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DIGITAL SYSTEM OF QUARRY MANAGEMENT AS A SAAS SOLUTION: MINERAL DEPOSIT MODULE

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ABSTRACT

Purpose. Improving the efficiency of functioning the mining enterprises and aggregation of earlier obtained results into a unified digital system of designing and operative management by quarry operation.

Methods. Both the traditional (analysis of scientific and patent literature, analytical methods of deposit parameters research, analysis of experience and exploitation of quarries, conducting the passive experiment and processing the statistical data) and new forms of scientific research - deposit modeling on the basis of classical and neural network methods of approximation – are used in the work. For the purpose of the software product realization on the basis of cloud technologies, there were used: for back-end implementation – server-based scripting language php; for the front-end – multi-paradigm programming language javascript, javascript framework jQuery and asynchronous data exchange technology Ajax.

Findings. The target audience of the system has been identified, SWOT-analysis has been carried out, conceptual directions of 3D-quarry system development have been defined. The strategies of development and promotion of the software product, as well as the strategies of safety and reliability of the application both for the client and the owner of the system have been formulated. The modular structure of the application has been developed, and the system functions have been divided to implement both back-end and front-end applications. The Mineral Deposit Module has been developed: the geological structure of the deposit has been simulated and its block model has been constructed. It has been proved that the use of neural network algorithms does not give an essential increase in the accuracy of the block model for the deposits of 1 and 2 groups in terms of the geological structure complexity. The possibility and prospects of constructing the systems for subsoil users on the basis of cloud technologies and the concept of SaaS have been substantiated.

Originality. For the first time, the modern software products for solving the problems of designing and operational management of mining operations have been successfully developed on the basis of the SaaS concept.

Practical implications. The results are applicable for enterprises-subsoil users, working with deposits of 1 and 2 groups in terms of the geological structure complexity: design organizations, as well as mining and processing plants.

Keywords: *3D-quarry, cloud technologies, strategies of information system development, block model of the deposit, data approximation, artificial neural networks*

1. INTRODUCTION

At the present time, Kazakhstan has a significant sector of economy associated with the extraction and processing of mineral deposits. Optimal planning of mining operations is an essential component of the economic success of mining companies and the national economy, which accounts for more than 17% of GDP from the subsoil users. At the same time, due to the complexity of mining and technical conditions for deposit development (increasing the depth of mining operations, increasing the hardness of rocks, involvement in the development of more complex deposits and hard-to-concentrate minerals) and as a result of the global economic crisis in mining and quarrying in 2016, the production has decreased by 2.7% caused by a reduce in iron ore production by 12.9%, coal and lignite – by 4.9%, and oil – by 1.8%. However, the natural gas production increased by 4.8%, while non-ferrous metal ores – by 7.8% (Results of EMS for 2016, 2016). In 2017 and 2018, conditioned by the crisis problems solution, the situation has improved, resulting in the growth of the mining industry (Results of EMS for 2017, 2017; Results of EMS for 2018, 2018).

When designing the new mining enterprises, the factors of resource expenses and calculation quality are of great importance for producing costs formation, and, consequently, for success, as well as for competitiveness of the mining enterprise. The access of subsoil users and design organizations to the fast and cheap system of modeling and calculation of technological processes, design of parameters and quarry indicators, focused on local specifics, will allow in a short period of time to plan and design technological processes, optimal in terms of resources consumption and economic efficiency, as well as organizational and technological solutions on the basis of achieved indicators of enterprises. Accordingly, this will significantly improve the efficiency of mining production (Pivniak, Pilov, Pashkevych, & Shashenko, 2012; Vagonova & Volosheniuk, 2012). The importance of such mechanisms is also emphasized by the main directions of the national economy, expressed in the state programs "Industry 4.0" and "Digital Kazakhstan".

The software market of subsoil users is attractive enough for developers and presented by more than 1000 various software products, both as small freely-distributed, so large proprietary. Moreover, the analysis of potential consumers of systems for planning and management of mining operations indicates that, despite the active state policy to legalize the software, many, especially small enterprises, continue to use pirated copies of software products.

The second distinctive feature of digital systems for subsoil using is the application of only the ASP concept in software development, which imposes certain restrictions on their use and applies additional difficulties in their "deployment" and support by customers.

At this stage, the development of digital technologies makes possible to solve some of these problems by using cloud solutions. The main restrictions of their application are the problems to protect from unauthorized access the data in the process of its storage and transmission over unprotected communication lines, the problems of providing the required rate of transmission and processing of data bulk, as well as data visualization by "weak" users' devices.

Both traditional (analysis of scientific and patent literature, analytical methods of deposit parameters research, analysis of experience and operation of quarries, conducting a passive experiment and statistical data processing) and new forms of scientific research (neuro-prediction in deposits modeling) were used.

The potential users of the obtained results can be both design and mining enterprises, as well as specialized educational institutions.

2. THE ISSUE STATE ANALYSIS

2.1. Performance analysis and classification of systems for automating mining operations

The level and complexity of digital control systems for mining operations has changed dramatically over recent decades. This has led to both changes in the activities of mining companies, and to a steady increase in their productivity. Modern programs for open-pit mining (OPM) belong to the third generation and are characterized by a developed toolkit of 3-dimensional geometric modeling and visualization. They combine the functions of the main processes optimization.

However, productivity growth in the mining industry has decelerated significantly as mining companies use information technology (IT) to improve individual processes rather than production as a whole. The enterprises continue to spend efforts to automate old methods instead of modernizing and improving them. The new, fourth generation of information technologies, which is currently being formed, should ensure dynamic productivity improvement.

All modern information systems for OPM can be classified as:

– mining systems of general purpose;
– specialized mining programs;
– production management systems;
– production registration systems (Lee, 2004).

General-purpose mining systems typically include such sections as: geological modelling, reserve assessment, design and planning of mining operations, calendar planning and surveying. The leaders are Datamine, GemcomSurpac, Micromine, ArcGIS, MapInfo, and Voxler.

Specialized mining programs usually include quarry optimization, scheduling, drilling and blasting operations, ventilation, geomechanics, ecology, etc. The market is represented by packages, which are created as by specialized companies, so mining enterprises and research institutions.

