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DIGITAL TOOLS FOR UNDERGROUND MINE PLANNING: CUT-AND-FILL MINING

Today, digital planning of mining operations has become one of the most in-demand tools for solving technological problems of industry.

A set of tools for planning underground mining operations has been developed based on the MGIS MINEFRAME software. The tools were designed taking into account the geological and geotechnical conditions at the PIMCU, PJSC and Yakovlevsky GOK JSC mines. The specificity of these mines is the use of the downward horizontal-slice dry-fill mining method.

A distinctive feature of the developed tool is a wide variation in the planning period (from long-term to short-term), which is achieved by using cyclograms to simulate technological processes of stoping and backfill operations. Furthermore, the tools available for creating and visualizing a dynamic model of mining progression provide ample opportunities to optimize and specify the mining plan.

Keywords: *digital planning tools, underground mining, stope models, slice mining, backfill operations, cyclogram, technological operations, transportation scheme.*

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Introduction

Software tools to support engineering of mining operations have evolved within rather a short time from models of specific geological and mining objects to challenging tasks of mine planning, design and management based on digital modeling of objects and processes of mining. One of the most in-demand tools of industrial engineering in mining is digital mine planning to provide both a mining scenario and its optimization options based on various criteria [1].

The aspects of computerized planning were addressed both in Russia and in the world as soon as it became possible to obtain digital representation of mineral resources, geometry of extraction blocks and sequence of their mining [2–5]. As the mathematical apparatus and optimization algorithms were advanced, quite intelligent mine planning software tools appeared, which focused on selection of an efficient mining sequence of extraction blocks which are often represented by block models without any regard to technologies of accessing and actual mining of mineral reserves [6, 7]. This approach is on the whole applicable to solving problems of long-term planning. However, in case of shorter period of planning, alongside with the volume and quality of produced minerals, it is required to take into account mine capabilities (tunneling speed, mining safety, availability of equipment and mine personnel, etc.) necessary to implement the proposed scenarios [8].

On this basis, in the environment of MINEFRAME mining geology information system (MGIS) [9, 10], a bundled suite of software tools has been developed to encompass geological and geotechnical conditions, as well as engineering constraints and processing limits. The software tools are developed for operating conditions of PIMCU [11] and Yakovlevsky GOK [12]. The specificity of these underground mining practices is the use of the downward horizontal-slice dry-fill method. The geological feature of PIMCU's mines is high tectonic stresses and variable geometry of stopes meant for cemented backfill. Yakovlevsky GOK's mines are geologically distinguished for the required minimization of displacement of overlying rocks at the sustained high rate of stoping operations.

Engineering support of backfill operations

An important part of engineering support in backfill is calculation of backfill volume, surface of backfill mixture spreading (which is particularly difficult in complex geometry stopes) and backfill quality control. Such works are automated using the tools of backfill modeling and control [13]. Online arrangement of backfill partitions during modeling makes it possible to divide the stoping void into backfill sections for the further skeleton modeling (**Fig. 1**).

When a section is composed of fragments of a few stopes, the frames of the latter are integrated into a single model. The models of the sections are structured and stored in the data base; thus, they can be uploaded with respect to their belonging to certain horizons, layers and dates.

For calculating the backfill volume and underfill size, the spreading surface algorithm is implemented, with a backfill feed point set in the model of a backfill section. There can be a number of the feed points. For modeling the backfill spread surface, we set an angle of flow subject to the backfill composition and an elevation of the spread surface at a chosen point of the space to be filled. Using the input data, the model of the backfill spread surface is constructed alongside with the fill mass model and the underfill model.

In each model of a backfill section, any number of models of backfill layers can be constructed with such characteristics as (**Fig. 2**): backfill height, angle of flow; backfill composition and design strength.

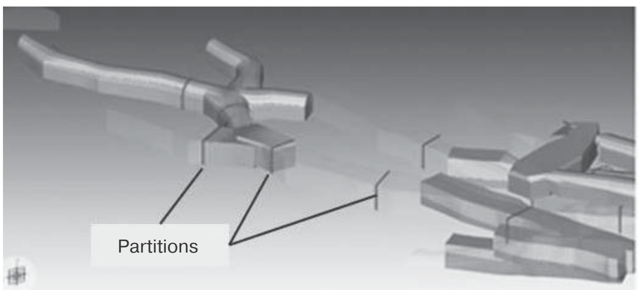

Fig. 1. Fill mass modeling

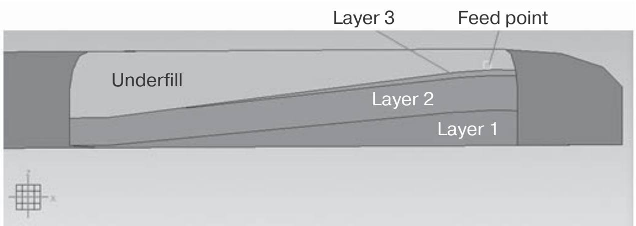

Fig. 2. Three-layer backfill in section

After surveying of the fill mass, all paperwork on the section, the backfill composition and its volume is prepared.

