specialist**

Abylay Kaimov
PhD, Researcher of Mechanics*

Talgat Kaiym
PhD, Professor
Department of Mechanics
Military Engineering Institute of Radio Electronics and Communications of the Ministry of Defense of the Republic of Kazakhstan
Zhandosova str., 53, Almaty, Republic of Kazakhstan, 050060

Altynay Primbetova
Master, Head of Department
Big Data Development Department
Alfa Bank
Al-Farabi ave., 40, Almaty, Republic of Kazakhstan, 050060

Saule Nysanbayeva
PhD, Information Technology Specialist**

Orken Mamyrbaev
PhD, Information Technology Specialist**

Karakoz Serikbayeva
Master in Information Technology
Rochester Institute of Technology
1 Lomb Memorial Dr, Rochester, NY 14623, United States, 050060

*Department of Mechanics
Institute of Mechanics and Engineering named after U. A. Joldasbekov
Kurmangazy str., 29, Almaty, Republic of Kazakhstan, 050010

**Department of Information Systems
Al-Farabi Kazakh National University
Al-Farabi ave., 71, Almaty, Republic of Kazakhstan, 050040

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1. Introduction

At the present time (2021), the development of solid mineral deposits is carried out in 178 countries of the World. Mineral raw materials extracted from the bowels of the Earth are the basis for the existence of a technocratic civilization. The main production processes for open-pit mining of solid mineral deposits are:

1) destruction of sections of a rock mass;
2) loading of rock mass into appropriate vehicles;

3) transportation of the rock mass from the location of its formation in the quarries to the areas of the earth's surface located near the design contours of the quarries, using various traditional methods.

As a result of the technical and economic analysis of the technological process of moving rock mass in operated quarries using a traditional type of transport, for example, automobile and conveyor, etc., which are operated using lifting machines, it was found that the cost of transporting 1 ton of rock mass is significant, and staff productivity is extremely low. For example, with a pit depth of 600 m, the volume of overburden that is removed from the design contour of the pit when making a transport berm in the pit is large and amounts to more than 150 million m^3. Therefore, when removing sections of the overburden rock mass located above the upper surface of the transport berm, the volume of which is approximately 100 million m^3, and the value of financial costs will be 2.5–3.0 billion US dollars [1].

One of the modern sustainable trends and patterns in the field of open-cast mining is the creation of automated dispatching systems for mining vehicles. However, the known systems [2, 3] for the development of solid minerals in an open way use traditional machines for transporting rock mass, which does not reduce the cost of transporting 1 ton of rock mass.

In this regard, the development of an expert system for automating the dispatching of mining transport machines with a subsystem for selecting and substantiating the innovative appearance of a machine for transporting rock mass with the control of operational parameters, taking into account the stochastic conditions of the mined sections of the rock mass, is an urgent task. The results obtained are intended to be applied in the operation of quarries, the annual productivity of which is unlimited, for example, up to 300 million tons of rock mass or more, and the depth of the quarry is unlimited, for example, up to 3000 m or more, while ensuring effective values of technical and economic indicators of mining fossils, i.e. highly profitable, ensuring safe working conditions for personnel, eliminating harmful effects on the environment during their use and operation under any climatic conditions.

2. Literature review and problem statement

The value of the rock mass extracted from the bowels of the Earth in all mining countries of the World during the year is 888.7 billion tons [4]. At the present time, in the development of deposits of solid minerals by the open method, about 75 % of the volume of the rock mass is mined [5]. The main production processes for open mining of solid mineral deposits are:

1) destruction of sections of the rock mass;

2) loading of rock mass into appropriate vehicles;

3) transportation of the rock mass from the location of its formation in the quarries to the areas of the earth's surface located near the design contours of the quarries, in various ways:

a) road transport of rock mass;

b) railway transport of rock mass;

c) conveyor transport of rock mass;

d) transportation of rock mass by skip hoists using lifting machines;

e) combined transport of rock mass (railway and road transport of rock mass; automobile and conveyor transport of rock mass, etc.) [6].

The main disadvantages of open mining of solid minerals when using all existing traditional methods of transporting rock mass is a significant cost of transporting 1 ton of rock mass and a low value of personnel productivity.

Another main disadvantage of open pit mining of solid mineral deposits is the poor ecology inside the quarry due to the presence of dust emissions into the mined-out space of the quarry [7].

For transportation of developed rock mass, road transport of rock mass is the most widely used. At present, about 65–70 % of the volume of rock mass extracted from quarries during their operation is transported with its use [8]. The main disadvantage of road transport of rock mass is the significant cost of transporting 1 ton of rock mass and the low productivity of personnel. For the movement of dump trucks when transporting rock mass in a quarry, a road is being built. As a result of the removal of these sections of rocks, the volume of removal of additional overburden is very significant. For example, with a pit depth of 600 m, the volume of overburden that is removed from the design contour of the pit when making a transport berm in the pit is large and amounts to more than 150 million m^3. Therefore, when removing sections of the overburden rock mass located above the upper surface of the transport berm, the volume of which is approximately 100 million m^3, and the value of financial costs will be 2.5–3.0 billion US dollars [1].

The use of traditional methods of transporting rock mass, for example, road transport, in open-pit mining, largely depends on climatic conditions, for example, hurricane, rain, downpour, frost, blizzard, snowfall, ice, heat, etc. For this reason, for example, when developing kimberlite deposits in Sakha (Yakutia), the value of the period of idle time of dump trucks in quarries reaches 25–30 % of the value of the duration of the year. As a result of these reasons, Joint Stock Company Alrosa Sakha (Yakutia) incurs losses, the amount of which is about 100 billion US dollars during the year [9]. These circumstances are the main reasons for the impossibility of using the existing traditional methods of transporting rock mass in open pits.

In the open mining of deposits of solid minerals, the second most important is the conveyor transport of rock mass. With its use in quarries, the depth of which is 200 m or more, the mining countries of the world transport about 20–25 % of the volume of rock mass extracted from quarries [10]. The advantages of rock mass conveyor transport are as follows:

1) a large value of conveyor performance when transporting rock mass in a quarry, the value of the depth of which is large, for example, equal to 200–400 m or more;

2) exclusion of the emission of harmful gases into the air of the atmosphere of the quarry, since the conveyor is operated using electricity;

3) the construction of a special transport road for the installation of a conveyor is eliminated.

The main disadvantages of rock mass conveyor transport are as follows:

1) the value of the cost of transporting the rock mass is large due to the high value of the cost of the conveyor;

2) the great importance of electricity consumption when transporting 1 ton of rock mass.

Transportation of rock mass by inclined lifting installations is widely used in the development of deposits of solid minerals by the underground method in all mining countries of the world. In the development of deposits of solid minerals in an open way, the movement of rock mass in quarries with inclined lifting installations is rarely used due to the relatively low productivity of inclined lifting installations. This situation is due to the fact that inclined lifting installations are made using drum hoisting machines, which can move lifting vessels – skip bodies, in which the rock mass is located, using one and/or two traction ropes [10]. The scheme of skip lifting of the rock mass is determined by its performance value. A single-skip lift of rock mass is used with a skip load capacity of 100–120 tons. The most productive is double-skip hoist. With a skip body carrying capacity of up to 40 tons, it is connected to the drum of the hoisting machine with one rope. With a larger skip load capacity, a multi-rope or block suspension is used to hoist it. One of the promising directions for the development of transport of rock mass in deep pits for the next 15–20 years is the creation and use of multi-rope inclined lifting installations, the payload capacity of the skip body is 30...180 tons, when transporting rock mass in quarries, allows to get a significant amount of profit in the extraction of minerals and/or minerals and significantly improve the environmental situation in quarries. In connection with this circumstance, the Closed Joint Stock Company "Novo-Kramatorsk Mechanical Plant (Kramatorsk, Donetsk region, Ukraine)" and the Institute of Technological Systems and Technologies "Transmag" of the National Academy of Sciences of Ukraine (Dnepropetrovsk) are developing a parametric series of fundamentally new multi-rope skip inclined quarry lifting installations with the carrying capacity of the skip body Q, equal to 30 tons; 42 t; 55 t; 80 t; 120 t; 136 t and 180 t [10]. The main disadvantage of this parametric range of skip hoists is the low load capacity of the skip body.