Production management systems combine programs and equipment used to manage production in in a real-time environment. Typical applications: management of mining transport, excavators, drilling machines, etc. The leaders are Modular Mining Systems, Wenco, Tritronics and Aquila. These programs are characterized by a trend towards integration with software for mining equipment (e.g. Komatsu and Caterpillar).

Production registration systems keep production records in real time and generate a variety of reports. With rare exceptions, such systems have been developed by mining companies or enterprises that develop ERP-systems.

At the same time, the entire range of systems for mining companies is divided into proprietary and freely-distributed programs. The second class is characterized by poor development, lack of technical support and maintenance. Accordingly, in the conditions of digital integration of all the processes, the enterprise cannot play any significant positive role, but rather acts as a kind of a "brake" of development and deteriorates the integral indicators of the company's development.

At present, there are dozens of IT-companies working in the world market of commercial computer programs for mining enterprises, offering more than 1,000 software products of different classes designed to automate the most diverse functions of mining management. The further analysis of the commercial software is carried out only on products of the Western manufacture. Both domestic (Kazakhstan) and developments of EurAsEC countries by the degree of interface development, reliability and optimization of the code are more the research software products than commercial systems. And also they have a very limited market for use.

All analyzed products are built on the concept of Application Service Provider (ASP) and are localized on customer hardware.

According to the price policy they can be divided into two large classes:

– cheap and the average cost commercial programs, offered by small specialized companies, such as RockWare, Golden Software, etc.;

– integrated systems of high cost, such as Datamine, GemcomSurpac, Micromine, ArcGIS, MapInfo, Voxler, which allow, without leaving the scope of this software product, to execute the whole spectrum of operations, beginning with the primary geological information processing to delivery of ready design decisions (Gu, Lu, Guo, & Jing, 2010).

2.2. Consumer analysis of systems for mining companies

In order to identify the market niche and the target consumer, an analysis of the mining calculations consumers has been performed. Mining systems can potentially be used by three types of users:

– mining companies and enterprises-subsoil users;

– design organizations in the design area;

– educational institutions involved in the training of specialists in mining, ecology, logistics, transport and auxiliary processes.

The market of enterprises-subsoil users in the Republic of Kazakhstan, which have licenses for the extraction of solid minerals or licenses for the design of mining enterprises, is represented by large corporations, medium and small companies (Table 1). From 2125 registered companies in 2017, 634 are active. The performed analysis by years shows a rather high stability of the number of registered and operating companies (“Organizations” Module, 2019).

Among educational institutions training the mining specialists in the territory of the Republic of Kazakhstan, there are only 11 universities that have the right to teach under educational grants (Calistratov, 2014). Also, the target consumer can be universities that train specialists involved in the organization of mining companies’ operation: logisticians, environmentalists, power engineers and others.

Table 1. Subsoil users in Kazakhstan (according to KazDATA INSIDER)

Type of activity	Registered			Operating
	Big	Medium-size	Small-size	
Extraction of metal ores	58	30	455	123
Hard coal and lignite mining	11	4	94	38
Companies in mining the stone, clay and sandstone quarries	84	41	1348	473
Total	153	75	1897	634

Thus, it can be assumed that the general target market of potential consumers of the software product in Kazakhstan alone is about 645 operating companies and educational institutions. With similar approaches and technologies for quarrying in Kazakhstan and EurAsEC countries, the potential market of only this region may be about 5000 clients.

The positive forecast for covering the potential market with software at successful marketing strategies of promotion is up to 20% of the total market share (provided that there is no non-price competition of monopolists) – up to 1000 clients. In case of negative development of the situation, as a rule, the coverage is up to 1% or 50 clients. These forecasts can be the basis for further calculation of the system price.

At the initial stage of the system development, in order to exclude the competition with major players of the IT market, small subsoil users, small design organizations and educational institutions have been chosen as the target audience. Also, this solution will allow these enterprises “withdraw from” the sector of using pirate copies of design and management programs of mining operations.

2.3. SWOT analysis of information systems-competitors

To identify threats to the project and opportunities for its development, an analysis of the strengths and weaknesses of competitors has been conducted and a threat and opportunity matrix (SWOT analysis) has been developed. The analysis of strengths and weaknesses of commercial mining programs is summarized in Table 2.

Table 2. Analysis of the strengths and weaknesses of competing programs

Solution	Strengths	Weaknesses
Cheap products	1. Affordable price 2. Low requirements for computer resources	1. Automation of individual calculations only 2. Lack of technical support 3. Localization for one user 4. Low prevalence 5. Difficult and often impossible to integrate with consumer enterprise and third-party manufacturer programs
Integrate solutions	1. Coverage of most tasks of any mining company 2. Developed technical support service 3. Developed marketing service and availability of educational programs 4. Established positive reputation among consumers 5. Own market share	1. High value 2. High requirements to the customer’s hardware 3. Consumers needs to have their own IT service 4. Consumer needs to have Data-center or servers 5. Significant functional redundancy paid by the consumer 6. Closed algorithms 7. Complexity, and often impossibility of integration with own developments and third-party products

It should also be noted that all software products of the extractive industries today offer tools only for reserves estimation, separate operations of designing and planning of mining operations. At the same time, such areas as calculation of systems of ventilation, power supply and drainage are poorly provided by effective systems of the automated designing.

In accordance with the SWOT analysis concept, a threat and opportunity matrix for system development has been developed by the existing development team. The results are summarized in Table 3.