It is also possible to generate a fill mass pattern and map with calculation of the stability factor for each section. To obtain information on actual condition of a fill mass (which is the roof of the underlying stopes in the test mines), the backfill is sampled and its strength and other characteristics, for instance, consolidation, are determined. This is a routine duty of a geomechanical safety service [14]. All data are entered in the sampling e-log connected with the models of the fill mass sections.

MGIS graphics ensures visualization of information on the fill mass (including sampling points) in the form of 3D models (**Fig. 3**), plan views and elevation views. In this manner, the real-time access is allowed to overall information on any section of the fill mass in the user-convenient format.

Mine planning: A case study of cut-and-fill method

The critical optimization criteria of mine planning are: sustainable ore flow of assigned quality, mining safety, efficient utilization of mining machinery and mining crews, and minimized cost of processes [15, 16]. On this basis, the automated planning tools have been developed to produce an optimized mining scenario at the preset criteria.

Figure 4 schematically describes digital underground mine planning algorithms.

Source data. The tools of planning use data on mining machines and mine personnel, mineral reserves and resources, properties of enclosing rock mass, design and actual stopes (**Fig. 5**). For instance, geological models inform on the content of useful components, on physical and mechanical properties of ore and rocks, as well as on their process characteristics.

The models of engineering objects (stopes and extraction blocks) contain information on mineral reserves and on geometry of mined-out void. These models can be added with such characteristics as: susceptibility to failure per sites, actual strength of backfill, etc. All these data can be included in the mining scenario planning and design.

The information on assets (personnel, mining machinery) is necessary to generate cycle sheets of process steps, and is also used as a constraint factor.

Scenario setup. For obtaining a mining scenario, a work schedule is

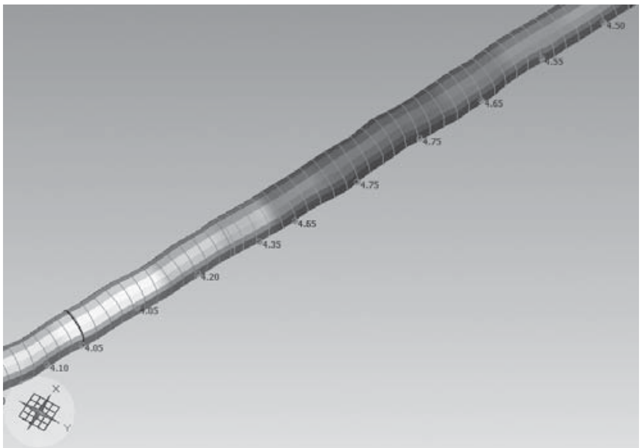

Fig. 3. Model of fill mass within the limits of stoping void (color palette is reflective of strength characteristics) with marked sampling points

generated, and a planning period with the performance targets is assigned. Design of a mining scenario can be implemented with allowance for all or a part of terms and constraints. This is applicable in medium-term and long-term planning which requires no comprehensive refinement of input information.

Cyclogram setup. Each cycle sheet represents a set of elementary operations for the specific conditions of mining. For this reason, a cyclogram is every time automatically selected based on the applicability criterion in the specific conditions. For instance, in selecting the method of drifting (disintegration or blasting), one of the applicability criterion can be the hardness of rocks. This allows automation of the process of planning mining operations presented as a package of cyclograms tied up with the specific underground excavations and specific geological conditions.

