UDC 001.891.57:622

A. V. VOSTRIKOV [1], *Associate Professor, Candidate of Egineering Sciences*
E. N. PROKOFEVA [1], *Associate Professor, Candidate of Egineering Sciences, eprokofyeva@hse.ru*
S. N. GONCHARENKO [2], *Professor, Doctor of Egineering Sciences*
I. V. GRIBANOV [1], *Analyst*

[1] *National Research University Higher School of Economics, Moscow, Russia*
[2] *National University of Science and Technology—MISIS, Moscow, Russia*

ANALYTICAL MODELING FOR THE MODERN MINING INDUSTRY

The modern mining industry has huge innovative potential for the introduction and development of digital revolution products. It has always been the most important industry of modelling development, as many operations and processes here are directly empirical and provide a large amount of data for quantitative analysis, which is now well suited to the use of digital intelligent technologies. With the development of digital technologies, effective integrated modeling techniques and the introduction of new process management, knowledge and data analysis tools are needed. Analytical models here are primarily designed to symbolize object properties in dynamics. Intelligent models and solutions based on the use of information technologies and methods of working with big data were becoming most popular, and the processes of integrated monitoring, personalization, risk management, search and generation of solutions, web orientation of programs and technologies and formation of network organizational structures of management were becoming particularly important. Mining enterprises have specific risks: mining and geological risks, risks of loss of market share and investment attractiveness due to biased valuation of useful fossil reserves, risks related to cybersecurity and innovation. Enterprises need to implement new technologies in a comprehensive manner, and information innovation is becoming very important in the face of a lack of financial resources. Expert systems, fuzzy logic, neural networks and genetic algorithms are the most relevant applications in international practice of geoinformation resource management, which largely determines the practical use of artificial intelligence methods and tools in interaction with pound-based management solutions. Modern analytical expertise includes the integration of process management systems, in particular those that are different, which is based on the development of a large number of integration technologies and techniques that apply different data models and are carried out through different procedures. The study examines the development of analytical models based on intelligent technologies, which are now increasingly used in various areas of the mining industry.

Keywords: *expert analytical modeling, mining, digital technologies, intelligent systems, geoinformation data.*
DOI: *10.17580/em.2019.02.07*

Introduction

In the information society, the main vector of development is not only material production, but also the production of knowledge and information based on advanced technologies and intelligent systems. Currently, the greatest attention is paid to the rational use of all space-time resources. The concept of formation and development of effective spatial data infrastructure in our country was determined by the Strategy of information society development in the Russian Federation in 2008, in the current adopted version — for 2017 — 2030. Modern geographic information system is a set of hardware and software and algorithmic procedures created for digital support, replenishment, management, manipulation, analysis, mathematical and cartographic modeling and image display geographic coordinate data for their effective use in solving scientific and applied tasks related to inventory, analysis, modeling, forecasting, and environmental management and territorial organization of objects [1–6]. The key vector of innovation development here is the creation and implementation of technological solutions using software and hardware tools that represent a complex system of expert analytical modeling, which should be understood as a procedure for obtaining an assessment of the problem based on the opinion of specialists (experts) for subsequent decision-making. Of great importance here are the programs of intelligent production and digital design, where control is carried out remotely or completely automatically. The effectiveness of the use of geographic information systems in industry is expressed in many ways: in updating and replenishing the topographic base for the territorial objects of enterprises; monitoring compliance with the boundaries of allotments and environmental zones; quality forecasting and environmental monitoring; integrated mapping of geological formations in the system of mineral exploration; in the planning of capital construction and the creation of infrastructure communications. In addition, digital technologies can significantly reduce production time and reduce its costs, and digital modeling of processes significantly reduces the number of field tests and experiments [7–14]. It will be difficult for Russian industry to remain competitive without the introduction of digital design systems and their life cycle management. That is, the effective modeling of processes, as well as the development of new methods and standards of digital design, are of great importance here. Based on the study of these materials of expert analytical reports of the largest professional consulting Agency PricewaterhouseCoopers in the areas of digital technology development in the global mining industry, we can identify three most promising strategic groups of models for innovative improvement of the functioning of organizations in the near medium term