Table 3. Threat and Opportunity Matrix

Threats	Possibilities
1. Lack of reputation in the software market of subsoil use 2. Attacks on IT resources of the system and users 3. Legal nihilism and use by consumers of unpaid (unlicensed) copies of the product 4. Lack of funding for the development 5. Difficulty of the product sale to state enterprises 6. Lobbying by large "players" of their software product and non-price competition	1. Availability of highly qualified specialists in the field of IT and mining, as well as in the field of auxiliary processes (Faculty of Energy and Information Systems, Mining and Metallurgical Faculty) 2. Presence of leading mining enterprises in the region 3. Availability of a database of formalized algorithms to solve the problems of mining enterprises 4. Opportunity to advertise the system to the participants of the Board of Trustees (as representatives of mining companies) 5. Availability of a test server to deploy and debug the demo-version of the system

In order to minimize threats, the following solutions have been developed:

– to minimize the costs from the lack of an established positive reputation, implement in the computational modules the transparency of calculations with the generation of pdf-document with calculations. This will make possible to avoid accusations of incorrect algorithms and to strengthen gradually our reputation;

– for protection against attacks (first of all for protection against unauthorized access to resources of system users) the decision has been made on the use of mechanisms of cryptographic protection. Also, the modular division of a system is supposed. It will allow to divide uniform potential object of attacks into set of small. Even at successful attack, with bringing out of service one or several modules, the entire system will keep working ability. Backup and transaction mechanism will allow to restore the operability of the attacked modules in the shortest possible time;

– to protect against threats of illegal use of the system, it is of interest to abandon the ASP concept and implement access to the paid resource through, for example, subscription mechanisms;

– in order to explore the possibilities of developing a system without external funding, it was decided to develop and implement the modules of the system in stages. This will minimize the unpaid working time of the developers. Also at the initial stage, it was decided to implement the system only for the first and second groups of deposits in terms of geological structure complexity;

– to implement the program to the market of Kazakhstan and EurAsEC countries, and later on in other markets, use SMM mechanisms and promote web resources. In order to focus on users from different language groups, the system should support a multilingual interface.

2.4. Identification of significant factors of successful development and strategizing the system development

For successful implementation and further promotion of the system with account of the SWOT-analysis results, it is necessary to identify the main conceptual solutions:

– the planned structure of the intellectual system with a built-in possibility of its development;

– the concept of providing the system to the end user;

– means of implementation;

– security policy;

– an integration strategy with external solutions;

– strategy for promoting the system to the market;

– a strategy to commercialize the system.

The last two strategies are included in the block of economic development of the project and are not studied in this paper, which represents the technical solutions.

3. RESULTS AND DISCUSSIONS

3.1. Development of the system structure

The structure of the system is shown in Figure 1. In the future it is possible to build up the system with other additional modules.

The algorithms of the Mining Operations Module have been developed within the framework of the State grant of the Ministry of Education and Science of the Republic of Kazakhstan (MOiN RK No. 0112RK02423) on the theme "Development of IS for supporting the decision-making in the formation of effective technological schemes to stabilize the mineral resource quality" (Zarubin, Statsenko, Zarubina, & Fionin, 2017). Within the framework of the current project, their actualization on cloud technologies and integration into the system are carried out.

The Hydrogeology Module was implemented in the Delpi7 environment in 2009. The work on updating its algorithms and processing on the basis of modern development tools is performed in the project.

The Environmental Impact Assessment Module (EIA) has currently been implemented as a separate web-project. In this regard, it is highlighted in the structural scheme of the system. It is also planned to integrate it into the system in the future.

The Official Module should perform the functions of administering the system by owner, and is not relevant to the actions of users – consumers of exploration, surveying, hydrogeological and mining works calculations. In this regard, it is also highlighted for the visual separation of modules into basic, ecological and official ones. Further development of the system may result in the occurrence and use of additional color schemes for new modules.

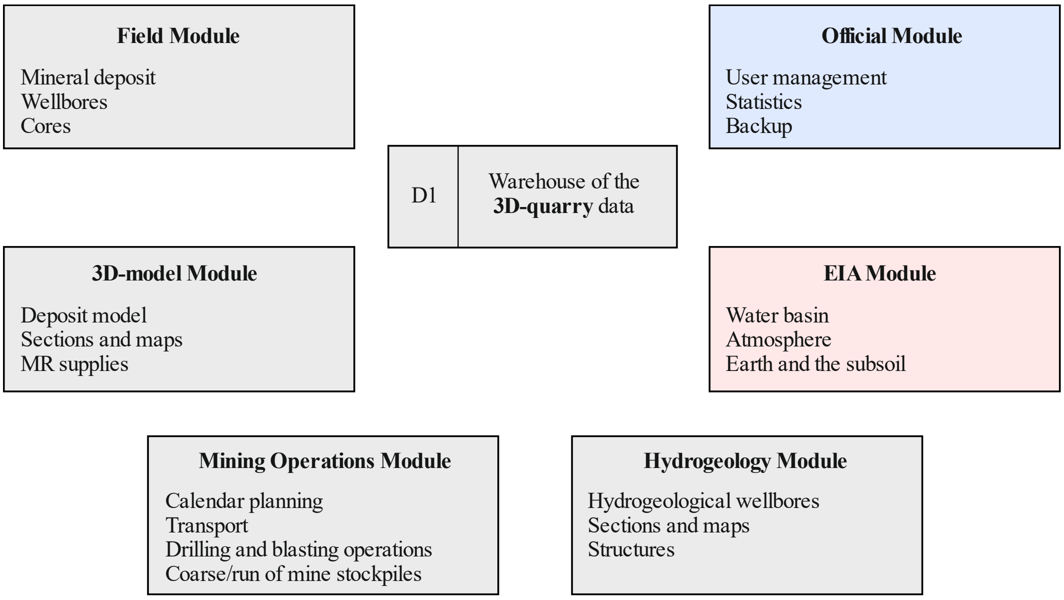

Figure 1. System structure

3.2. Determining the concept for providing the system to the end user

The analysis of IT-market development trends in other areas has revealed a gradual rejection of localized products and the move to the "cloud" for most IT-solutions. The analysis of the companies that have already made a changeover to cloud technologies showed the following:

– placing of IT-infrastructure in the cloud makes it possible to reduce the total cost of IT ownership by 30 – 70%;

– save up to 50% of the data centers resources of the enterprises (electricity, cooling, space);

– 50 – 70% reduction of equipment reservation costs with the same level of reliability;

– reducing the product licensing costs by up to 30%;

– reducing the time for deployment of new services by up to 90%.