Mine personnel and equipment are the constraints in the mining scenario design. Availability of high-skilled technicians and professionals in a mine crew, as well as equipment

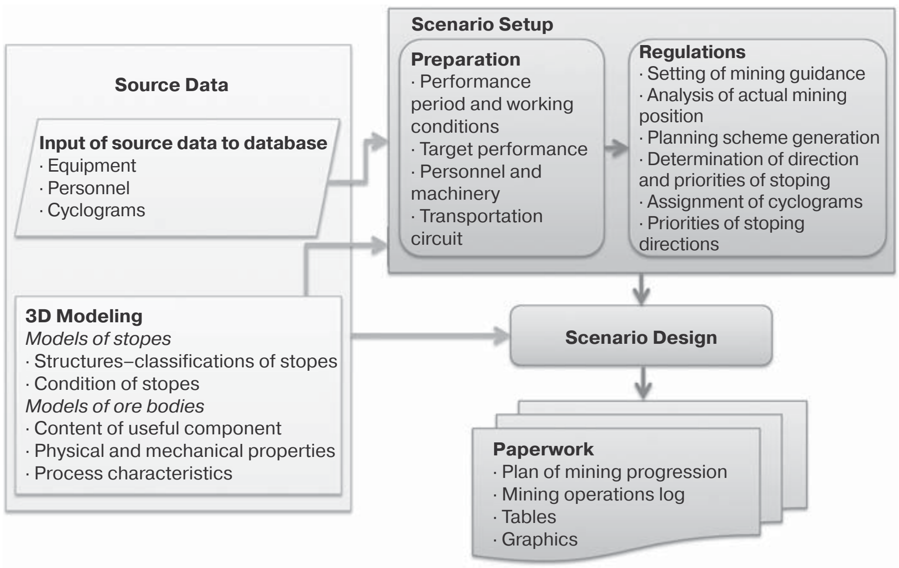

Fig. 4. Algorithms of digital planning of underground mining operations

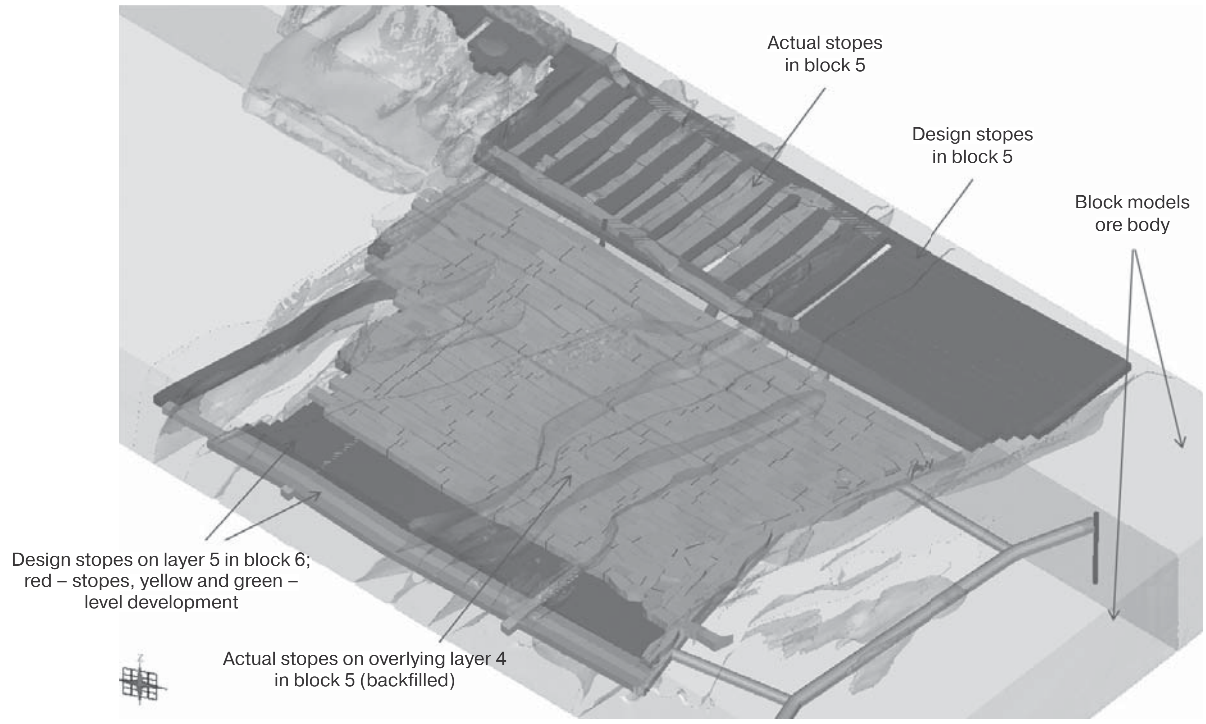

Fig. 5. Models of objects involved in planning (Yakovlevsky mine)

with certain specifications predetermines their workability in certain mining conditions.