(5–10 years), taking into account the specifics of Russian enterprises and the situation in the industry:

1. Digital intelligent mining management based on knowledge bases, expert work with big data, generation of relevant management solutions by comparing rational options, implementation of change management tools and forecasting systems of technical and economic figures, creation of virtual management structures and development of telecommunication systems and network structures for departments and within the framework of inter-organizational interaction. Some elements of the active implementation of these models are now typical in our country for the divisions of the Mining and metallurgical company Norilsk Nickel.

2. Implementation of effective process management structures for digital design and modeling based on modern quality management standards, complex systems of organizational stability and safety management, application of balanced scorecard and performance indicators methodologies, in particular BSC (Balanced Scorecard), international development methodologies and project activity standards — application of Agile, Scrum, Kanban, Lean, Just-in-Time project management methods, etc. In addition, the transition from a rigid classical model of project management to flexible iterative-incremental methods is particularly relevant for mining enterprises in digital development planning. Also important is the implementation of standards of comprehensive generic process cost measurement and analysis of the implementation stages of the projects by different teams of specialists, for example, the monitoring of progress based on the SEMAT initiative. The Siberian coal energy company is a bright example of successful current implementation here.

3. Implementation of digital project training for high-quality continuous training and advanced training of specialists in accordance with international standards of quality of engineering education using mixed learning technologies and virtual training programs based on geo-information data.

It should be borne in mind that the harmonious effective development of the entire industry will be possible only in the case of an integrated implementation of a system of multiple methods, tools and process control models for a number of groups with approximately equal frequency and frequency of application, which will provide a synthesis of expert analytical approaches and a synergistic effect. On the basis of comparative analysis of risk assessment methods of business projects of mining enterprises, it was found that in the conditions of high uncertainty accompanying the modernization of production processes, the expert analytical approach to risk analysis takes the leading position. The basis for the construction of expert analytical models are complex risk management systems and systems of intellectual efficiency of production processes at the mining enterprise. Here, among the key drivers of formation of systems of organizational stability and business process management, based on research data, reports and international ratings of ore and metallurgical enterprises, made by Ernst & Young over the past 3 years, it is necessary to highlight the TOP 10 factors: 1. Optimize the use of all types of resources. 2. Efficiency, investment attractiveness and capital intensity. 3. Growth of productivity and production capacity. 4. Social and corporate responsibility. 5. Transparency, availability and adaptability of functional data. 6. The growth of requirements for environmental safety and quality of production. 7. Development of technologies for efficient use of energy resources and new energy sources. 8. Enterprise integration and clustering. 9. High requirements of computer security. 10. Innovative potential.

One of the directions of formation of intelligent automated systems of process control at mining enterprises is the construction of dynamic matrix risk rating maps, where all elements of arrays in functional areas and the order of the matrix determine the probability of risk and the value of the degree of negative consequences on different scales (from small to maximum value). Intelligent processing allows integrated qualitative and quantitative assessment of different risk groups to compare the probabilities of favorable and unfavorable situations and generate effective solutions. When creating 3D matrix maps, the dynamic guide (vector) is the behavior of stock markets and political factors. The development of information and analytical systems that support the development of the enterprise in these areas, as well as their implementation in practice, can significantly improve the quality of engineering and management decisions taken under the conditions of risk and information uncertainty.