The German company Thyssen Krupp Technolodzhik (Thyssen Krupp Resource Technologies GmbH) is currently (2013) developing a transport system, with the use of which it is planned to transport the rock mass more technically and economically efficiently and with a significantly lower degree of harmful impact on the environment than when transporting the rock mass by dump trucks, all other things being equal [11]. The transport system consists of a rope-driven skip hoist moving along a rail transport route located on a flyover mounted on the surface area of the non-working side of the quarry, between the surface area of the bottom of the quarry and the area of the earth's surface located near the design contour of the quarry. The angle between the longitudinal axis of the rail transport route and the horizontal can be up to 75 degrees. When using the skip system, the dead weight of one skip body is completely balanced by the dead weight of the second skip body, which are interconnected by ropes. Therefore, during the operation of the drive system of the skip installation, the main part of which is the lifting machine, the amount of additional energy is not consumed when moving the empty body of the skip along the rail transport route. The skip body used for rock mass transportation using the Thyssen Krupp conveyor-skip system has a carrying capacity of 136 tons. Its width is 4 m, its length is 13 m, and its height is 5 m. the mass of the skip is approximately 90 tons. The number and dimensions of the undercarriages are determined by the steepness of the rail transport route, the shape of the rail profile and the permissible value of the contact pressure of the wheels on the surface of the rail transport route. The Thyssen Krupp conveyor-skip system for transporting rock mass during the operation of quarries provides a high degree of readiness for transporting rock mass in operated quarries, as it retains its full operational capacity under adverse climatic conditions. When operating an inclined skip hoist when moving it along a rail transport route mounted on a section of the surface of the pit wall, dust emission into the mined-out space of the quarry is excluded [11]. The main disadvantage of this conveyor-skip system for transporting rock mass is the mandatory use of special lifting machines.

The fundamental disadvantage of rock mass transportation by skip hoists in all mining countries of the world is the mandatory use of expensive and energy-intensive lifting machines that transport skip bodies containing rock mass, the volume of which is insignificant, for example, up to 136 tons [11]. Also, the value of the depth of the operated quarry, in which the rock mass is transported by the skip hoist, is small, for example, up to 400 m. This circumstance is due to the fact that the rope capacity of the drums of traditional lifting machines is small [10].

In connection with these circumstances, the need to create rational designs of innovative single-rope and multi-rope steeply inclined skip hoists for transporting rock mass in a quarry with a skip body structure of any size of its carrying capacity for highly profitable environmentally friendly mining in quarries of unlimited depth and annual productivity is an urgent problem.

In [12], the soil conditions for the operation of earth-moving machines in Kazakhstan were studied. Experimental and theoretical results of studies of the process of destruction of soils and rocks are presented. At the same time, it is noted that one of the main factors affecting the efficiency of the process of destruction of soils and rocks is the destruction angle α_p (the cutting angle formed by the trajectory of motion and the front face of the cutting wedge). A regression dependence of the force of resistance to destruction of a section of a soil mass (rock mass) on the geometric parameters of the bulldozer blade, the strength coefficient of the destroyed section of the soil mass K_p and the depth of its destruction (cutting) at known intervals of change in the value of the angle of destruction (cutting) α_p is established. In this case, the law of change of the random value of the force of resistance to destruction of a section of the soil mass, for example, placers, peat, is a uniformly distributed random value of the resistance force to the destruction of a section of the soil mass. Its main disadvantage is the lack of reliability in assessing the force of resistance to destruction (cutting) of a section of a rock mass, for example, placer, peat.

One of the modern sustainable trends and regularities in the field of open-pit mining is the creation of automated dispatching systems for mining transport machines using subsystems for choosing an innovative design of a mining transport machine and controlling its operational parameters, taking into account the stochastic conditions of the developed rock mass area.

In the process of analyzing patent and scientific and technical information, it was found that the leading organization in the Republic of Kazakhstan on this issue under study is the Institute of Mining named after D. A. Kunaev (Almaty, Republic of Kazakhstan). The information system for modelling mining transport operations developed at this institute, taking into account planned ore flows for a given period, includes a full and comprehensive account of their relationships, their hierarchy and the degree of influence on the functioning of mining transport complexes inside open pits in time and space [2]. Rock mass transportation there is proposed to be carried out using traditional vehicles, for example, by road, which significantly increases the cost of transporting 1 ton of rock mass.

In the article [13], the dispatching of rock mass transportation is proposed to be carried out using traditional mining and transport machines without taking into account the stochastic conditions for the destruction of a section of a rock mass, which leads to significant financial losses from downtime of excavation-loading and transport equipment.

In [14], an automated system was developed. The absence in this system of a reference and information expert subsystem for selecting and substantiating the innovative appearance of mining transport machines with the control of their operational parameters, taking into account the stochastic conditions of the developed rock mass areas, leads to significant financial losses in the development of solid mineral deposits.

The article [15] uses satellite technologies and data processing algorithms to improve the positioning accuracy of mining vehicles. However, the issues of managing the operational parameters of these machines, taking into account the stochastic conditions of the mined section of the rock mass, have not been considered, which is the reason for the significant downtime of the equipment.

In [16], the issues of existing solutions for the dispatching of mining and transport operations are investigated. However, the issues of choosing the innovative look of mining and transport machines based on the functional and economic assessment of their operation are not considered which leads to a significant increase in the cost of transporting 1 ton of rock mass.

In the article [17], the questions of the movement of heavy dump trucks are investigated. Rock mass transportation is proposed to be carried out by traditional modes of transport, for example, by road, conveyor, etc. However, the task of developing an intelligent expert system for automating the dispatching of mining and transport machines with a subsystem for selecting and justifying their innovative appearance with the control of their operational parameters, taking into account the stochastic conditions of the developed sections of the rock mass was not considered. The use of this dispatching system for mining and transport machines is associated with a significant increase in the cost of transporting 1 ton of rock mass and significant downtime of these machines.

The analysis of the current state of this issue, related to the improvement and automation of the control system for the ore preparation process in open pit mines, showed that today there is a developed general methodological base for managing the qualitative characteristics of the intrapit ore flow, a methodology and digital tools for simulation modelling and planning of ore flows have been developed, a methodological base and an effective method for operational planning and adjustment of the organization of the ore preparation process within the framework of automated monitoring and dispatching systems for mining and transport operations has been proposed, a methodology for the operational assessment of the effectiveness of managing the quality characteristics of the intrapit ore flow has been developed and tested.

The problematic issues of this automated control system for the quality characteristics of intra-quarry ore flows that require additional consideration are the following:

– the impossibility of achieving the minimum cost of transporting 1 ton of rock mass using traditional machines for transporting rock mass;

– the impossibility to increase the efficiency of the use of mining transport machines without taking into account the physical and mechanical characteristics of the stochastic environment of the section of the destroyed rock mass and the choice of innovative designs of their working bodies.

One of the modern sustainable trends and patterns in the field of open-cast mining is the solution of the problem under consideration within the framework of automated monitoring systems for the dispatching of mining and transport operations is the development of an information system for automating the processes of mining and transport operations with the choice of an innovative appearance of the mining and transport machine and ensuring an increase in the efficiency of their use, as well as creation of a theoretical basis for improving the design of the actuators of these machines.