That is, cloud technologies allow to expand the possibilities of the mining enterprise, optimize the IT-infrastructure and at the same time to save money. But in addition to the economic benefits, "clouds" also offer qualitative advantages:

– the ability to access resources from any point where there is an Internet;

– the fail-safe operation of the company (providing that there is a reliable Internet service provider) by backing up data on the side of the cloud system owner;

– increased security through consolidation of computing resources;

– improving the quality of provided IT-services with smaller number of highly qualified specialists involved;

– the tenfold reduction of time spent on implementation and operational reallocation of resources.

Given this, as well as the active development of cloud technologies, a logical conclusion is that it is necessary to make a changeover to the use of cloud technologies for the management of mining operations.

In this connection, the decision has been made to implement the 3D-quarry system as a cloud service, built on the web-application technology.

The proprietary systems of large manufacturers presented in the market are built on the principle of a single application, have a significantly redundant functionality and do not allow the client to select for purchasing the minimum required configuration. For flexibility of forming the subsystems necessary for the concrete end user, and for a decrease in expenses for a system, the approach for constructing the "3D-quarry" system, as a set of enable services (the SAAS-solution) is offered. Accordingly, it is assumed that each end user defines the necessary list of subsystems. In the future, if necessary, the user will be able to pay for and connect new additional subsystems, as well as disconnect the unused. The SAAS cloud computing model reduces software maintenance costs at the user's side by eliminating the resource self-administration, providing users with the convenient resource cross-platform, and independence from customer-side hardware and software resources. For example, from a customer's perspective, both classic computers and tablets (smartphones) can be used as hardware. The browser only, included in the basic equipment of any operating system and the Internet connection are the necessary software resources for the work.

An additional requirement, when actualizing this approach, is the implementation of an adaptive interface (for the used formats, as well as the user's screen resolution of the devices used).

The important factors for choosing the SAAS as a promotion model were the economic parameters and the use of resources of the system owner: the convenience when controlling the resource monetization, the convenience of protection against the use of unauthorized copies compared to the concept of Application Service Provider (ASP) and the development of "start-up" mechanisms and promotion of the resource as a web-site.

The additional strategy parameters are the following:

– selectable modularity of the application for the end user;

– transparency for the end user of the methods used.

The modular architecture gives an ability to flexibly manage the necessary resource structure, to build up and upgrade it (including the ability to attract third-party developers), as well as to assess the contribution of each of the modules to the resource profitability. Accordingly, it is quite simple and transparently for the developer of each of the modules to determine the shares of the total profit.

The transparency of used techniques with generation of the pdf-document with calculations allows the skilled end user to "see" alternative ways of quarry development offered by a resource, if necessary to form evidentiary base for making certain decisions, and for the inexperienced user – to study using the examples of calculations made by a resource.

To implement the selected concept, it is proposed to divide the resource into the back-end and front-end sides of the web resource. The back-end is used to identify and authenticate users, administer and manage data in the database. On the front-end, there is encryption and processing of end-user data, its representation and visualization.

3.3. Development of information security policies

To ensure the security of client data, a solution of data opacity for the resource administrator is proposed.

The opacity of the data for the resource administrator and storage of data encrypted with personal user password allows transparently realize the secrecy of commercial activity for the end user. The use of stronger encryption algorithms allows to protect the data from both external attacks on the resource, and from potential attempts to "make pressure" on the resource owner in order to disclose customers' information.

The AES algorithm with encryption/de-encryption on the client side, and as hashing algorithms – MD5 or SHA3Of are of interest as symmetric encryption algorithms. The first is a common standard for web-development, although officially recognized as fragile since 2011, the second is adopted as a standard in the U.S. in 2012 and is the most cryptographically stable at the moment (Gérault, Lafourcade, Minier, & Solnon, 2018).

Replacing one encryption module with another is possible by connecting the necessary of these functions.

The only drawback of such a solution is a significant increase in the computational load on both the client's hardware resources and the communication channel. However, an increase in the performance of both fixed and mobile computing devices, as well as the widespread introduction of high-speed communication networks, at least on the basis of LTE standard, make it possible to quite successfully solve the problem of transmitting and processing data bulk.

The work of all modules implementing the client data processing is assumed in the mode of end-to-end data encipherment. The modern standards of symmetric encryption as AES (USA data encryption standard), GOST-28147 (standard of the Russian Federation) and DSTU 7624:2014 "Kalina" (Ukrainian standard) and NPSS Crypto (symmetric code of information security laboratory of the Institute of Information and Computer Technologies of the Republic of Kazakhstan) are considered as algorithms.

Based on the analysis results of both encryption strength and encryption speed, the AES algorithm has been chosen as the most optimal encryption algorithm. Further development of the system also assumes a mechanism for changing the encryption algorithm by adding and selecting a new function of encrypting and re-encrypting all consumer data.

For encryption, it is possible to use the user's personal password as an encryption key or to add the service (hidden) master key of the enterprise to each authorized user (from each enterprise).

Using a user password for identification and authentication as an encryption key is provided for:

– additional load on the service module to re-encrypt all the user data when the user changes his personal password;

– increased requirements for the safety of the user personal password, as the loss of this single password will lead to the complete loss of all user data of the enterprise;

– the use of this protection method also implies the use of only one account to access data of one enterprise (deposit) and the impossibility of processing data by several users under different accounts.

These problems in the concept of security with the use of personal password as an encryption key predetermined the need to use the enterprise master key inherited by each new user of the enterprise. The new user can only be added by the owner of a valid master account of the enterprise. To ensure that the data is not transparent to the system administrator, the inherited master key is stored in the system in the form encrypted with the user' private key. Thus, it becomes possible both to work with several personalized accounts for the enterprise and to eliminate the problem of data loss in case of loss of the enterprise password/key in the presence of at least two enterprise accounts. The system service module is intended for administering and does not provide for end-to-end encryption.

3.4. Substantiation of tools for implementing the system

The chosen conceptual decisions define system as a cloud-based web-application that imposes its own restrictions on development tools of the given information system and assumes the use of web-oriented development tools.

Although development tools, such as high-level languages, allow for the development of cloud products, they require significantly greater time resources for implementation that is conditioned by their different orientation.

The accepted separation of the resource functionality into the back-end side and front-end side of the interface also imposes restrictions on development tools.

