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WORKFLOW AUTOMATION FOR MINING OPERATIONS ANNUAL PLANS

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АВТОМАТИЗАЦИЯ ПРОИЗВОДСТВЕННЫХ ПРОЦЕССОВ ПРИ СОЗДАНИИ ГОДОВЫХ ПЛАНОВ РАЗВИТИЯ ГОРНЫХ РАБОТ

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potassium salt deposit, geological and mining information system, software module, annual plans for the development of mining operations, digital plans, database management system.

This paper presents the results of workflow automation as a solution for Annual Plans for the Development of Mining Operations preparation at Uralkali PJSC's.

An annual plan specifies areas for the development of mining operations, mineral output, mine preparation work, throughput of mineral raw materials, conservation of mineral resources, balanced and comprehensive use of raw materials, and safe operation.

This technical document was mainly prepared by specialists from mining, geology, and survey departments, and thus the dedicated software tools for such services were implemented within the developed software modules on mining operations planning.

The developed set of software modules for Annual Plans for the Development of Mining Operations feature the following functions: preparation and analysis of input data (design data, production output planned figures, standards and guidelines, mineral management license conditions, etc.); analysis of actual and expected indicators of mining work performance for the period preceding a planned year; determination of planned indicators of mining work performance (the optimised parameters of the mining system, mineral output, amount of mine preparation and backfilling operations); specification of the target performance of mechanical equipment and allocation of mechanical equipment during mining operations; identification of planned loss and depletion of minerals for each mining unit; use of the geological environment and mine workings 3D-models for optimised the mine workings arrangement; creation and pre-print preparation of tables, plots and text documents as a part of Annual Plans for the Development of Mining Operations.

Ключевые слова:
месторождение калийных солей, горно-геологическая информационная система, программный модуль, годовые планы развития горных работ, цифровые планы, система управления базами данными.

Приводятся результаты работ по автоматизации решения задач, стоящих перед техническими службами рудников ПАО «Уралкалий» при создании годовых планов развития горных работ (ГПРГР).

Годовой план определяет направления развития горных работ, объемы добычи полезных ископаемых, производства горно-подготовительных работ, объемы переработки минерального сырья, мероприятия по охране недр, рациональному и комплексному использованию минерального сырья, безопасному ведению работ.

В создании данного технического документа в основном принимают участие специалисты горного, геологического и маркшейдерского отделов рудников. Поэтому разработанные программные модули по планированию горных работ были распределены по программным комплексам, созданным для соответствующих служб.

В целом совокупность программных модулей, созданных для решения задач, связанных с разработкой ГПРГР, позволяет: подготавливать и анализировать исходные данные: проектные данные, плановые показатели производства продукции, нормы и нормативы, лицензионные условия на пользование недрами и др.; анализировать фактические и ожидаемые показатели ведения горных работ за период, предшествующий планируемому году; определять плановые показатели при ведении горных работ: оптимальные параметры системы разработки, объемы добычи полезных ископаемых, объемы производства горно-подготовительных и закладочных работ; определять плановую производительность средств механизации и осуществлять расстановку средств механизации при ведении горных работ; определять нормативы плановых потерь и разубоживания полезного ископаемого по каждой выемочной единице; использовать созданные 3D-модели геологической среды и горных выработок для принятия оптимальных решений при планировании размещения горных выработок; составлять и подготавливать к печати табличную, графическую и текстовую документацию к ГПРГР.

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Introduction

Efficient planning of mining work is the most important and determining factor of the successful operation of any mining company. At the moment of planning, it is necessary to consider a lot of parameters, look through various options of a mining schedule and select the best options. Advanced software solutions are of help in solving these problems.

The rapid development of information technologies led to the emergence of more than a dozen of such software systems in the international market; such systems include various modules to plan underground mining [1–4].