Therefore, the article sets the task of developing an intelligent expert system for automating the dispatching of mining transport machines with a subsystem for selecting and substantiating their innovative appearance with the control of their operational parameters, taking into account the stochastic conditions of the developed rock mass areas.

3. The aim and objectives of the study

The aim of the study is to develop an intelligent expert system for automating the dispatching of mining and transport machines with a subsystem for selecting and justifying their innovative appearance.

To achieve this, the following objectives were set:

– to develop a general concept of the operation of the information system for mining and transport operations;

– to justify the innovative design of a mining transport machine for transporting rock mass;

– to justify the design of an innovative skip rope hoist with a skip body for transporting rock mass of any carrying capacity;

– to substantiate the parameters of the innovative actuator of the bulldozer blade with a removable horizontal cutting knife for the development of rock mass (clay, placers, peat).

4. Materials and methods

The studies were carried out using the theory and practice of mining deposits of solid minerals in a quarry way, including the analysis of the technological process of transporting rock mass from quarries. The choice of mining and transport vehicles was analyzed, for example, the assignment of excavators to planned excavation sites in a quarry. As a result of the technical and economic analysis of the technological process of moving rock mass in operated quarries using road transport, conveyor and transportation of rock mass by single-rope and multi-rope steeply inclined skip hoists, which are operated using hoisting machines, it was found that it is unprofitable to use any traditional type of rock mass transport in quarries, the depth of which is 600 m or more. The studies were carried out using the methodology of a systematic approach to analysis and synthesis in the analysis of complex business processes of the systems of modern companies, which include the technological process of developing deposits of solid minerals in a quarry way. The systems for managing the quality indicators of the ore flow in open pits were studied, using various geographic information systems, for example, the Global Positioning System (global positioning system), as well as systems for simulating business processes of modern enterprises. It was found that in the existing information systems for dispatching mining and transport machines there are no subsystems for choosing their innovative appearance with the control of their operational parameters, taking into account the stochastic conditions of the destroyed section of the rock mass. Rational designs of innovative single-rope and multi-rope steeply inclined skip hoists for transporting rock mass in a quarry have been created. On the basis of the functional-economic approach, innovative designs of the skip body of any size of its carrying capacity of single-rope and multi-rope steeply inclined skip hoists for highly profitable environmentally friendly mining in quarries of unlimited depth and annual productivity are substantiated.

The study was carried out using the methods of the theory of machines and mechanisms, methods of mathematical modelling, for example, probabilistic and uncertain mathematical models for making an optimal management decision. On the basis of which a mathematical model was developed and created for constructing the perspective appearance of mining and transport machines and their functional and structural assessment, reduced to solving a multi-criteria problem based on one of the following methodological principles: folding a system of particular criteria into a generalized criterion of the required effect (efficiency); appointment of the main criterion and restrictions on other indicators.

The study was carried out using the methods of the theory of machines and mechanisms, methods of mathematical modelling, for example, probabilistic and uncertain mathematical models for making an optimal management decision. On the basis of which a mathematical model was developed and created for constructing a perspective view of mining and transport vehicles using the example of a bulldozer and its functional and structural assessment, reduced to solving a multi-criteria problem based on one of the following methodological principles: folding a system of partial criteria into a generalized criterion of the desired effect (efficiency); appointment of the main criterion and restrictions on other indicators. Methods have been developed for substantiating and selecting the structural, dimensional and regime parameters of the adaptive actuator of a bulldozer blade with a removable cutting knife, taking into account the principle of adaptation to the conditions of the mined section of the rock mass. These methods are the basis for creating innovative competitive adaptive actuators of the working bodies of mining and transport machines. The research methodology is based on a systematic approach, in which the executive mechanism of the bulldozer blade – the environment being developed is considered as a single system of interconnected and interacting elements.

5. Results of the development of modules for an intelligent-expert system for automation of mining and transport operations

5. 1. The general concept of the operation of the information system for mining and transport operations

The information system is intended for mining enterprises with open pit mining of mineral deposits and carrying out the main technological process using an excavator-vehicle complex.

The scope of the system is determined by the list of the following tasks to be solved:

– control of the location of mining dump trucks and excavators;

– control of the general course and state of the technological process of mining and transport operations;

– operational accounting and analysis of the operation of mining dump trucks and excavators;

– organization of storage and processing of information received with the help of the system (operational and long-term);

Using the system allows:

– increase the level of reliability and efficiency of transportation of information about the technological process of mining and transport operations to dispatching services;

– to automate the processes of control, accounting and analysis of information about the technological process of mining and transport operations;

– raise the level of digitalization of the enterprise;

– to improve the technological process of mining and transport works;

– to create prerequisites for the subsequent introduction into production of an automated control system for the technological process of mining and transport operations;

– ensure the coordinated work of all parts of the managed facility and improve the technical and economic indicators, the rhythm of work, and the rational use of production capacities;

– increase the time of productive use of equipment during the work shift;

– ensure resource savings while achieving the required production volumes;

– improve the labour and technological discipline of the personnel;

– to create the basis for an objective assessment of the activities of the services and sections of the enterprise;

– to create the preconditions for systematic repair and maintenance of the enterprise's fleet of machines;

– to create the basis for optimizing cargo flows. The industrial implementation of the system will help improve the process of managing the technological process of mining and transport operations and improve the technological discipline and economic efficiency of mining production.

The structure of the software, which is shown in Fig. 1:

1. Formation of a data package – this block collects all the data necessary for accurate and reliable calculation on the system server, namely: geographical coordinates, time of determining coordinates, data from sensors of technical and technological parameters of the monitored object (if any), identification number of the object. Physically, this block is executed in the microcontroller of the onboard complex.

2. Reception, demodulation and decoding of the signal – in this block, "listening" to the air is carried out in order to identify the information signal and decode it. Physically, this block is executed at the base station.

3. Data processing and conversion – in this block, the CRC-16 checksum is checked and converted to ASCII codes for the convenience of further work. Physically, this block is executed in the RECEIVER program installed on the information system server.

4. Calculation – in this block, calculations of all the main technological indicators are carried out. A feature of the block is the streaming (parallel) structure of the work of various processes. Physically, this block is executed in the SERVER program installed on the information system server.

5. Visualization – a block of graphical and tabular display on the monitor of the current state of mining and

transport operations. Physically, this block is executed in the DISPATCHER program installed on the dispatcher's computer.

6. Entering an explanation of emerging events – a block responsible for entering responses to messages about emergency situations by the dispatcher. Physically, this block is executed in the DISPATCHER program installed on the dispatcher's computer.

7. Entering additional information – The block is intended for entering additional information. Physically, this block is executed in the ADMINISTRATOR program installed on the administrator's computer.

8. Visualization – a block of graphical and tabular display on the monitor of the current state of mining and transport operations. Physically, this block is executed in the CLIENT program installed on the computers of other, not described above, users of the system.

The article proposes additions to an intelligent expert system for automating the dispatching of mining and transport machines with a subsystem for selecting and substantiating their innovative appearance with the control of their operational parameters, taking into account the stochastic conditions of the developed sections of the rock mass, and the technology for substantiating the innovative design of a skip hull of any size of its carrying capacity of single-rope and multi-rope steeply inclined skip hoists for highly profitable environmentally friendly mining in quarries of unlimited depth and annual productivity.

5. 2. Justification the innovative design of a mining transport machine for transporting rock mass

The idea is to develop an innovative design of mining vehicles for transporting rock mass and its development, for example, a skip hoist for transporting rock mass and a bulldozer blade for direct work in a section of a rock mass in the development of solid minerals.