The use of specific machines is governed by their technical state, which is connected with the equipment operation and maintenance schedule set by a user.

Transportation. One of the productivity limitations in an underground mine is its material handling system capacity [17, 18]. When implementing the mining scenario design, it is possible to set transportation chains and their components represented by mobile and immobile objects: load–haul–dumpers, dump trucks, railroad transport, mine hosting systems, ore passes, bunkers, etc. The list of the engaged components and their operation parameters are set for each transportation chain.

A haulage route is calculated automatically based on the settings. A route is selected with the regard to certain conditions, namely: minimum haulage distance, availability and accessibility of an intake object. Calculation of rock volumes to be handled is accompanied with the estimate of useful component content in these volumes. The haulage time from the point of loading to the point of unloading is calculated with regard to the actual haulage distance, characteristics of involved equipment and properties of rock mass being transported.

Scheme of mining. Each system of mining has a plan of level development operations, face-entry drivage and actual stoping. In the underhand cut-and-fill method, an extraction block is assumed prepared for mining when all drifts and raises are cut, as a rule. Other alternatives are also possible to reduce the transition time between drifting and stoping [19].

In Yakovlevsky mine, stopes are cut in parallel to each other. Stoping can be started if there is no operation in the neighborhood, or the neighbor stopes are already cut and filled, and the fill mass has developed the standard strength. Stoping on the lower lying level starts after the overlying layer is cut and filled. The drifts and face entries, apart from safety cuts, remain unfilled until all operations in this extraction block are finished. These and other regulations should be set and included in the planning tool in the mining scenario design.

The algorithm included in the planning tool generates a planning chart based on the models of underground excavations. It determines condition of an object (intact, cut, or filled) or its fragment, and also defines the sequence and direction of stoping. The choice of the stoping sequence takes into account priority grades of stopes; the choice of the stoping direction considers the location of ore passes. A user can adjust and correct conditions of stopes, as well as directions and sequences of stoping.

After setting a scheme of mining, the cyclograms are automatically assigned to the related excavations with regard to geological and geotechnical conditions. The key optimality criterion is the maximum speed of advance in stoping at minimized changeover of cyclograms.

Setting priority grades. One of the options of mining scenario management is allocation of available resources to different objects of a mine [20]. This is implemented by assigning outputs per extraction blocks and by setting priorities of some excavations over the other cuts. With regard to this information and data from cyclograms tied to the excavations, the number of faces to be cut concurrently to ensure the preset output is determined for each extraction block. The resource allocation algorithm ensures operation of the preset number of faces to reach the performance targets.

Scenario design. Design of a mining scenario takes into account all preset performance targets, regulations and constrains, namely:

• The stoping sequence is determined from the set regulations of mining operations and is based on the assigned priorities;

• The cut-and-fill modeling is carried out by cycles in the direction of minimized haulage cost;

• No operation is allowed until mining safety is ensured, including development of the standard strength of backfill in neighbor stopes;

• The resources engaged in operation in a stope cannot be used in another stope until they are released;

• The operations included in a cyclogram can only be executed by a crew composed of the technicians with the pertinent skills;

• When it is impossible to start or continue operations for any cause (no equipment or technicians are available, haulage is infeasible, etc.), the work is suspended until this cause is eliminated.

Presentation of the results is put through as scenario – the dynamic model of mining progression as a sequence of cutting, filling and haulage operations in time. The offered tool provides the options of animation and generation of tabular and graphical reports on:

• Outputs per each stope, mine crew (operation district), shift, equipment unit;

• Target time of operation of each equipment unit;

• Planned periods of cutting and filling;

• Traffic and haulage routes along the preset transportation chains.

All calculation results are stored in the data base of MGIS as models and tables, and can be used for the comparison of different mining scenarios.

Conclusions

The distinctive aspect of the developed tool is a wide variation of the planning period (from long-term to short-term), which is achieved through the use of cyclograms for modeling process flows, and owing to flexible setting of terms and constraints. At bottom, the minimum time span of planning is a work shift, which, after certain updating, allows using the tool as the mining management facilities given the benefit of visualization of the planning results. An important advantage of the proposed tool is its integration in the unified digital environment of MGIS MIINEFRAME, which ensures all-inclusive solution of geological surveying and technological tasks, and withdraws the need of import and export of data.

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