Based on the performed analysis results, the decision was made to use the following software resources:

– for back-end implementation – server scripting language php;

– for front-end – multi-paradigm programming language javascript, javascript framework jQuery and asynchronous data exchange technology Ajax.

It was decided not to use other tools and frameworks at the stage of demo-version implementation. The working version is implemented using the Laravel framework.

For the implementation of the data warehouse, the analysis of freely distributed web-oriented Data Base Management System (DBMS) has been performed. It was decided not to use proprietary DBMS for commercial reasons at once. The analysis of correspondence of DBMS capabilities allowed to reveal and choose

MySQL relational DBMS as one of the most wide-spread for web projects.

In connection with the preparation of protection documents for the developed system, the database structure implemented in DBMS MySQL and some of the algorithms are not disclosed in this article.

3.5. Development of the Mineral Deposit Module

In order to build a digital deposit model, it is necessary to obtain accurate data in the place where the core is extracted from the well, as well as the data of its laboratory analysis. Accordingly, the structure of the well for the introduction of geological data and, partially, for the introduction of geodetic data on the location of the collar of the well can be represented by the information presented in Table 4 and Figure 2.

Table 4. Data on the well

Parameter	Measurement unit
Well collar coordinates:	
– longitude	degree
– latitude	degree
– altitude	metre
Well depth	metre
Well site:	
– depth of the well site beginning	metre
– zenith angle of the well site	degree
– azimuth angle of the well site	degree
– length of the well site	metre
Well cores	table
Well data sheet	Pdf-document

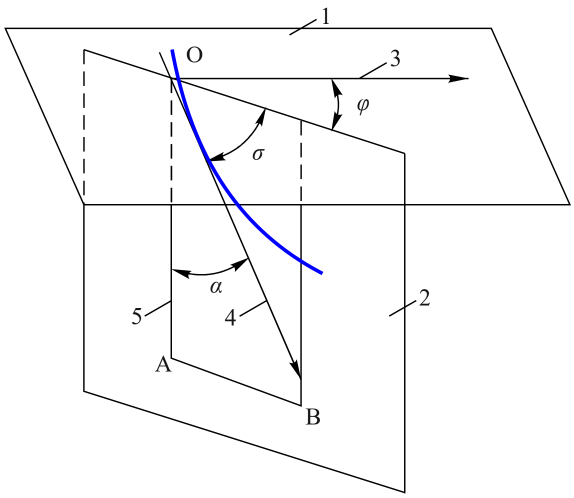

Figure 2. Well: 1 – horizontal plane; 2 – apsidal plane; 3 – magnetic meridian; 4 – tangential to the well shaft point; 5 – vertical line through the point of angles measurement

Due to the fact that for the majority of deposits of the 1st and 2nd group in terms of complexity of geological structure only ordinary vertical straight wells are used, therefore, it was decided to abandon specially curved wells in the demo-version. In terms of genesis, such deposits are usually sedimentary, which implies the formation of a deposit under the same conditions over a large area, so the use of specially curved wells is not rational. Accordingly, the approximation algorithms implementation on these vertical straight wells consisting of one section, is easier and cheaper.

Also in the system, in order to reduce the computational load instead of absolute values – longitude, latitude and altitude – relative values in meters from the origin of the deposit coordinates (the standard left upper corner) are used.

Depending on the position of exploration wells, geologists distinguish the proper networks formed by the wells: square, rectangular and rhombic. Setting the coordinates of each well allows to specify any network of wells in the system. However, to simplify the approximation algorithms in the future, it was decided to implement only the square and rectangular networks. If it is necessary to density the network of wells, the decision was made to add additional, clarifying networks of wells to the proper regular network of wells.

Table 5 is completed with data on both the useful component content and on the content of harmful impurities, in order to enter the data of the laboratory studies on cores into the system. If the content of the useful component in the mineral is lower than the boundary value, the volumes of low-grade ores are allocated. These include reserves, which even in the remote prospect, can be (after revision of the conditions) assigned to the balance reserves. If the core is represented by waste rock, the physical and mechanical properties of the rocks are determined: hardness and fracturing. At considerable overburden volumes of one type (for example, more than one railway train), it can be designated as a mineral of a secondary type No. 1, 2, 3 ..., that means stocking this overburden on a separate site of a dump (a separate dead end), since dumps of a similar type overburden can be considered as deposits of rocks of the type: type No. 1, 2, 3...

The chosen deposits of groups 1 and 2 are, as a rule, characterized by the content of monocomponents of the mineral resource. The polymetallic deposits, for example, due to geothermal genesis, rarely belong to the third, but more often to the fourth group in terms of complexity of the geological structure.

The demo-version presents a simplified version of the system solution, although it is also possible to store a multi-dimensional array of minerals in the core.

Table 5. Core data

Parameter	Measurement unit
Core number	figure
Length of the core	metre
Rock hardness	number
Rock fracturing	number
A mineral	
– name	literal
– formula	formula
– % content	%

The results of the Mineral Deposit Demo-Module development are shown in Figure 3 (deposit) and Figure 4 (well and core).

In order to save space in this paper, only the functional parts are represented of the developed demo-version of the web-application without a “header”, “footer” and interface part of the web-windows. Also, the result is presented only in the resolution for monitors without showing the scaling options for smartphones and tablets.