In the modern period of time, the scale of the use of mining and transport and earth-moving construction machines is sharply increasing, for example, bulldozers are widely used in the development of alluvial mineral deposits. During their operation, about 90 % of gold, silver, platinum, tungsten, molybdenum and rare metals mined all over the world are mined. Therefore, one of the important aspects of increasing their efficiency is to ensure the adaptation of their working bodies to the stochastic conditions of their interaction with the developed section of the rock mass. Also, bulldozers are widely used in the development of peat, which is the main raw material for thermal power plants. At present, peat is one of the main sources of solid fuel along with coal used in the operation of thermal power plants. In most countries of the world, the volume of its use, for example, in Canada, Finland, Denmark, Belgium, Holland, Germany, Poland, etc., is decisive and constantly increasing. The total area of peat deposits in all countries of the world reaches 176 million hectares. At the same time, the world balance reserves of peat are estimated at 500 billion tons [4].

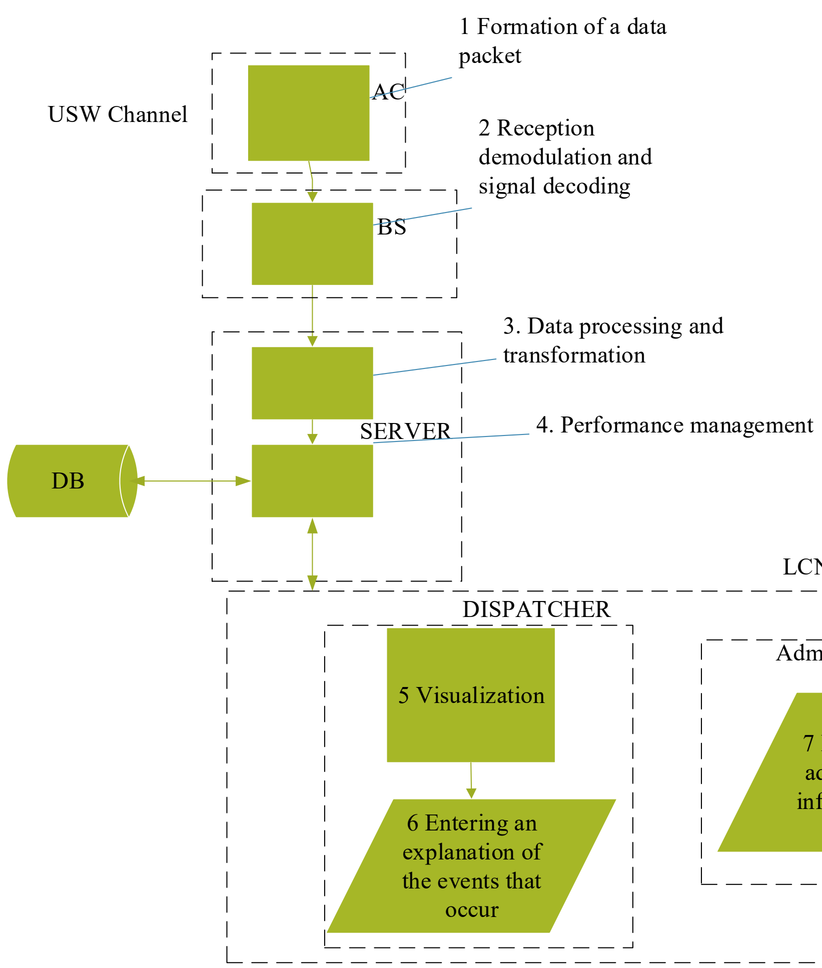

Fig. 1. Information system software structure

An important reserve for improving bulldozers is the use of adaptive actuators of the working bodies of the bulldozer blade, which have wide functionality, including the ability to adapt to the types of work and the conditions of the environment being developed. The transition from the existing image (initial state) of the aggregate of machines to its new image of the perspective state of the machines is carried out in order to increase the efficiency of their operation. Efficiency is defined as the ratio of the effect obtained to the costs invested to achieve it, or to achieve both, that is, the required effect with the lowest possible economic and material costs.

To calculate the real economic parameters of the bulldozer, it is necessary to have information about the values of the parameters of the existing and prospective machine. In general, the methodological approach to substantiating and choosing a rational version of the appearance of a machine is based on the basic principles of system analysis and synthesis of complex structures according to the criterion "efficiency-cost" [18].

The solution of the problem of economic assessment of options for the appearance of a promising bulldozer should be carried out by the method of two-level optimization according to the scheme of multi-criteria analysis of alternatives. As private indicators of the effectiveness of a bulldozer during its operation, an expert analysis of the evaluation of solution options based on the results of a patent information search is used. Based on the transformation of the results of expert analysis, it is proposed to take into account the following indicators for evaluating the effectiveness of the bulldozer: (X_1) – adaptability, i. e. property of adaptability to operating conditions; (X_2) – maintainability, i. e. quality, which consists in adaptability to restore the serviceability of the structural elements of the bulldozer by preventing, detecting and eliminating malfunctions and their failures; (X_3) – durability, i. e. the property of the product for a long time (with possible breaks for repairs) to maintain performance under certain operating conditions until destruction or other limiting state; (X_4) – reliability of machines, i. e. the property of the product to continuously maintain operability in certain modes and operating conditions; (X_5) – profitability, i. e. performance of technological operations at the lowest cost; (X_6) – performance, i.e. volume and speed of production operations; (X_7) – simplicity of the control system, i.e. number of management levels; (X_8) – the service life of the structural elements of the running gear and the mechanisms of movement of the skip hoist; (X_9) – the quality of the structural-kinematic schemes of the actuators of the skip hoist, i. e. the possibility of accurate reproduction of the programmed movement of the skip hoist actuator and the distribution of forces between the links of its design.

In this model, the first nine criteria (X_1)–(X_9) constitute the basic part. To get a more complete picture of the efficiency of construction machines, an additional parameter to the basic model is proposed – (X_{10}) the degree of perception of the constructive solution of the machine by innovative changes carried out in accordance with the requirements of its effective functioning.

The matrix of the main operational parameters of the mathematical model of the prospective appearance of mining and transport vehicles on the example of a bulldozer operated in the development of rock is presented in the form of the presence of operational parameters marked "1", and their absence - "0".

In the process of developing and creating a mathematical model for constructing a promising appearance of mining and transport machines, their functional and structural assessment is reduced to solving the problem: folding a system of particular criteria into a generalized criterion of the required effect (efficiency).

These criteria characterize a mining and transport machine that has the following operational parameters: productivity, reliability, adaptability to the conditions of the technological process, productivity, equipment with replaceable working bodies, control system, infrastructure and comprehensive provision of spare parts, etc. [18].

The implementation of the algorithm for selecting many criteria consists in constructing a generalized criterion by linear convolution of the criteria. It boils down to the fact that the generalized criterion is expressed as a linear combination of the values of the remaining criteria:

$$U(x)=\sum w_i x_i, \tag{1}$$

where w_i – weight (importance) of the i-th criterion assigned by experts; x_i – quantitative assessment according to the X_i-th criterion.

The structure of the appearance of the skip hoist is changing due to ongoing activities aimed at increasing the value of one or another of its parameters. The solution of the problem comes down to rebuilding the structure of the state of the appearance of the skip hoist, trying to bring it closer to the final, target state.

The economic part of the calculation block of the presented methodology begins with determining the need for financial resources to implement the plan for the formation of a new look for the skip hoist in full and the time required to achieve this goal with a given level of funding, which are determined by the formula:

$$\Phi=\sum(K_i-C_i)\cdot S_i, \tag{2}$$

where Φ is the need for additional financial resources for the implementation of the program for the formation of a new look for the skip hoist at a given level of funding; K_i is the value of the i-th parameter of the prospective appearance of the skip hoist; C_i is the value of the i-th parameter of the existing shape of the skip hoist; S_i is the price per unit of the i-th measure of the formation of a new look for the skip hoist [18].