The best-known mining and geological information systems used abroad in the mining industry to design, plan, and manage basic mining operations are Gemcom (Canada) [5], Surpac (SoftwareInternational, Australia) [6], Datamine (MIC Ltd, Great Britain) [7], Micromine (MicrominePtyLtd, Australia) [8], Vulcan (Maptec, Australia) [9], MineScape (Mincom, Australia) [10], GeoviaSurpac™ (Vélizy-Villacoublay, France) [11], Techbase (Minesoft, the USA), etc.

However, as some specialists note [12–14], the listed integrated systems cannot fully embrace the entire range of specific tasks which mining companies may encounter, including mining planning tasks. Therefore individual companies start developing dedicated solutions for the mining planning. The best known systems among them are MINE2-4D (ASTMining, Canada) [15], MineMAXPlanne (MineMAXPtyLtd., Australia) [16], Four-X Analyser (WhittleProgramming, Australia) [17], NPV Scheduler (the USA), etc.

The implementation of foreign integrated systems and dedicated software packages for mining production planning in Russian mining companies encounters serious challenges. Such challenges include difficulty and, sometimes, impossibility to adapt to aspects of the current regulatory and legal framework, as well to the requirements of corporate standards and safety procedures. Another factor is that software codes are closed and it is difficult to modify systems by users and, as a result, impossible to adapt such systems to aspects of the workflow in place at a particular mining company. Remote locations of the developers, high costs of the systems and their support rendered by the developer are also among contributing factors. Recent years have added another challenge to the abovementioned list: the risk of sales and support sanctions by the countries, where such system are developed, applied to Russian companies.

Mining and geological information systems developed in Russia are not competitive yet. However, over recent years, we have seen work in progress in this field. At the moment, domestic software products are being developed to address the production problems of a particular mining company or a group of companies, performing mining operations at mining deposits of the same type. For instance, some mining companies use software solutions developed in Apatity (Mining Institute of the Kola Science Center of RAS), Belgorod (Viogem), Moscow (Integral), Perm (Perm National Research Polytechnic University (PNRPU)), and some others [18–27].

Workflow to prepare annual plans for the development of mining operations at Uralkali PJSC's mines

Conventionally, mining work planning is divided into a long-term (over 5 years), a medium-term (up to 5 years), and a short-term (up to 1 year) planning.

In the framework of this paper, we are going to discuss the results the authors' work focused on the automation applied to solve workflow problems encountered by Uralkali PJSC's specialists working in mining, geology, and survey departments when they prepare Annual Plans for the Development of Mining Operations, i.e. we are going to talk about the short-term planning limited to one year.

An annual plan for the development of a mining company is based on the technical part which sets the trend for the development of mining operations, mineral output, performance of second working and mine preparation work, mineral throughput, measures to protect mineral resources, responsible and comprehensive use of minerals, and safe operation.

The sections dedicated to financial and economic, marketing, legal, political, environmental, and other types of assessments represent an equally important constituent part of an annual plan (Table 1). However, this paper does not address these issues.

An Annual Plan for the Development of Mining Operations is the main document regulating engineering and production operations of any mining company; it is effective as a juridical law and shall be complied with in terms of all quantitative and qualitative indicators [28].

Table 1

The scope of work performed by different departments of a mining company in the process of preparing an annual plan

No.	Task	Responsible
1	Issuance of an order on the procedure and deadline of the elaboration of a plan	Chief Engineer of the Mine Administration. Planning and Economic Department
2	Determining the sales volume	Marketing (Sales) Department
3	**Production programme elaboration (*Annual Plans of the Development of Mining Operations*)**	**Technical Department of mining companies (including departments responsible for surveying, geology, mining, and geomechanics)**
4	Sales and operations planning	Planning and Economic Department and Sales Department
5	Development of standards and guidelines	All functional departments
6	Equipment and material procurement planning	Procurement Departments and Planning and Economic Department
7	Personnel and payroll budget planning	Labour and Wages Department and Planning and Economic Department
8	Cost and profit planning	Planning and Economic Department, Finance Department
9	Investment and major construction planning	Construction Department
10	Financial planning (budgeting)	Finance Department and Planning and Economic Department

In practice, all constituent parts of an annual plan of any mining production in Russia are regulated by a vast number of regulatory documents [29–32 et al.]. Uralkali PJSC's mines, in addition to the requirements of regulatory documents issued by the state, also comply with the guidelines concerning safe mining and the specificities of the development of Verkhnekamskoye field of potassium and magnesium salts [33–35 et al.].