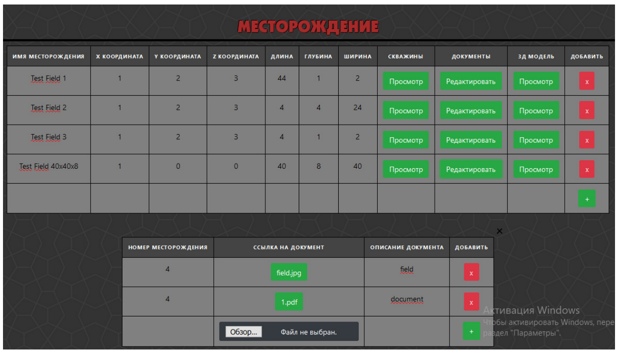

Figure 3. Window Deposit

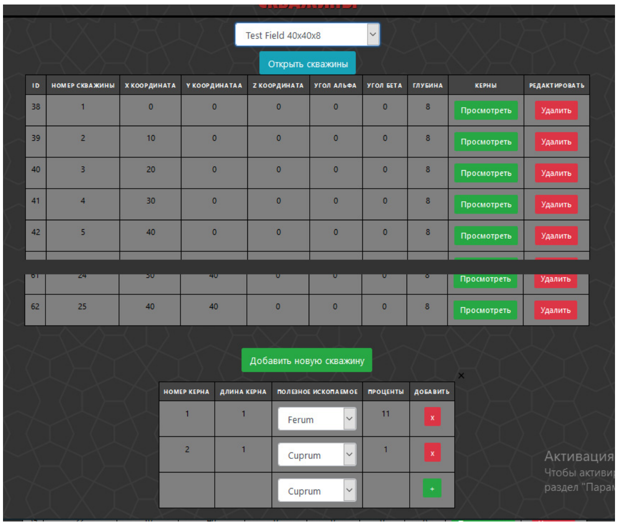

Figure 4. Window Wellbores and Cores

The implementation of the Mineral Deposit Module has revealed the necessity to add visual representation in the system of well data on the topographic base and data of cores.

3.6. Development of the 3D-model Module

In the project, the frame modeling is carried out on the basis of data of wells and cores. The problem of representation is the use of unequally-spaced network of wells on real objects, which requires the system to bring the frame model to the points of regular network when performing the next stage.

The block models are formed within the boundaries of their frame models. The determination of the content of useful components in the blocks is carried out on the normalized model of geological samples using interpolation methods (inverse distance and kriging). In order to use kriging, a geostatistical study of the deposit should be previously carried out. When using both methods, the anisotropy of mineral resource distribution within the boundaries of mineralization zone, as well as the dimensions of zone of the samples impact may be taken into account. The block model can be either regular or sub-block based.

When implementing in the Project at the first stage, it was decided to abandon kriging and to use only regular block models.

To implement the 3D-model of the deposit, work was made to create a 3-D network, the well data were averaged over 3-D network cells and the data was interpolated into all the cells of the model.

As a result of the analysis it was revealed that data interpolation can be performed both by classical methods of interpolation and by methods of artificial intelligence systems. The first methods are quite simple to implement (especially if the simplest methods of piecewise linear interpolation are used), but have low accuracy and are not capable of learning according the characteristic features of deposit types (Oliver, 2004).

The methods based on artificial intelligence systems have greater computational complexity, but are capable of learning, i.e. they are able to remember the peculiarities of types of deposits (for example, by the known type of mineral and genesis) and more accurately interpolate the same type of deposits.

It should be noted that there is a large amount of interpolation values, which affects both the interpolation rate and the expenses of data storage and output. The interpolation in the system is based on the content of the useful component, hardness and fracturing of rocks. Accordingly, even in a "crippled" demo-version with a single component of the mineral resource, the data structure represents three 3-D data arrays with a dimension equal to the fraction number of geometric dimensions of the deposit per the dimension of a single block of the model. For example, for a 200×200 m deposit with a depth of up to 50 m and 1 m model block, the number of blocks will be 200×200×50 = 2000000 units with respect to only one parameter.

Previously, the project team conducted studies of the effectiveness of neural networks in the management of the processing complex (Zarubin & Zarubina, 2013). In the current project, this studies are extended to interpolation of the deposit geo-data.

The software product implements data interpolation on the basis of piecewise linear approximation and studies the possibility of interpolation of geo-data on the basis of both classical methods and the apparatus of neuromathematics – artificiall neural networks (ANN). When interpolating the simulated deposit space, the classical methods of polynomial interpolation and cubic spline interpolation were initially investigated.

The polynomial interpolation of the function consists in finding the interpolant:

$$y_i = \sum_{k=0}^{N} c_k x^k \quad . \tag{1}$$

To describe the interpolating function, it is necessary to determine $N+1$ of the unknown polynomial coefficients and to solve the system of $N+1$ linear algebraic equations. To interpolate the dependence of 3 measurements, a system of $3\cdot(N+1)$ equations is required for each of the parameters (Imamoto & Tang, 2008).

The polynomial interpolation is characterized by an increase in the polynomial degree (polynomial system) with an increase in the number of starting points, which leads to a groundless increase in computational loads. And the behavior of polynomials is very unstable – significant jumps of approximating functions are possible, which may differ greatly from the behavior of the modeled functions, and increasing the polynomial degree does not always allow to solve this problem. In this connection, it was decided to refuse using the polynomial approximation even when modeling deposits with a "simple" structure.

When interpolating by cubic splines, the interval of function determination is divided into segments, as well as in the case with piecewise linear interpolation. On each of the segments, the interpolated function is represented of the form of a third degree:

$$y_i = a_i + b_i\left(x_i - x_{i-1}\right) + \\ + c_i\left(x_i - x_{i-1}\right)^2 + d\left(x_i - x_{i-1}\right)^3 + \ldots, \tag{2}$$

where:

$i = 1...N$, where N – segment number.

At the same time, the function, as well as its first and second derivatives must be continuous. To describe the function, it is necessary to determine the $4N$ unknowns and solve the system of $4N - 2$ equations. To approximate the dependence of 3 measurements, a system of $3\cdot(4N - 2)$ equations is also required for only one simulated parameter. The number of equations is 4 times greater than at approximation by polynomials, but the type of functions is simpler, therefore, the computing expenses are comparable.

The approximation by cubic splines – a method that gives a more stable result, but has its disadvantages. Firstly, it is a rather cumbersome view of the resulting functions. Secondly, the method experiences some difficulties in case of irregular input data. Thirdly, the volume of spline coefficients sometimes exceeds the volume of initial data, and this leads to significant computational loads.

The accuracy of modeling using these methods is higher compared to linear interpolation, but for the selected groups of deposits the increase in accuracy is not significant. Also, for these methods, there is a problem of data plasticity – clarifying the geo-data value by means of drilling of additional wells leads to recalculation of value of all the interpolation function coefficients. It is possible to use other classical interpolation methods, for example, b-splines of Schoenberg will solve the problem of plasticity. However, the problem of processing data bulk by classical methods while maintaining high accuracy of prediction is still relevant to them.