Term T, during which the program for the formation of a new look of the skip hoist will be implemented, is determined by the formula:

$$T=\Phi/F, \tag{3}$$

where T is the period during which the program for the formation of a new image of the skip hoist will be implemented; F is the need for additional financial resources for the implementation of the program for the formation of a promising image of the skip hoist at a given level of funding.

After that, the rate of deviation of the initial state of the existing shape of the skip hoist from its final target state is calculated, expressed as a percentage, which is determined by the formula:

$$N=(\sum C_i/K_i)/I, \tag{4}$$

where N is the norm of the existing state of the appearance of the skip hoist; I is the total number of parameters characterizing the structure of the existing appearance of the skip hoist [18].

The final solution of the problem comes down to finding the maximum value of the norm of deviation of the achieved parameters of the state of the prospective appearance of the skip hoist for a given level of funding:

$$H \to \max;\ H = (\sum P_i / K_i)/I \quad (5)$$

and

$$F = \sum (P_i - C_i) \cdot S_i, \quad (6)$$

where H is the norm of the achieved state of the prospective appearance of the skip hoist;

P_i is the value of the i-th parameter of the achieved perspective appearance of the skip hoist;

S_i is the price per unit of the i-th measure of the formation of the prospective image of the skip hoist;

F is a given level of (allocated) funding for the formation of a perspective image of a skip hoist within a certain period of time (usually within one year);

K_i is the value of the i-th parameter of the final, target perspective appearance of the skip hoist;

C_i is the value of the i-th parameter of the existing shape of the skip hoist;

i is the serial number of the structure parameter of the existing shape of the skip hoist [18].

The results of calculating the parameters of the functional-economic model for assessing the prospective appearance of the skip hoist during a given period of time, performed for a conditional example, are shown in Table 1.

At the second stage, the calculation is detailed, where the achieved calculated indicators are determined relative to the final, target parameter of the state of the perspective appearance of the skip hoist. Table 1 shows the deviations of each calculated indicator relative to the final perspective appearance of the skip hoist. The structure of the achieved prospective appearance of the skip hoist has changed significantly, the value of one parameter (in the conditional example it has the number 3), which is 4 % on the initial state, has reached 100 % [18].

5. 3. Justification the design of an innovative skip rope hoist with a skip body for transporting rock mass of any carrying capacity

On the basis of the functional and economic approach developed by them, specialists have created a promising look for a skip hoist for transporting rock mass in a quarry [18]. At present, specialists have created several variants of innovative single-rope and multi-rope steeply inclined skip hoists, the use of which will allow transporting lumpy rock mass in one step in one skip, the volume of which is unlimited, for example, up to 100 thousand tons and more, in quarries, the depth which are unlimited, for example, up to 3000 m and more, with an annual productivity of a quarry up to 300 million tons of rock mass and more, while excluding the harmful effects of the technological process of transporting rock mass on the environment and when operating them under any climatic conditions.

At present, to solve this extremely important world-class scientific and technical problem, specialists have created several options for innovative designs of single-rope and multi-rope steeply inclined rock mass skip hoists. In each of them, the main structural device is the structure of the skip body.

Table 1

Initial data and calculation results of the perspective view of the skip hoist for a conditional example

The Appearance of the skip hoist					
Allocated funds, unit	Required funds, unit	Time to achieve the goal, year	Initial state norm, %		The rate of the achieved state, %
70	144	2.5	64		81
Calculation results					
Parameter name	The initial state	Required Appearance	Unit price	Received appearance, %	Perspective appearance (goal achievement), %
Safe working conditions for quarry personnel	38	50	2	80	100
Reduced downtime of the skip hoist by taking into account the stochastic conditions of the developed area of the rock mass	16	20	2	80	100
The carrying capacity of the skip body can be different, for example, from 50 tons to 100 thousand tons of rock mass and more	4	10	2	100	100
Low energy consumption when transporting the rock mass with an innovative skip hoist with a counterweight	16	20	5	80	100
Reliability of structural components and parts of the innovative skip hoist and the simplicity of its control system	8	10	5	80	80
Improving the ecology inside the quarry	7	15	5	80	100
Low production cost of skip hoist	3	4	10	80	100
Low Maintenance Cost of Skip Hoist	1	3	10	80	100

Justification of the innovative design of the skip, the carrying capacity of which is any, for example, up to 100 thousand tons of rock mass and more, innovative single-rope and multi-rope steeply inclined skip hoists, which are planned to be operated in quarries, the annual capacity of which is unlimited, for example, up to 300 million tons of mining mass and more, the value of the depth of open pits is unlimited, for example, up to 3000 m and more, to ensure effective values of technical and economic indicators of mining, i.e. highly profitable, safe working conditions for personnel, elimination of harmful effects on the environment, when operating quarries under any climatic conditions.

The main structural components of the innovative single-rope steeply inclined skip hoist are:

1) skip body;

2) box-shaped device, which is a counterweight;

3) metal and/or graphene or synthetic and other traction rope, metal and/or synthetic chains, etc.;

4) a pulley for placing on it a section of a traction rope, etc., attached to the body of the skip body;

5) braking device or braking devices for braking the movement of the traction rope, etc.;

6) protective device for the surface of the traction rope, etc. from moisture and icing;

7) a pulley for placing on it a section of a traction rope, etc., attached to a counterweight device;

8) an innovative transport route for moving along the upper surface of its innovative skip, built on the surface of the non-working side of the quarry;

9) an innovative transport route for moving along the upper surface of its innovative counterweight, built on the site of a non-working side of a quarry, and other structural elements of an innovative single-cable steeply inclined skip hoist.

The main structural part of the innovative skip body is the body of the skip body, the carrying capacity of which can be different, for example, from 50 tons to 100 thousand tons of rock mass and more. Depending on the carrying capacity of the skip body, its design will be different.

According to the first version, the main structural components of the innovative multi-rope steeply inclined skip hoist are:

1) the body of the skip, which is one integral structural device;

2) a box-shaped device, which is a counterweight, represented by one integral structural device or several separate structural devices;

3) metal or graphene or synthetic traction ropes, metal chains, etc.;

4) pulleys for placing on each of them a section of a separate traction rope attached to the skip body, or a separate section of the traction chain attached to the skip body;

5) pulleys for placing on each of them a section of a separate traction rope, etc., attached to the counterweight device;

6) braking or braking devices for braking the movement of each traction rope, etc.;

7) braking or braking devices for braking the movement of the skip body;

8) top cover of the skip body;

9) a device for irrigating the interior of the skip body with water drops when loading a mixture of rock pieces into it;

10) protective device for the surface of the traction rope, etc. from moisture and icing;

11) a transport route for moving along the upper part of its skip or skips, built on the surface of the non-working side of the quarry;

12) a transport route for moving along the upper surface of its counterweight or counterweights, built on the surface of the non-working side of the quarry.

According to the second variant, the main structural components of the innovative multi-rope steeply inclined skip hoist are individual skip bodies pivotally connected to each other by connecting links. The carrying capacity of each skip body can vary from 50 tons to 100 thousand tons of rock mass and more, as well as in the implementation of an innovative single-rope steep skip hoist.

The construction of each innovative individual skip body consists of the following structural elements: a skip body that will not accommodate a movable transverse dividing panel; the top cover of each individual skip body; a device for irrigating the internal space of each skip body with water drops when loading a mixture of rock pieces into it; a braking device or braking devices for braking the movement of each individual skip body; a hinged side panel of the body section of each individual skip body, in which the mixture of mineral pieces is transported, used in removing the mixture of mineral pieces from the section of each individual skip body; a hinged side panel of a section of each individual skip body in which a mixture of pieces of waste rock is transported, used in removing the mixture of pieces of waste rock from each individual skip body; a hinged panel at the bottom of a section of each individual skip body in which the mixture of mineral chunks is transported, used in removing the mixture of mineral chunks from each individual skip body; a hinged panel at the bottom of each individual skip body, in which a mixture of pieces of waste rock is transported, used in removing the mixture of pieces of waste rock from each individual skip body.