Uralkali PJSC has five operating mines and two mines under construction; there, annual plans are prepared by departments of the Engineering Office and Mineral Management Office. The structure of this technical document is specified in the internal regulatory document [36] and consists of four volumes and appendices:

Volume 1. Explanatory note with tables.

Volume 2. Graphical presentation.

Volume 3. Specified limits of losses and depletion.

Volume 4. Mineral processing. Appendices.

A schematic diagram showing the participation of each technical department of the mining company in the process of preparing an Annual Plan for the Development of Mining Operations and technical documentation workflow is given in Figure 1.

Automation of workflow to prepare annual plans for the development of mining operations

The authors' first developments associated with the automation of operations as applied to the preparation of Annual Plans for the Development of Mining Operations based on digital survey plans were completed in the period from 2000 to 2003 [37–41]. Software modules developed in that period were designed, first of all, to assist specialists working in mining, geology, and survey departments of mines then belonging to Silvinit JSC and Uralkali JSC (in May 2011, Silvinit JSC and Uralkali JSC merged under the corporate name of Uralkali PJSC). Those programmes mainly dealt with tasks associated with the execution of graphic documentation on digital plans of mining operations and with their transfer on hard copies, as well as with the determining planned limits of loss, depletions, and mineral production output.

In 2014, Uralkali PJSC started developing its corporate mining-and-geological information system (GGIS of Uralkali PJSC). The authors of this paper have been directly participating in this work [24, 25]. This project is being developed in order to provide a comprehensive approach to workflow automation as applied to the planning of mining operations.

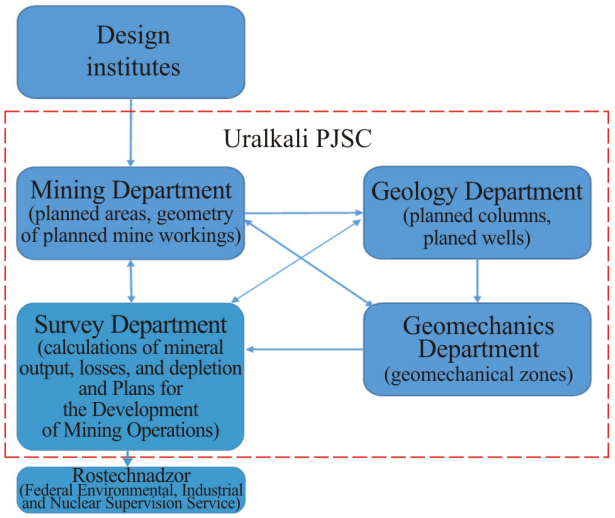

Fig. 1. General scheme of the interaction between technical departments of the mining company at the moment of preparing annual plans for the Development of mining operations

Mining Department	– Plan of mining operations – Planning of mine workings – Planned backfilling
Geology Department	– Planned column – Planned wells
Geomechanics Department	– Pillar loading degree – Safe conditions for undermining the water blocking layer – Mines
Survey Department	– Mining machine – Planning of mine workings – Specified limits set by an Annual Plan for the Development of Mining Operations

Fig. 2. Software modules used by different mines technical departments to prepare annual plans for the development of mining operations

Elaboration of Annual Plan for the Development of Mining Operations requires participation of experts from different departments of the company, and thus the developed software contains dedicated modules for such departments. The list of software modules used by different technical departments of mines is given in Figure 2.