The building of geospatial data modeling systems

Modelling is one of the ancient and at the same time the latest methods of scientific information and data management, which undergoes continuous dynamic development and modification. It finds application in a wide range of mining industries in solving specific scientific and technical problems. As is known, the model was understood to be a material sample of other objects as a prototype, preserving a certain structure and properties of the original, but over time the model has increasingly become also a mentally created structure or analytical algorithm. The use of the process of modeling geospatial objects is primarily due to the fact that models are usually more convenient to study, measure and record their characteristics for expert analysis and conclusions [15–19]. The organization of modeling as process, as a rule, includes a number of consecutive phases: initial inspection, creation and verification of initial hypotheses of structure, properties and the nature of an object, identification of analogies and prototypes, definition of key characteristics of process, specification and definition of a method of modeling, the empirical or heuristic analysis of opportunities, formation of model, comparison of result to the set conditions and parameters, the analysis of compliance and improvement. In mining, subject and abstract oriented modeling has been developed, the first is the display on the required scale of key geometry, physical, dynamic and functional characteristics and properties of the object is conditionally divided into physical, analog and natural models. The abstract mo-division of spatial data is represented by heuristic and iconic elements. When the physical nature of the model and the object corresponds, physical modeling

takes place. Studies of phenomena on models of different physical nature, but through the same mathematical equations, are analog model-generation. The method of electrohydrodynamic analogs based on analogy between current flow in a conductor and water filtration in a porous medium, heat transfer due to heat conductivity in a solid body can be given here. The electric analogy method developed by Gutenmacher, the hydroplacial analogy method proposed by Lukyanov (Lukyanov's hydraulic integrator), could also be considered. The development of computer technologies made it possible to effectively solve equations by numerical methods, the analog direction of modeling almost lost its importance.

A heuristic approach is defined by general perceptions and considerations of real phenomena without the use of clearly fixed sign complex systems, for which it is difficult to create mathematical models. In these cases, intuition, accumulated professional experience, ability to formulate certain stages of the problem-solving algorithm are used for research. In the computing plan some difficult algorithms can be replaced simplified without any proofs on the basis of expert solutions. Heuristic models often are called scenarios of the phenomenon. It demands on multistage approach and collecting missing information, repeated correcting of results. This form are based on forming of expert and analytical models for processing of geospatial data. At the same time different forms of natural empirical modeling found wide circulation in hydrogeological practice in production experiments and observations on natural objects. For example, for the forecast of change of the mode of subsoil waters of the reclaimed territories, for forecasting of a drainage of subsoil waters and for other tasks data of researches in the same or other, similar territories are used. But to development of technologies of visualization and digital technologies there is forming of the integrated modeling methods on the basis of systems analysis, appear effective expert and analytical models and solutions based on integrated management of data. A special kind of models are the test stands, programs exercise machines and simulators based on use of the special devices combining physical and mathematical models with natural devices and objects [20–25]. Besides, a variety of conditions of bedding and mining, high cost of technology solutions in mining represent reasonable monitoring of options of conducting works with use of a computer hardware and the software. Such simulation experiments allow to answer before real investments into production questions: what solutions will be able to increase labor productivity? how to coordinate work of sections of a technological chain? what equipment will be required upon transition to other sections of production? what schedule for work of sections is more effective? how to manage technical risks? Simulation modeling found active application in mining, since the second half of the last century, it was used for planning of drilling, detonation, loading and fastening in faces of the coal mine, on the basis of simulation modeling on the Fortran the task of the analysis of functioning of work of a mine transport network was solved. P.V. Grechishkin used a problem-oriented Petri net simulator to simulate the long-face cleaning process. Now relevant simulation models of mountain processes even more often develop on the basis of the systems of modeling of general purpose – GPSS (General Purpose Simulation System).