5. 4. Justification of the parameters of the innovative bulldozer blade for the development of rock mass (placer, peat)

To improve the technical and economic indicators of the destruction of the soil massif of the bulldozer dump, an innovative scheme of its design and operation is proposed [19].

The technical effect is achieved by the fact that a quick-detachable plate wedge-shaped cutting knife is rigidly attached to the lower edge of the bulldozer blade, the transverse axis of the lower base of which is located horizontally and parallel to the upper outer horizontal surface of the destroyed section of the soil mass. At the same time, the destruction of the soil massif of the bulldozer blade with a removable cutting knife is carried out by applying a force to it, due to the optimal position of the bulldozer blade with a removable cutting knife, determined by its installation angle, depending on the geometric and kinematic parameters of the actuator of the bulldozer blade with a removable cutting knife and structural parameters of a bulldozer blade with a removable cutting blade [19].

The adjustable angle of installation of the bulldozer blade with a removable cutting knife is determined by the formula:

$$w=\alpha+\beta_0, \quad (7)$$

where w is a variable (controlled) installation angle of a bulldozer blade with a removable cutting blade between a straight line connecting the outer upper and lower edges of the blade and a horizontal line of the outer transverse axis of the base of a rigidly installed removable cutting blade of a bulldozer blade during the destruction of a horizontal section of the soil mass, rad.; *s* is a variable angle between the line of the longitudinal axis of the pusher bar and the line connecting the hinges of the attachment of the lower pusher bar to the bulldozer blade with a removable cutting blade, and the hinges of the brace attachment to the bulldozer blade with a removable cutting blade, depending on the geometric and kinematic parameters, the actuator of the bulldozer blade with a removable cutting blade knife, as well as the design parameters of the bulldozer blade with a removable cutting knife, i. e. $\alpha=f(j, y, d, r, R, L, l)$, which is determined by the formula [20]:

$$\alpha=\arccos\left(\frac{L^2+l^2}{2Ll}-\frac{R^2+r^2}{2Ll}+\frac{Rr}{Ll}\cos(\varphi-\psi)-\delta\right), \qquad (8)$$

where δ is a constant design angle between the line, which is a continuation of the longitudinal axis of the pusher bar, and the line of the longitudinal axis of the bracket, radi.; *j* is the angle between the longitudinal axes of the push bar and bracket, rad.; *y* is the angle between the line connecting the hinges of the bracket fastening and the line connecting the brace hinges, rad.; *L* its the bracket length between push bar and brace, *m*; *l* is the distance between the hinges of fastening the pushing bar and the brace to the bulldozer blade with a removable cutting knife, *m*; *r* is the length of the pushing bar between the hinges of its attachment to the bulldozer blade with a removable cutting knife and the hinges of its attachment to the bracket, m; *R* is the length of the brace between the hinges for attaching it to the bulldozer blade with a removable cutting knife and the hinges for attaching it to the bracket, *m*; β_0 is a constant constructive angle between a straight line connecting the outer upper and lower edges of the bulldozer blade with a removable cutting knife, and a line connecting the hinges of the push bar and brace to the bulldozer blade with a removable cutting knife, rad, shown in Fig. 2 [20].

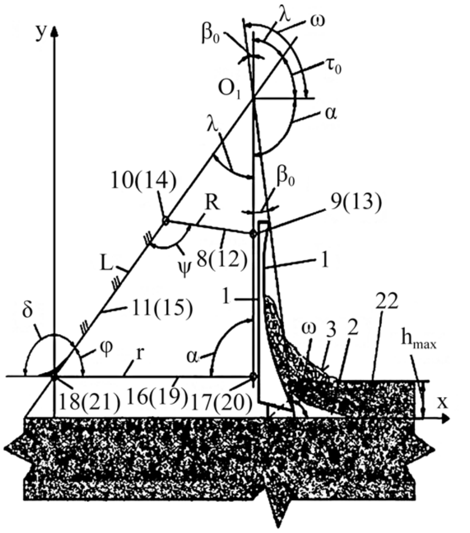

Fig. 2. An innovative structural-kinematic diagram of the bulldozer blade actuator with a removable cutting horizontally located knife and a diagram for determining the angle of cutting of a section of the soil massif by a bulldozer blade with a removable cutting knife and setting its optimal position depending on the physical and mechanical properties of the destroyed section of the soil massif

In the process of synthesizing the actuator of the bulldozer blade, depending on the conditions of the task, some parameters must be set, i. e. they will be the so-called given parameters. The remaining parameters of the structure diagram of the bulldozer blade actuator are to be determined by calculations, i. e. they are called defined parameters. The initial problem is reduced to the synthesis of a hinged four-link link according to the given five positions of the input and output links *r* and *R*, where *r* is the length of the pushing bar between the hinges of its attachment to the bulldozer blade with a removable cutting knife and the hinges of its attachment to the bracket; *R* is the length of the brace between the hinges of its attachment to the bulldozer blade with a removable cutting knife and the hinges of its attachment to the bracket; *L* is the length of the bracket between the push bar and the brace; *l* is the distance between the hinges of fastening the push bar and the brace to the bulldozer blade with a removable cutting knife; ω is the variable (controlled) installation angle of the bulldozer blade with a removable cutting blade between a straight line connecting the outer upper and lower edges of the bulldozer blade, and the horizontal line of the outer transverse axis of the base of the rigidly installed removable cutting blade of the bulldozer blade with a removable cutting blade of a horizontally located section of the array being destroyed soil; δ is a constant design angle between the line, which is a continuation of the longitudinal axis of the pusher bar, and the line of the longitudinal axis of the bracket; β_0 is a constant design angle between the straight line connecting the outer upper and lower edges of the bulldozer blade with a removable cutting knife, and the line connecting the hinges of the push bar and brace to the bulldozer blade with a removable cutting knife; α is the variable angle between the line of the longitudinal axis of the push bar and the line connecting the hinges of the lower push bar to the bulldozer blade with a removable cutting knife, and the hinges of the brace to the bulldozer blade with a removable cutting knife; φ is the angle between the longitudinal axes of the push bar and the bracket; ψ is the angle between the line connecting the bracket attachment hinges and the line connecting the brace hinges. According to the synthesis condition, the following parameters are set: ω, δ, β_0, α, φ_i, ψ_i, where i=1, 2, 3, 4, 5. Structural diagram of the bulldozer blade actuator with a removable cutting knife is represented as a closed vector system: After projecting onto the Cartesian axes of this system of coupled vectors, the following system of equations is obtained:

$$\begin{cases} r\cos(\phi+\delta)+L\cos\beta_0+R\cos(\psi+\omega)=l\cos\alpha, \\ r\sin(\phi+\delta)+L\sin\beta_0+R\sin(\psi+\omega)=l\sin\alpha. \end{cases} \qquad (9)$$

After transformation and introduction of appropriate notation, the following transcendental equation is finally obtained [20]:

$$B_iX_1+C_iX_2+D_iX_3+E_iX_4= \\ =\cos\left[(\phi_i-\psi_i)+(\omega-\delta)\right]-\cos\left[(\phi_i-\psi_i)-(\omega-\delta)\right], \qquad (10)$$

where

$$X_1=\frac{\cos\delta}{R};\; X_2=\frac{\sin\delta}{R};\; X_3=\frac{\cos\omega}{r};\; X_4=\frac{\sin\omega}{r};$$

$$B_i = L(\cos\phi_{i-1} - \cos\phi_i);\ C_i = L(\sin\phi_{i-1} - \sin\phi_i);$$

$$D_i = L(\cos\psi_{i-1} - \cos\psi_i),\ E_i = L(\sin\psi_{i-1} - \sin\psi_i)$$

and

i=2, 3, 4, 5.