Table 2 contains the workflow process at each stage of planning, mining companies departments in charge, and names of applicable software modules developed by Perm National Research Polytechnic University. More detailed information on the functionality of the listed programmes can be found in dedicated publications referenced in square brackets in the table.

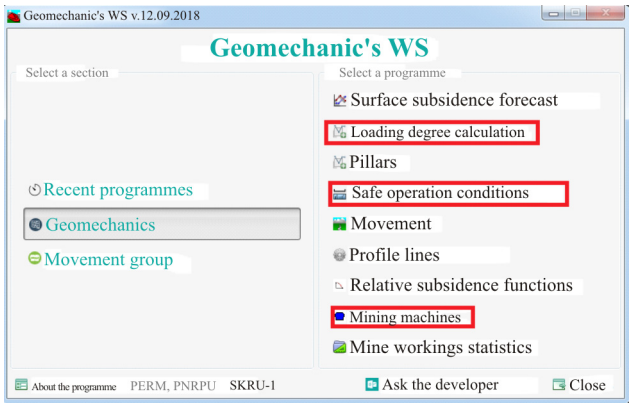

Fig. 3. Geomechanic's WS menu with highlighted programmes used for mining operations planning

Each work station (WS) in respective technical departments of a mining company has a software module for automated Annual Plans for the Development of Mining Operations preparation installed. More detailed information on the structure of software solutions (WS) can be found in [25]. Figure 3 shows a menu of a geomechanic's WS with the list of software modules.

The module-based structure of software solutions allows us to customize a workstation of each user in accordance with his/her requirements.

System requirements of the developed software modules are: Windows operating system of at least 7th version, TCP/IP, client-server architecture. Oracle 12c (12.1.0.1) is used as a database management system. Software codes of modules were developed in C++ programming language.

Graphic visualization is implemented in QGIS. The development and rules of work with digital graphic documentation are specified in a classifier of objects for digital plans and layouts developed by the authors [37].

Conclusion

Finally, it is important to note that, while writing this paper, specialists working in the Department of Mine Survey, Geodesy, and Geographic Information Systems of Perm National Research Polytechnic University have developed 91 software modules (including 10 programmes to plan mining operations) shared between 21 workstations of different mining company specialists (from the first line specialists at mines to the company management). At the moment, the activities focused on the development of the mining-and-geological information system (GGIS) of Uralkali PJSC are in progress; therefore, the number of software products is likely to increase.

Table 2

The workflow and list of issues addressed at the stages of planning of mining operations with the use of software modules developed by specialists of Perm National Research Polytechnic University