The application of Artificial Neural Network (ANN) for deposits geo-data interpolation has also been studied. Currently, according to the universal approximation theorem, an ANN with one hidden layer can approximate any continuous function of many variables with any accuracy (Calistratov, 2014). However, despite this, most of the ANN algorithms give excellent results for the points with data where the training took place, and the unacceptable results in intermediate points, unknown to network. In practice, different network configurations (forward and back-propagation of error networks, radial basis networks, etc.) can be used to interpolate dependences, or proprietary ANN architectures can be designed (Nguyen-Thien & Tran-Cong, 1999).

The project investigates the applicability of the following types of neural networks: forward and back-propagation of error networks and radial basis networks.

The first of the studied networks was the Neural Network with Back Propagation Training Algorithm (NNwBPTA). NNwithBPTA is based on multilayer perceptrons. The classical algorithm of training is used - the algorithm of back propagation of error. In the project, only Fermi function (exponential sigmoid) is used as an activation function for the network, because, for example, large computing expenses are required to calculate the hyperbolic tangent:

$$f\left(s\right) = \frac{1}{1 + e^{-2as}}\ , \tag{3}$$

where:

s – neuron adder output;

a – some parameter.

The Fermi function is monotonically increasing and has non-zero derivatives over the entire determination area. These features ensure the correct operation and training of the network.

The network with back propagation of error has provided the problem solution. However, the time spent on primary training led to the need to bring the algorithm of its training into the external module and disable time control for the php-server. It may be relevant to approximation of these complex deposits with trained networks for specific deposit types, but for simple deposits, it is irrational consumption of server resources and additional waiting time for the client to form a deposit model. It should be noted that at the moment there are faster training algorithms of this network type than those used in the project. Perhaps, the application of these algorithms will make NNwithBPTA applicable for practical use in this system in the future.

The second option was an attempt to use a Counter Propagation Network (CPN or Hecht-Nielsen Neurocomputer). This type of network was developed by *R.* Hecht-Nielsen in 1986. Although the CPN has been trained much faster than NNwithBPTA, it has not been possible to achieve reliable or at least applicable results. Most likely, the reason for the failure is that the optimal number of neurons in the network layers was not found.

The third and the most successful option was a system consisting of Radial Basis Function Network (RBFN). The RBFN paradigm is understood as the architecture proposed in 1988 by D. Bruchmed and D. Lowe in 1989.

In many sources (Lin & Chen, 2004; Shafizadeh-Moghadam, Hagenauer, Farajzadeh, & Helbich, 2015), it is said that the Radial Basis Network confidently "works" only with those images that were "presented" in the process of creation. The special RBFN variations have been developed for models with large input data variance (Liu, Zhang, Ma, Lu, & Su, 2011). However, even the basic network has shown enough high accuracy in other points as well. A distinctive feature of this type of networks is that they do not have a training process and are customized once in the process of creation. The computational complexity of customizing process in comparison with training is insignificant, but still exceeds the time of interpolation by splines.

It should also be noted that the main advantage of the ANN – parallelism of calculations – on the used server due to the absence of graphics processors and a supercomputer was not implemented. Correspondingly, the computational advantage of the neural network apparatus in the current conditions turned into a disadvantage – increased computational load on a single processor.

In summary, the following conclusions can be drawn:

– firstly, the problems associated with the solution of the problem of geo-data interpolation can be solved successfully enough by methods of artificial intelligence systems;

– secondly, proceeding from the discussed methods, both back propagation of error networks and radial basis networks can be applied;

– thirdly, the use of ANN is more resource-intensive than classical methods and can only be substantiated for deposits with a complex geological structure.

To visualize the data in the system, the mechanism of formation according to the model of any number of sections (vertical sections of the deposit) and maps (horizontal sections of the deposit) is implemented. In the current system implementation, the sections and maps are formed only by one coordinate (*X*, *Y* or *Z*). The implementation of inclined sections generation is more time-consuming and does not give a significant advantage in understanding the geological occurrence of a mineral resource. Therefore, its implementation has been postponed until the next system version.

The Canvas mechanism was originally used to visualize the model and section data. The mechanism is implemented on the client side via JavaScript. The choice of front-end mechanisms is based on the fact that in the process of further development, the implementation has been provided for rotation or stratification mechanisms of the model. The implementation of these functions on the back-end and php language mechanisms will require constant pages reloading.

However, further work has shown that the use of the Canvas mechanism was a mistake: visualization and effects required unreasonably high computational loads. Therefore, the module was redeveloped to use the WebGL library. The visual representation of the block model of the deposit, implemented through WebGL, is shown in Figure 5.

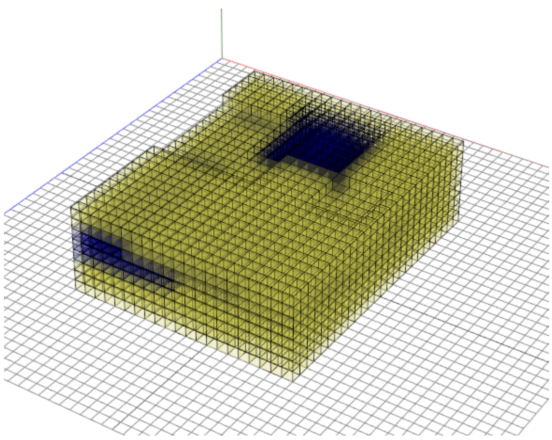

Figure 5. Block model of a test deposit with one mineral resource type (web-page interface is "cropped")

The use of a dark background of the interface was also found to be an unsuccessful solution.

3.7. Testing and debugging the module

The primary testing of the system modules is performed on the local server. For this purpose, there were used: apache 2.4.28 server, php 7.1.10 language, MySQL 5.0.12 DBMS. Ultrabook with 1366×768 screen resolution was used as a client. The Ultrabook features: Intel Core i7-3517U processor, RAM 8 Gb, Windows 10 Pro operating system. Testing was conducted in Google-Chrome, Mozilla, IE, Opera browsers.