In the same paper [20], a regression relationship was established between the cutting angle α_P and the geometric parameters of the bulldozer blade actuator:

$$u_k = 2.2\cdot10^{-4}\cdot L^2 + 5.009\cdot10^{-4}(1+r)^2 + $$
$$+5.7824\cdot10^{-12}(1+r)^2\cdot L^2 - 1.6\cdot10^3, \tag{11}$$

where L is the bracket length between push bar and brace, m; l is the distance between the hinges of fastening the push bar and brace to the bulldozer blade with a removable cutting knife, m; r is the length of the pushing beam between the hinges of its attachment to the bulldozer blade with a removable cutting knife and the hinges of its attachment to the bracket, m; R is the length of the brace between the hinges for attaching it to the bulldozer blade with a removable cutting knife and the hinges for attaching it to the bracket, m.

At the same time, random errors caused by the deviation of the designed actuator of the bulldozer blade with a removable cutting knife from its "ideal" model (8), and representing random errors, are determined by statistical moments $M\gamma_i$, whose values and their distribution laws do not depend on time (iteration numbers i); mean error values are zero: $M\gamma_i=M\delta_i=0$; the law of distribution of random variables may not be known, but their variances are known σ_γ^2 and σ_δ^2; it is assumed that all random errors are independent [21].

It is assumed that at the i-th step the filtered value from the sensor is found x_i^{opt}, which approximates the true coordinate of the system x_i. Unknown value x_{i+1} is determined by:

$$x_{i+1} = x_i + u_i + \gamma_i, \tag{12}$$

where u_i is the value that controls the evolution of the state matrix of the position of the removable cutting blade of the bulldozer blade in the developed section of the soil massif; γ_i and δ_i is accordingly, the errors of the mathematical model for determining the position of the removable cutting blade of the bulldozer blade in the developed section of the soil massif and the measurement errors of the position of the removable cutting blade of the bulldozer blade in the developed section of the soil mass, measured by technical measuring instruments.

Therefore, while not yet receiving the value from the sensor, it is assumed that at the step i+1 the system evolves according to this law and the sensor will show a value close to the value $x_i^{opt}+u_i$. On the other hand, at step i+1 there is an inaccurate reading from the sensor z_{i+1}. The idea is to get the best approximation to the true coordinate x_{i+1} so-called "golden" mean between the indication z_{i+1} source from the sensor and $x_i^{opt}+u$, being its prediction. The sensor reading is given a Kalman weight K, and the predicted value (1–K) is given a value x_{i+1}^{opt} is determined by the formula:

$$x_{i+1}^{opt} = K\cdot z_{i+1} + (1-K)\cdot(x_i^{opt}+u_i), \tag{13}$$

where K is the Kalman weight coefficient, the value of which is chosen such that the resulting optimal value of the coordinate x_{i+1}^{opt} would be closest to the value of the true coordinate x_{i+1}. For example, if it is known that the readings from the sensor are very accurate, then the degree of confidence in it will be greater and the value of z_{i+1} has a greater weight (K is close to one). If, on the contrary, the sensor is completely inaccurate, then it is necessary to focus more on the theoretically predicted value $x_i^{opt}+u_i$. In general, to find the exact value of the Kalman coefficient, it is necessary to minimize the amount of random and systematic errors γ_i and δ_i.

In general, to find the exact value of the Kalman coefficient, it is necessary to minimize the value

$$e_{i+1} = x_{i+1} - x_{i+1}^{opt}. \tag{14}$$

After substituting formula (13) into equation (14), it turns out:

$$e_{i+1} = (1-K)\cdot(e_i+\gamma_i) - K\cdot\delta_{i+1}. \tag{15}$$

The average value of the mathematical expectation from the squared error is minimized:

$$M(e_{i+1}^2)\to\min. \tag{16}$$

The mathematical expectation of the square of the error of penetration of the removable cutting blade of the bulldozer blade into the developed section of the soil mass is determined by the formula:

$$M(e_{i+1}^2) = (1-K)^2(Me_i^2+\sigma_\gamma^2) + K^2\sigma_\delta^2. \tag{17}$$

This expression takes on a minimum value under the condition:

$$K_{i+1} = \frac{Me_i^2+\sigma_\gamma^2}{Me_i^2+\sigma_\gamma^2+\sigma_\delta^2}. \tag{18}$$

To determine the Kalman weight coefficient, it is necessary to calculate the statistical moments of random errors of its mathematical model and systematic errors in measuring the resistance force of destruction of a section of the soil mass of the actuator of the bulldozer blade and the thickness of the layer of the destroyed section of the soil mass. Thus, an algorithm is implemented for solving the developed mathematical model, evaluating the stochastic system of the dynamic process of interaction between the actuator of the bulldozer blade with a removable cutting knife and the developed section of the soil mass using an iterative formula for calculating the weight coefficient K [21].

The theoretical provisions set forth in the study were confirmed by experimental studies to establish a confidence interval for estimating the mathematical expectation of a random value of the cutting resistance force of the rock mass (soil category III (clay) in the interval of changing the cutting angle 20°<α_p<30°. The value of the average sample of the random value of the cutting resistance force of the III category soil at n=50 was P=81.35 kN. Confidence interval at the reliability level γ=0.95 and σ_δ=10 and Student's coefficient $t(\gamma,n)$=2.009 was (78.52;84.18). The constructed confidence interval for estimating the mathematical expectation of the random value of the resistance force to the destruction of a section of a rock mass (soil category III (clay) with a cutting angle in the range from 20° to 30° and the value of the Pearson criterion, at a significance level of α=0.05, allowed draw a conclusion about the normal distribution of the general population of the random variable under study, the force of resistance to the destruction of a section of the rock mass *R*. The value of the force of resistance to the destruction of the rock mass section, obtained by analytical and experimental methods, is refined by finding the optimal Kalman coefficient at σ_γ=1 and σ_δ=10 and at *K*=0.1, stabilization of changes in the values of the Kalman coefficient was observed [21].

6. Discussions on the results of the development of an information expert system

Development of an expert system for automating the dispatching of mining transport vehicles with a subsystem for selecting innovative mining transport vehicles with the control of their operational parameters, taking into account the stochastic conditions of the developed section of the rock mass.

Fig. 1 shows the general concept of building an automated control and dispatching system for mining and transport vehicles in the development of deposits of solid minerals in an open way. With a description of its main subsystems with the functional purpose of each of them, and the structural and functional relationships between them in the implementation of the dispatching of mining and transport machines in the development of deposits of solid minerals in an open way.

The functional and economic assessment of rock mass movement by traditional mining transport machines, proposed in the article, for example, automobile, conveyor, single-rope and multi-rope steeply inclined skip hoists, which are operated using lifting machines, showed that it is unprofitable to use rock mass transportation in quarries, the depth of which is 600 m or more. The development of a mathematical model for constructing a prospective appearance of mining and transport machines based on their functional and structural assessment is reduced to solving the problem: folding a system of partial criteria into a generalized criterion of the required effect (efficiency). These criteria characterize a mining and transport machine that has the following operational parameters: productivity, reliability, adaptability to the conditions of the technological process, productivity, equipment with replaceable working bodies, control system, infrastructure and comprehensive provision of spare parts, etc. The results of calculating the parameters of the functional and economic model for assessing the appearance of the skip hoist during a given period of time, performed for a conditional example, is shown in Table 1.