Planning stages	Scope of work and issues addressed at the stages of planning	Responsible	WS/Software module
I	1. Issue an Order on the preparation of an Annual Plan for the Development of Mining Operations	Chief Engineer of Uralkali PJSC	–
	2. Prepare a Mining Production Schedule divided by types of minerals (sylvinite, carnallite)	Planning and Economic Department, Procurement Department, Finance Department	–
II	Prepare the design documentation for an Annual Plan for the Development of Mining Operations: – design zones for field development; – design parameters of losses and depletion; – design parameters of rock and soil surface movement and deformations in the area of planned mining operations, etc.	Galurgia JSC	–
III	1. Break down planned mineral output by mining machines, types of operations, mining areas, as well as by mineral types (carnallite, sylvinite) for each month. 2. Delineate planned areas of work performed by each mining machine on digital plans of mining operations. 3. Break down backfilling by panels and blocks for each month depending on the type of backfilling (as well as by protection measures). 4. Develop and prepare for printing standard graphic documentation and tables of an Annual Plan for the Development of Mining Operations.	Mining Department	Miner's WS / Plan of mining operations
	5. Form cross-sections of planned mine workings based on the results of survey measurements of cross-sections of operating mechanisms of road heading machines. 6. Calculate the average specific loss of broken rock mass for a selected mining machine. 7. View the information by planned mineral output for a selected mining machine. 8. Develop and prepare for printing documentation by mining machines as a part of an Annual Plan for the Development of Mining Operations	Survey Department	Surveyor's WS / Mining machines [42]
IV	1. Calculate the averaged geologic columns for deigned mine development areas. 2. Determine qualitative and quantitative indicators of rocks by a selected designed mine development area. 3. Determine a planned position of wells to analyse the physical and mechanical properties of rocks and channel sampling. 4. View digital plans of mining work together with the information on the mine layout including panels and blocks, boundaries of areas of replacement of minerals with adjacent formations, on development of mine areas and boundaries of designed development areas.	Geology Department	Geologist's WS / Planned column [26] Geologist's WS /Planned wells [26]
	5. Prepare the initial geologic data to determine the parameters of the development system. 6. Based on design data, make a preliminary calculation of coordinates of room axes within the boundaries of designed zones.	Survey Department	Surveyor's WS / Planning of mine workings [34]
	7. Map preliminary positions of mine workings (permanent, development workings, and rooms) and boundaries of mining units on the digital plan together with a calendar breakdown by quarters. 8. Calculate planned backfilling taking into account the backfilling method (hydraulic, mechanic, and combined). 9. Simulate the hydraulic backfilling process to determine the best-designed positioning of backfill wells and stopping. 10. Map mining operations, as well as longitudinal and cross-sections of mine workings of planned backfilling on the digital plan. 11. Develop and prepare for printing standard graphic documentation and tables of an Annual Plan for the Development of Mining Operations.	Mining Department	Miner's WS / Planning of mine workings Miner's WS /Planned backfilling [43]
V	1. Calculate pillar loading to have more detailed data on designed parameters of the development system while paying attention to requirements of protective measures during mining operations. 2. Develop and prepare for printing standard graphic documentation and tables of an Annual Plan for the Development of Mining Operations. 3. Check safety before undermining the water blocking layer when detailed data on the development system parameters are available. 4. Develop and prepare for printing standard graphic documentation and tables of an Annual Plan for the Development of Mining Operations.	Geomechanics Department	Geomechanic's WS / Pillar loading degree [41] Geomechanic's WS / Safe conditions to undermine the water blocking layer [41, 45, 46]
	5. Adjust the boundaries of the design zones based on detailed data on the design parameters of the development system (the boundaries of planned zones are specified based on data of geomechanics calculations).		Geomechanic's WS / Mines [29]
	6. Bind attributive information to graphic objects of planned development zones. 7. Calculate planned values of depletion by planned zones.	Geology Department	Geologist's WS / Planned column
VI	1. Recalculate qualitative and quantitative parameters of rock mass within the detailed boundaries of planned zones and taking into account the types of planned mining operations (room work, development, and permanent).	Geology Department	Geologist's WS / Planned column
	2. Adjust coordinates of axes of mine workings based on modified averaged indicators of geologic columns and parameters of the development system within the detailed boundaries of planned zones	Survey Department	Surveyor's WS / Planning of mine workings
VII	1. Based on detailed data on the positioning of axes of mine workings, determine the parameters and map the boundaries of mining units, as well as the boundaries of development workings and rooms, on the digital plan of mining operations with the breakdown by quarters (colour-coded indication). 2. Develop and prepare for printing standard graphic documentation and tables of an Annual Plan for the Development of Mining Operations	Mining Department	Miner's WS / Planning of mine workings
VIII	1. Calculate planned figures concerning mineral loss for each mining unit. 2. Develop and prepare for printing standard graphic documentation and tables of an Annual Plan for the Development of Mining Operations	Survey Department	Surveyor's WS / Specified limits set in an Annual Plan for the Development of Mining Operations [44]

The developed software modules designed for planning of mining operations completed the pilot operation stage already and, as of the moment of publication of this paper, they have been put into commercial operation at Uralkali PJSC's mines.

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