In Russia from the second half of the last century of development in the field of simulation modeling of mining operations were run on the basis of scientific centers of Research Institute for the Problems of the Kursk Magnetic Anomaly, Institute of Comprehensive Exploitation of Mineral Resources Russian Academy of Sciences (IPKON), Central Research Geological Prospecting Institute of Non-Ferrous and Noble Metals, Mining Institute of Kola Science Center of Russian Academy of Sciences. These developments were directed to creation of simulation calculations and representation of the simulation sequences of the equations. Since the end of the eighties years of work on simulation modeling of space data in our country were practically not conducted, only in the last decade in the conditions of digital revolution and calls of information society for the Russian enterprises there was relevant a creation of new methods and instruments of expert and analytical modeling. At the same time, it should be taken into account that development of the integrated systems of geospatial modeling and implementation of digital systems in design of processes is irrational without creation of effective geo-information solutions and forming of standards directly in forming of these systems. Creation of effective solutions is impossible without development of information products and knowledge bases for high-quality management here. In the field of space information the set of the organizations is engaged in questions and creation of formal standards. Need of improvement of standardization of processes is defined by the problems connected with quality of formal standards and also for their implementations. The specifications created by Open GIS Consortium are divided into two types - the abstract specification (Abstract Specification) which regulates the basic principles of creation of geographic information systems, and specific specifications in software development (Implementation Specification) which number constantly grows. So far, the Russian companies are not participants of Open GIS Consortium. Thus, there is a need of increase in efficiency and quality of geographic information systems for improving competitiveness of technologies in the international market, including, by rational use of systems of the integrated standards and rational models. Let's consider modern most perspective types of digital modeling and geospatial data analysis and the direction of their development and also methods of management of digital design at the mountain enterprises.

Prospects for development of expert and analytical modelling in mining industry

Modern development of digital design demonstrates that the set functional purposes of the strategic program of development of the enterprise are supported with the defined well thought over unique techniques, tools and tactical decisions created in each concrete organization that plays an important role in success of the mining sector of the country. However, in the last decade in Russia,

Modern directions of development of expert analytical systems and model of work with geospatial information: key prerequisites and characteristics

Big Data	Methodologies for dealing with non-standard information	Synthesis of information	Complex Analytics and structuring information	Visual Outputs and Tool Selection
Exponential growth of data and you-number capacities in turn multiplies the number of opportunities for obtaining useful information	Telematics, satellite technologies, sensor readings, digital voice/ video text recordings and other new technologies create analytical solutions and expert data, knowledge based on previously impossible analytical, machine-based quantitative processing of information flows	The development of data analysis and processing technologies increases our ability to extract results and solutions from complex, erratic and unstructured information flows	Advanced analytical techniques, such as digital modeling and optimization, enable you to adapt previously inaccessible source information into real-time structured data	Presenting complex amounts of data in a visually simple and meaningful format begins with the right choice of a certain tool, which ultimately greatly accelerates decision-making and results

much attention was paid to complex development of the knowledge-intensive economy, development of expert and analytical systems and digital design at the mountain enterprises concedes to some other the industries, in particular the Military-Industrial Complex (MIC). The traditional scheme of technical modernization of the equipment in the current situation does not bring necessary competitive advantages any more. For cluster initiatives of the real sector special attention is paid to knowledge, the expert analysis of data and digital control by processes. Relevant world trends in the field of modeling and processing, analytics and visualization of data in mining industry are presented in **table**.

Within the mountain enterprise great importance is presented by algorithms, models and the sequence of operational implementation of projects and project management to a stage of effective functioning that in turn requires a system solution of a number of tasks: forming of the complex digital integrated coordinate space on the basis of creation of databases with use of satellite navigation technologies and robotic systems; modeling of virtual objects of an organization and production structure of the companies; creation of visual objects of space for preventive management of technical risks and reliability of functioning of processes; definition and modeling of key discrete objects of geospace and geosystems; program creation of visual cartographic images and iconic models of a part of spaces; forming of rational applied software solutions in the field of digital design; automation of expert techniques of management and standardization, creation of knowledge bases, digital 3D design within geoinformation environments.

On the basis of studying of the Russian and foreign experience in the mountain industry it is possible to formulate a number of criteria for comparison purposes of quality of the implemented expert and analytical systems and geoinformation solutions: technical opportunities, properties and parameters of a system of modeling, width of coverage of functional use, uniqueness and adaptivity, efficiency of subsystems of management and acceptance / generation of solutions, simplicity in operation, the user interface and opportunities, compliance to the Russian and international quality standards, reliability (non-failure operation) and possibilities of self-regulation and intellectual assessment, network orientation, efficiency of help and expert knowledge bases, the module of training and settings of interaction in the person machine system, monitoring systems, assessment, risk management and environmental safety, interaction with navigation satellite systems and the systems of remote sensing of Earth, efficiency and coverage of modules of control and monitoring of processes, possibilities of modification and integration, efficiency of work and the general dynamics on restructuring and changes, qualitative data of polls of opinion of users and experts, cost efficiency, social result, overall effectiveness and synergy effect.