Based on the developed functional-economic approach [18], the article proposes a promising view of a skip hoist for transporting rock mass in a quarry. Several variants of innovative single-rope and multi-rope steeply inclined skip hoists without a lifting machine are proposed, the use of which will allow transporting lumpy rock mass in one step in one skip, the volume of which is unlimited, for example, up to 100 thousand tons and more, in quarries, the depth of which is unlimited , for example, up to 3000 m and more, with an annual productivity of a quarry of up to 300 million tons of rock mass and more, while excluding the harmful effects of the technological process of transporting rock mass on the environment and during their operation under any climatic conditions.

Methods have been developed for substantiating and selecting the structural, dimensional and regime parameters of the operating mechanism of the working body of a mining transport machine using the example of a bulldozer blade with a removable cutting knife, taking into account the stochastic conditions of the developed section of the rock mass [19], which increases the accuracy of their assessment. These methods are the basis for creating innovative competitive adaptive actuators of the working bodies of mining and transport machines. In [12], the soil conditions for the operation of earth-moving machines in Kazakhstan were studied. Experimental results of studies of the process of destruction of soils and rocks are presented. At the same time, it is noted that one of the main factors affecting the efficiency of the process of destruction of soils and rocks is the angle of destruction α_p (cutting angle formed by the path of motion and the leading edge of the cutting wedge). In the same place, the regression dependence of the force of resistance to destruction of a section of the soil mass (rock mass) on the geometric parameters of the bulldozer blade, the strength coefficient of the destroyed section of the soil mass K_p and the depth of its destruction (cutting) at known intervals of change in the value of the angle of destruction (cutting) α_p. In this study, the analytical dependence between the cutting angle and the structural-kinematic parameters of the bulldozer blade actuator is substantiated (8). This circumstance increases the accuracy of estimating the cutting resistance force of the rock mass and allows to automatically adjust the cutting depth of the rock mass by changing the structural and kinematic parameters of the bulldozer blade actuator. The theoretical provisions set forth in the study were confirmed by experimental studies to establish a confidence interval for estimating the mathematical expectation of a random value of the cutting resistance force of the rock mass (soil category III (clay) in the interval of changing the cutting angle $20° < \alpha_p < 30°$. The value of the average sample of the random value of the cutting resistance force of the III category soil at n=50 was P=81.35 kN.

The confidence interval at the level of reliability γ=0.95 and σ_δ=10 and Student's coefficient $t(\gamma,n)$=2.009 was (78.52;84.18). The constructed confidence interval for estimating the mathematical expectation of the random value of the resistance force to the destruction of a section of a rock mass (soil category III (clay) with a cutting angle in the range from 20° to 30° and the value of the Pearson criterion, at a significance level of α=0.05, allowed draw a conclusion about the normal distribution of the general population of the studied random value of the force of resistance to the destruction of a section of the rock mass *P*.

The value of the resistance force to the destruction of the rock mass section, obtained by analytical and experimental methods, was refined by finding the optimal Kalman coefficient at $\sigma\gamma$=1 and σ_δ=10, and at *K*=0.1, stabilization of changes in the values of the Kalman coefficient was observed [21].

The results obtained are the theoretical basis for the creation by an expert dispatching system of mining transport machines with a subsystem for selecting their innovative appearance with the ability to control their operational parameters, taking into account the stochastic conditions of the developed sections of the rock mass. This system is intended to be used in the operation of quarries, the annual productivity of which is unlimited, for example, up to 300 million tons of rock mass or more, and the depth of the quarry is unlimited, for example, up to 3000 m or more, while ensuring effective values of technical and economic indicators of mining fossils, i.e. highly profitable, ensuring safe working conditions for personnel, eliminating harmful effects on the environment during their use and operation under any climatic conditions.

In subsequent articles, it is planned to present research on the development and creation of mathematical and computer models of the perspective appearance of a skip hoist for transporting rock mass in a quarry and its main structural elements. It is planned to test the working version of the automated dispatching system for the control and dispatching system of mining transport machines with an expert subsystem for choosing their innovative appearance with the ability to control their operational parameters, taking into account the stochastic conditions of the developed sections of the rock mass in the development of deposits of solid minerals in an open way.

7. Conclusions

1. A general concept is proposed for the construction of an automated control and dispatching system for mining transport machines in the development of deposits of solid minerals in an open pit with an expert subsystem for selecting their innovative appearance with the ability to control their operational parameters, taking into account the stochastic conditions of the developed sections of the rock mass. Existing systems for the development and transportation of rock mass use traditional modes of transport, for example, automobile, conveyor, skip hoist with a lifting machine, this circumstance determines the high cost of transporting 1 ton of rock mass. In addition, the known systems do not have an expert subsystem for managing the operational parameters of mining vehicles, which is the reason for their inefficient use. The proposed system has an expert subsystem for selecting an innovative design of a transport vehicle with practically unlimited carrying capacity and without the use of a lifting device, and, for example, eliminates the need to build special transport routes (berms) for vehicles inside the quarry, which determines the low cost of transporting 1 ton of rock mass. In addition, the proposed system allows to automatically control the operational parameters of mining and transport machines, depending on the stochastic conditions of the developed section of the rock mass.

2. The article proposes a mathematical model for constructing the prospective appearance of mining and transport machines based on their functional and structural assessment, which boils down to solving the problem of folding systems of partial criteria into a generalized criterion of the required effect (efficiency). These criteria characterize a mining and transport machine that has the following operational parameters: productivity, reliability, adaptability to the conditions of the technological process, productivity, equipment with replaceable working bodies, control system, infrastructure and comprehensive provision of spare parts, etc.

3. Based on the developed functional-economic approach [2], the article proposes a promising view of a skip hoist for transporting rock mass in a quarry. Several variants of innovative single-rope and multi-rope steeply inclined skip hoists without a lifting machine are proposed, the use of which will allow transporting lumpy rock mass in one step in one skip, the volume of which is unlimited, for example, up to 100 thousand tons and more, in quarries, the depth of which is unlimited , for example, up to 3000 m and more, with an annual productivity of a quarry of up to 300 million tons of rock mass and more, which significantly reduces the cost of transporting 1 ton of rock mass, practically eliminates the harmful effect of the technological process of transporting rock mass on the environment and ensures their operation under any climatic conditions. The existing traditional means of transporting rock mass from a quarry do not have such quality indicators. In well-known works, such problems were neither posed nor solved.

4. Methods for substantiating and selecting the structural, dimensional and regime parameters of the operating mechanism of the working body of a mining transport machine using the example of a bulldozer blade with a removable cutting knife were developed, taking into account the stochastic conditions of the developed section of the rock mass, which increases the accuracy of their assessment. These methods are the basis for creating innovative competitive adaptive actuators of the working bodies of mining and transport machines. The analytical relationship between the cutting angle and the structural-kinematic parameters of the bulldozer blade actuator is substantiated. This circumstance increases the accuracy of estimating the force of resistance to cutting the rock mass and makes it possible to automatically adjust the cutting depth of the rock mass depending on the stochastic conditions of the developed environment – the bulldozer blade by changing the structural and kinematic parameters of the bulldozer blade actuator. The theoretical provisions set forth in the study were confirmed by experimental studies to establish a confidence interval for estimating the mathematical expectation of a random value of the cutting resistance force of the rock mass (soil category III (clay) in the interval of changing the cutting angle $20°<\alpha_p<30°$. The value of the average sample of the random value of the cutting resistance force of the III category soil at n=50 was P=81.35 kN. The confidence interval at the level of reliability γ=0.95 and $\mathbf{s_d}$=10 and Student's coefficient $t(\gamma, n)$=2.009 was (78.52; 84.18). The constructed confidence interval for estimating the mathematical expectation of the random value of the resistance force to the destruction of a section of a rock mass (soil category III (clay) with a cutting angle in the range from 20° to 30° and the value of the Pearson criterion, at a significance level of α=0.05, allowed draw a conclusion about the normal distribution of the general population of the random variable under study, the force of resistance to the destruction of a section of the rock mass R.

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