A conditional test deposit of 40×40×8 size was formed for testing. For the deposit, 30 wells on a uniform network were entered into the database. For each well, up to 8 cores with a length of 1 meter are specified. When testing, the modeling was used of the same type of rock with different content of mineral resources. The visualization was carried out both by gradation of color transparency depending on the content of the mineral resource and with different colors. The first method is more informative.

The necessity to improve the interface of the "3D-deposit" module for the possibility of switching off/on the display according to the entered minimum value of the mineral content percentage has been revealed.

The first release of the "3D-quarry" system was sent to the working server and the students continued to test their specialized educational programs on stationary computers, laptops and smartphones.

4. CONCLUSIONS

As a result of the conducted research stages, the analysis of the software market for planning and management of mining operations has been performed. The strategies for promotion of the system as a cloud solution, as well as the policies and structure of a system have been developed. A demo-prototype was implemented as a cloud solution to test the applied solutions: the geological structure of the deposit has been modeled and a block model has been built.

Both classical and neural network algorithms of geological data approximation based on the laboratory studies results of well cores have been studied in the course of building a block model. It has been revealed that the use of neural network algorithms does not give a fundamental increase in the accuracy of the block model for the deposits of 1 and 2 groups in terms of the geological structure complexity. However, their use leads to unreasonably high expenses of computational resources of the server. According to the testing results, the problems have been revealed of large arrays visualization of the geo-data when using the web-solutions and ways of their solution have been found.

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ЦИФРОВА СИСТЕМА УПРАВЛІННЯ КАР'ЄРОМ ЯК SAAS-РІШЕННЯ: МОДУЛЬ "РОДОВИЩЕ"

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Мета. Підвищення ефективності функціонування гірничорудних підприємств та агрегація раніше отриманих результатів в єдину цифрову систему проектування і оперативного управління роботою кар'єрів.

Методика. У роботі використані як традиційні (аналіз науково-патентної літератури, аналітичні методи дослідження параметрів родовища, аналіз досвіду й експлуатації кар'єрів, проведення пасивного експерименту та статистичної обробки даних), так і нові форми наукового дослідження – моделювання родовища на основі класичних і нейромережевих методів апроксимації. Для реалізації програмного продукту на основі хмарних технологій використані: для реалізації back-end – серверна скриптова мова програмування php; для front-end – мультипарадігменна мова програмування javascript, javascript framework jQuery і технологія асинхронного обміну даними Ajax.

Результати. Виявлено цільову аудиторію системи, проведено SWOT-аналіз, визначено концептуальні напрями розвитку системи 3D-кар'єр, розроблені стратегії розвитку та просування програмного продукту, розроблені стратегії безпеки й надійності додатки як для клієнта, так і власника системи. Розроблено модульну структуру програми, вироблено розподіл функцій системи для реалізації як back-end і front-end додатки. Розроблено модуль "Родовище": проведено моделювання геологічної структури родовища та побудована його блокова модель. Доведено, що використання нейромережевих алгоритмів не дає принципового підвищення точності блокової моделі для родовищ 1 і 2 груп за складністю геологічної будови. Виявлено недоліки нейромережевих алгоритмів, такі як високі витрати обчислювальних ресурсів сервера і проблеми візуалізації великих масивів геоданих при використанні web-рішень, знайдені шляхи їх вирішення. Доведено можливість і перспективність побудови систем для надрокористувачів на основі хмарних технологій і концепції SaaS.

Наукова новизна. Вперше на основі концепції ASP успішно побудовані сучасні програмні продукти для вирішення завдань проектування та оперативного керування гірничими роботами.

Практична значимість. Результати корисні для підприємств-надрокористувачів, які працюють з родовищами 1 і 2 груп за складністю геологічної будови – проектних організацій і ГЗК.

Ключові слова: *3D-кар'єр, хмарні технології, стратегії розвитку інформаційної системи, блокова модель родовища, штучні нейронні мережі*

ЦИФРОВАЯ СИСТЕМА УПРАВЛЕНИЯ КАРЬЕРОМ КАК SAAS-РЕШЕНИЕ: МОДУЛЬ “МЕСТОРОЖДЕНИЕ”

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Цель. Повышение эффективности функционирования горнорудных предприятий и агрегация ранее полученных результатов в единую цифровую систему проектирования и оперативного управления работой карьеров.

Методика. В работе использованы как традиционные (анализ научно-патентной литературы, аналитические методы исследования параметров месторождения, анализ опыта и эксплуатации карьеров, проведение пассивного эксперимента и статистической обработкой данных), так и новые формы научного исследования – моделирование месторождения на основе классических и нейросетевых методов аппроксимации. Для реализации программного продукта на основе облачных технологий использованы: для реализации back-end – серверный скриптовый язык программирования php; для front-end – мультипарадигменный язык программирования javascript, javascript framework jQuery и технология асинхронного обмена данными Ajax.

Результаты. Выявлена целевая аудитория системы, проведен SWOT-анализ, определены концептуальные направления развития системы 3D-карьер, разработаны стратегии развития и продвижения программного продукта, разработаны стратегии безопасности и надежности приложения как для клиента, так и владельца системы. Разработана модульная структура приложения, произведено деление функций системы для реализации как back-end и front-end приложения. Разработан модуль “Месторождение”: проведено моделирование геологической структуры месторождения и построена его блочная модель. Доказано, что использование нейросетевых алгоритмов не дает принципиального повышения точности блочной модели для месторождений 1 и 2 групп по сложности геологического строения. Выявлены недостатки нейросетевых алгоритмов, такие как высокие затраты вычислительных ресурсов сервера и проблемы визуализации больших массивов геоданных при использовании web-решений, найдены пути их решения. Доказана возможность и перспективность построения систем для недропользователей на основе облачных технологий и концепции SaaS.

Научная новизна. Впервые на основе концепции ASP успешно построены современные программные продукты для решения задач проектирования и оперативного управления горными работами.

Практическая значимость. Результаты применимы для предприятий-недропользователей, работающих с месторождениями 1 и 2 групп по сложности геологического строения – проектных организаций и ГОКов.

Ключевые слова: *3D-карьер, облачные технологии, стратегии развития информационной системы, блочная модель месторождения, искусственные нейронные сети*

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