Digital design and standardization of process management based on knowledge base construction as essential quality assurance tools at the start-up and operation stage are of great importance. But also planning of mining enterprise industrial processes, when there is a possibility of maximum reduction of time and cost of works, It is possible to take into account the largest number of negative factors, in particular in the system of technical risk management - new digital mechanisms and research tools are used here (Monitoring and modelling), fully replacing expensive direct empirical experimental works [26–32].

The international practice of organizing efficient technical processes in the mining industry demonstrated the widespread use of project management to develop innovation in all functional areas. Domestic practice is no exception. At the moment, our country has implemented and is implementing quite a few projects of various sizes using systems of automated analysis of big data and artificial intelligence, for example, during the organization of the Olympic Games-2014 in Sochi, during the implementation of Federal programs for the construction of roads and nuclear power plants, during the development of the Arctic shelf and the Pacific region, in the development of global navigation systems for automation of object management in space.

A common class of multi-criterion choice management solution tasks is the task of comparative evaluation of alternative innovative projects. A number of methods and tools were relevant to the development of intelligent systems for innovative projects, in particular the hierarchy analysis method and the analytical network method, which were used in cases where it was necessary to take into account the links between hierarchy elements, to integrate the many factors involved in solutions, which made it easier to find solutions by presenting a complex problem in the form of a consistent analysis of simpler

tasks. The effective choice of an innovative project at an early stage of its justification was difficult to make on the basis of any rigorous mathematical models or statistical analysis, and should be based on the competent opinions and expertise of professional experts familiar with the specifics of the innovative projects. The intelligent automated principle of expert interviewing and data processing is of great importance.

A key problem in hierarchy analysis was the rigid subordination of elements, with upper-level elements dominating lower-level elements. It was important to consider the interaction of hierarchical levels for components, since not only did the importance of the criteria affect the priorities of alternatives, but the importance of the alternative also affects the priorities of the criteria, which justified the need to move to the set models. The big advantage of feedback networks was the possibility of obtaining solutions that made it possible to anticipate the future, which was particularly important in the case of investment projects for the development of mountain enterprises in the context of sanctions in the current period of time.

Expert analytical information systems are implemented in various applications, in particular, systems based on Expert Solution and Expert Decide have been used and are being developed at Russian enterprises. The implementation of forward and reverse hierarchical models, which were followed by the order of criteria and alternatives, was particularly important. The direct model first prioritized the criteria and then the priorities of the alternatives, in reverse, the two levels changing places. The second — the inverse model - is formed automatically, but also in the direct hierarchy, experts then have to perform paired comparisons of the model elements. Then, also in automatic mode, a network model is formed, which takes into account the mutual influence of the block of groups of criteria and the block of alternatives. At the stage of the set model, experts no longer participate in the survey, the formation of the block supermatrix and the calculation of priorities are carried out by the system in automatic mode.

The application of criteria not only in the limited field “Opportunities — Risks,” but also taking into account factors and dynamics of future development on the section “Benefits - Costs,” that is, comparisons of benefits, costs, opportunities and risks of various projects are applicable for research and selection of options for organization of transportation of energy resources, which has now found active application in the USA and is especially relevant for our country. Also for Russian mining enterprises, the development of intelligent systems and expert and analytical modelling of technological, economic and environmental risks was of great importance at the moment. The key parametrical probabilistic factors here are: mining and geological and climatic features of the terrain, types of technological processes, peculiarities of mining transport complex management, types of equipment, physical wear and tear and methods of di-station control, time and age of development and functioning by volume in space, intensity of operational processes, level and importance of non-controlled factors, financial capabilities and intellectual potential. The development of multifunctional systems of training and expert work, remote forms of control and control based on satellite navigation systems, robotic control systems and intelligent software and decision-making were important in that case.

