Modeling of underground mining processes in the environment of MATLAB / Simulink

Peter Janič[1], ***Slávka Jadlovská***[2], ***Jakub Zápach***[3] *and* ***Lukáš Koska***[2]

The article is focused on the creation of a computer model for the planning of the mining process and its application in the planning of the mining activities. The use of computers and specialized software in mining has brought great new possibilities to speed up and refine the planning process. The paper deals with the use of software tools in mining and their application, the overview of available market planning software and their functions. The main part of the article is the design of a computer planning model of mining. The presented article is focused on modeling in MATLAB/Simulink environment, preparation of input data, a description of its function and its application. MATLAB is a worldwide popular software for technical computing and simulation. It is a convenient tool for simulating mining processes. The purpose of the article is to point on possibilities of modeling of mining processes in the MATLAB environment. The emphasis on creating the model was based on the simplicity and difficulty in inputting the input parameters and the overall work with the created model. At the end of the article, additional options for expanding and improving the model are summarized.

Key words*: model, modeling, mining, MATLAB, process*

Introduction

The development of computer technology and its introduction into all areas of human activity has brought new opportunities and accelerated many activities. This trend did not exclude mining and mineral mining (Bauer, 2014). In countries that are among the leaders in the mining industry abroad, their use is already standard. These programs have facilitated, accelerated, and streamlined many of the activities involved in the design, planning, and management of mining operations. Traditional methods for designing and modeling surface and underground operations are based on manual calculations of mining parameters and manual output of graphical outputs (Fahrman, 2016). The basis of this method is a long time for data processing and the design of an optimal solution that greatly complicates work. Specialized software enables faster, more quality, and more creative work. IT applications in mining, allow the introduction of new methods for surface and deep mining, which differ significantly from traditional methods (Rybár et al., 2017; Blistan et al, 2015) . Planning and designing underground mining operations involves a comprehensive process of integration of three-dimensional data through the use of information from exploration, engineering, and extraction processes. Planning of the deposit mining process involves the transfer of knowledge and technology between disciplines such as geology, technology, research, accounting, and management (Blistan, 2007). Since operations are becoming more and more complex, effective communication is becoming more and more complex (Hall, 2018). Methods of reducing the number of errors and risks in exploration, mining, planning, and operations will help increase the safety and productivity of mines (Kaiser et al., 2002). The introduction of innovative technologies in the process of raw material extraction planning in Slovak mining companies is essential for increasing the efficiency of mining, reducing the costs of mining and operation and also for the maximum rational utilization of mineral resources (Cehlár et al., 2017).

Computer modeling in the mining industry

At present, there is a whole range of software solutions that cover the full range of mining industry activities, including comprehensive mining planning solutions to specialized programs designed to address specific technological processes in mines and quarries such as drilling and blasting, ventilation or geotechnical modeling. This subchapter briefly sums up the available software and its specifics in the mining planning process.

With the onset of computing, mining techniques have evolved into new design methods. New methods have emerged since the 1960s in the US, the UK, Australia, and South Africa. Classical methods are based on manual calculations of technical and technological parameters and graphical interpretations. Methods require long and

[1] *Peter Janič*, NDS a.s., Dúbravská cesta 14, 841 04 Bratislava, Slovak Republic, peter.janic@ndsas.sk
[2] *Slávka Jadlovská*, *Lukáš Koska*, Faculty of Electrical Engineering and Informatics, Technical University of Košice, Department of Cybernetics and Artificial Intelligence, Letná 9, 042 00 Košice, Slovak Republic, slavka.jadlovska@tuke.sk, lukas.koska@tuke.sk
[3] *Jakub Zápach*, Faculty of Mining, Ecology, Process Control and Geotechnologies, Technical University of Kosice, Department of Montaneous Sciences, Letná 9, 042 00 Košice, jakub.zapach@tuke.sk

demanding work over a longer period of time, especially when different solutions are being developed (Miladinovič et al., 2011).

Benefits of using software:

- quick update option,
- three-dimensional view of objects,
- thanks to the third dimension, high transparency,
- considerably faster creating different variants of projects or models,
- digitally stored data can be used in different types of software,
- the ability to run different types of simulations and calculations,
- the ability to quickly and conveniently share data and results over the Internet.

Computer programs that are used in mining, depending on the purpose, can be divided into the following groups:

- **universal software packages:** mining computer programs for modeling and design of deposit for surface and underground mining,
- **specialized software packages:** designed to optimize surface or underground mining and analyzes of mining activities,
- **special application software:** designed to analyze specific problems associated with mining design or mining technologies, cost analyses, solving some technical problems such as slope stability, blasting design, ventilation, transport and others (Miladinovič et al., 2011).

The leaders in mining software development are companies GEOVIA, DATAMINE, MAPTEK, Hexagon Mining, and Micromine. Each company has different software packages created for specific types of operations or specialized operations within the mining industry.

Mining-technical start points for modeling of mining processes

Mining of mineral deposits has several characteristics and peculiarities that are given by the specific production process of mining, which differs, respectively. It is incomparable with manufacturing processes in other industries, in engineering or metallurgical production. As Mining Characteristics of mining of mineral deposits, we understand the content, forms, typology, and system of deposit mining, based on the application of the above mining and mining-related scientific disciplines. Mining and system characterization of the mining industry is primarily a result of mining and system analysis of technological processes and technical phenomena taking place in the production process of deposit extraction. In the production process of the mining industry and in the individual technological processes of mineral extraction, several separately existing but parallel development stages of the mining business, which are realized on the deposit for rational obtaining of the maximum amount of mineral / raw material (Bauer, 2014).