Conclusion

The review in the article showed the possibilities, prospects and importance of the development of expert and analytical modelling as a basis for modernization of key processes of mining production management and an effective tool for reducing technological and time costs. The development of effective management systems was inextricably linked to the improvement of information technologies, while, at the same time, the development and transfer of new knowledge were key factors in the success of management and efficiency, which defined fundamentally new tools and led to a fundamental change in the ideology of information management and information and analytical systems (IAS) for production processes, where the creation of remote service of solutions based on geographic information data and tools becomes the most relevant. Of great importance here is also the effective construction of training systems, and it is necessary both technical-oriented — methods of machine learning and neural networks, and personal-oriented — digital methods and modules of project training and qualification of professionals on the basis of standards of training of mountain engineers. A comprehensive, balanced, expert-based mix of developed tools could bring maximum benefit to each mining enterprise and industry as a whole.

References

1. Forecast of scientific and technological development of the Russian Federation for the period until 2030 (approved. The government of the Russian Federation on 3 January 2014). Available at: http://www.garant.ru/products/ipo/prime/doc/70484380/#ixzz4aP1zXHhy (accessed: 27.03.2019).
2. The Development Strategy of Information Technology Industry in the Russian Federation for 2014–2020, and the Prospect for 2025; Available at: http://government.ru/docs/8024/ (accessed: 27.03.2019).
3. Yeralin Z. M., Goncharenko S. N. Models for solving key problems of strategic development of uranium mines. *GIAB*. 2019. No. 4. pp. 199–208.
4. Prokofeva E. N., Vostrikov A. V. Assessment of the quality of information flow management in organizations. *Vestnik RIAT*. 2017. No. 2. pp. 45–48.
5. Prokofeva E. N., Vostrikov A. V., Fernandez E., Borisov N. Navigation satellite systems as the audit foundation for mining companies. *Eurasian Mining.* 2017. No. 1. pp. 30–32. DOI: 10.17580/em.2017.01.08
6. Prokofeva E. N., Vostrikov A. V., Shapovalenko G. N., Alvarez A. The development of effective geomonitoring for mining area with industrial review. *Eurasian Mining.* 2017. No. 2. pp. 61–63. DOI: 10.17580/em.2017.02.15
7. Everything about mining. Extractive industries. Available at: http://industry-portal24.ru (acccessed: 5.04.2019).
8. Mining – Info portal. Available at: http://mining-info.ru/sovremennye-sistemy-modelirovaniya-p/ (acccessed: 27.03.2019).
9. Zotov L., Frolova N., Shum C. Gravity Changes over Russian River Basins from GRACE. Planetary Exploration and Science:

Recent Results and Advances. Berlin : Birkhauser, Springer, 2015.
10. Zotov L., Bizouard C., Shum C. A possible interrelation between Earth rotation and climatic variability at decadal time-scale. *Geodesy and Geodynamics*. 2016. Vol. 7, No. 3. pp. 216–222.
11. Aleskerov F. T., Karabekyan D., Ivanov A., Yakuba V. I. Individual manipulability of majoritarian rules for one-dimensional preferences. *Procedia Computer Science.* 2018. Vol. 139. pp. 212–220.
12. Vasin S., Gamidullaeva L., Shkarupeta E., Finogeev A., Palatkin I. Emerging trends and opportunities for industry 4.0 development in Russia. *European Research Studies Journal*. 2018. Vol. XXI, Iss. 3. pp. 63–76.
13. Tolstykh T., Shkarupeta E., Shishkin I., Dudareva O., Golub N. Evaluation of the digitalization potential of region's economy. *Advances in Intelligent Systems and Computing*. 2018. Vol. 622. pp. 736–743. DOI: 10.1007/978–3-319–75383–6
14. Goncharenko S. N., Duong L. B., Petrov M. V., Stoyanova I. A. Modeling of parameters of innovation water-protection measures on the basis of industrial-technological indices of coal mining at Vietnam enterprises. *Gornyi Zhurnal*. 2014. No. 9. pp. 143–146.
15. Potekhin I., Mischenko V., Mottaeva A., Zheltenkov A. Evaluation of possibility to increasing sustainability of high-rise buildings through use university intellectual property. *E3S Web of Conferences.* 2018. Vol. 33. 03020. DOI: 10.1051/e3sconf/20183303020
16. Gaydin A. M. From Geotechnology to geoesthetic. *Gornyi Zhurnal*. 2009. No. 4. pp. 72–76.
17. Ilin S. A., Kovalenko V. S., Pastikhin D. V The overcoming of the open cut mining initial disadvantages: experience and results. *Gornyi Zhurna*l. 2012. No. 4. pp. 25–32.
18. Mineral Commodity Summaries 2016, United States Geological Survey. p 202. Available at: https://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf (accessed: 10.03.2019).
19. A Report on the State of the Canadian Mining Industry. Facts-and-Figures-2016. 119 p. Available at: http://mining.ca/sites/default/files/documents/Facts-and-Figures-2016.pdf (accessed: 09.03.2019).
20. Ludden J. BGS and the Comprehensive Spending Review 2015. Available at: http://britgeosurvey.blogspot.ru/2015/12/bgs-and-comprehensive-spending-review.html (accessed: 17.03.2019).
21. Fernández S., Fernández J. E., Álvarez A. Assessment of quality assurance models University institutional evaluation and academic achievement. European University Association. Spring, 2018. pp. 71–78; 100.
22. Ganitskiy V. I., Dayanits D. G., Vorobyev A. G., Eyrikh V. I. About development of innovation activity and it's staffing in the mining industry. *Gornyi Zhurnal*. 2011. No. 12. pp. 27–30.
23. Aleskerov F., Ivanov A., Karabekyan D., Yakuba V. Manipulability of Aggregation Procedures in Impartial Anonymous Culture. *Procedia Computer Science*. 2015. Vol. 55. pp. 1250–1257.
24. Vartanov A. Z., Petrov I. V., Kobyakov A. A., Romanov S. M., Fedash A. V. Ecological and economic aspects of the transition of the mining enterprises on the principles of best available technologies. *GIAB*. 2015. No. 1. pp. 511–521.
25. Goncharenko S. N., Kobyakov A. A., Petrov I. V., Stoyanova I. A. Economic-mathematical modeling of the distribution of the value of the cost of the preservation and restoration of the environment in the areas of mass closure of coal mines. Ecological and economic problems of the mining industry and development of fuel and energy complex of Russia: Preprint. *GIAB*. Special articles (special issue). Moscow : Mining book, 2012. pp. 20–25.
26. Kaplunov D. R., Ryl'nikova M. V., Radchenko D. N. Utilization of renewable energy sources in hard mineral mining. *Journal of Mining Science*. 2015. No. 1. pp. 111–117.
27. Korinek J., Ramdoo I. Local content policies in mineral-exporting countries. OECD Trade Policy Papers. 2017 No. 209. DOI: 27. 10.1787/4b9b2617-en.
28. Mining Digital Report 2017. PwC School of Mines. Available at: http://www.pwc.com (accessed: 09.03.2019).
29. Mining for efficiency reports. PwC School of Mines. Available at: http://www.pwc.com (accessed: 01.04.2019).
30. Temkin I., Deryabin S., Konov I. Soft computing models in an intelligent open-pit mines transport control system. *Procedia Computer Science*. 2017. Vol. 120. pp. 411–416.
31. Temkin I. O., Do Chi Thanh, Agabubaev A. T. Some algorithms of functioning analytical platform in the control system of ventilation methane abundant mine. *GIAB*. 2018. No. S16. pp. 3–15.
32. Temkin I. O., Klebanov D. A., Deryabin S. A., Konov I. S. Haul road condition determination under controlled interaction of robotic elements in open pit mining and transport system. *Gornyi Zhurnal*. 2018. No. 1. pp. 78–82. DOI: 10.17580/gzh.2018.01.14 EM