The basic and general features of mineral deposit extraction that represent the specificities of ore, non-ore, and energy raw materials extraction can be summarized as:

- stages of mining processes,
- a time sequence of mining,
- preparedness of mining,
- variability of mineral deposit quality ratios,
- the selectivity of mining,
- energy consumption of mining processes,
- the economic burden of mining,
- reduced security of mining facility,
- large surface and directional vastness of excavation,
- environmental friendliness of mining processes.

The mining of mineral deposits is characterized as a very complex, specific and dynamic production process, taking place in a constantly changing time, and the boundary of the mining area of the deposit in which the various phases of the mining process are realized (Bauer, 2014).

A process of a model making in MATLAB / Simulink interface

The computer model intended for the planning of mining processes solves underground excavation of non-ore raw material. A model is simulating mining in two positions in mine. In each position is placed one workplace, on witch the mining itself takes place. The mining method used in the model is stopping with the filling of the open underground spaces. In simulation is used non-rails transport. Each mining position is separated into smaller blocks. The geometry of mining positions and distribution to mining blocks is displayed in Figure 1.

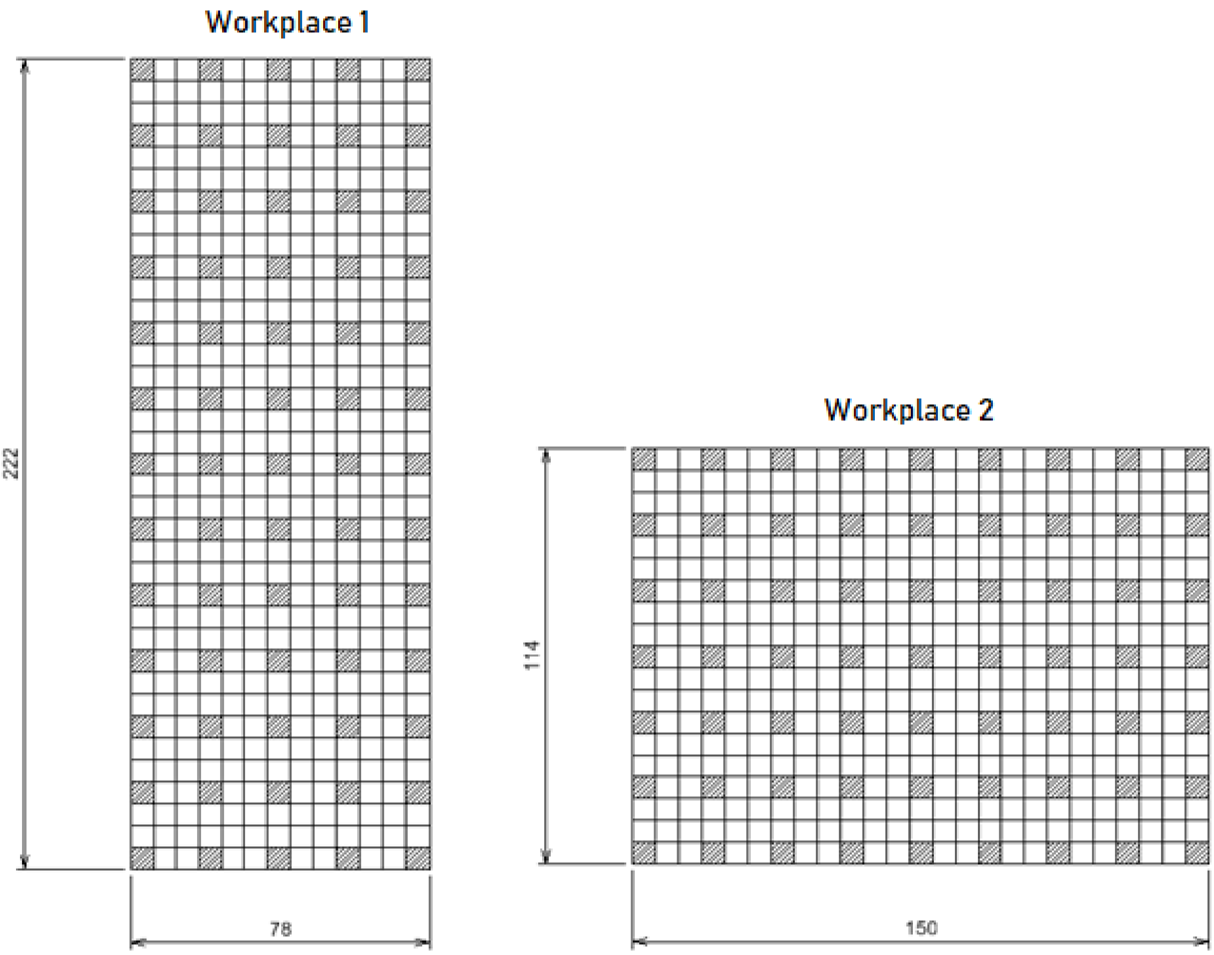

Fig. 1. Geometry of the workplaces (Janič et al., 2018).

The Modeled situation is expecting that the opening of the mine was already done and mining of new mining corridors is not expected. Mining vehicles are used for the transportation of ore. The routing of loaded and empty mining vehicles is realized in transport corridors of the mine. The timing of transportation is calculated from generally using formulas for calculation of the mining transportation performance. The model works with three products of the mining process based on the content of raw material (Fig. 2).

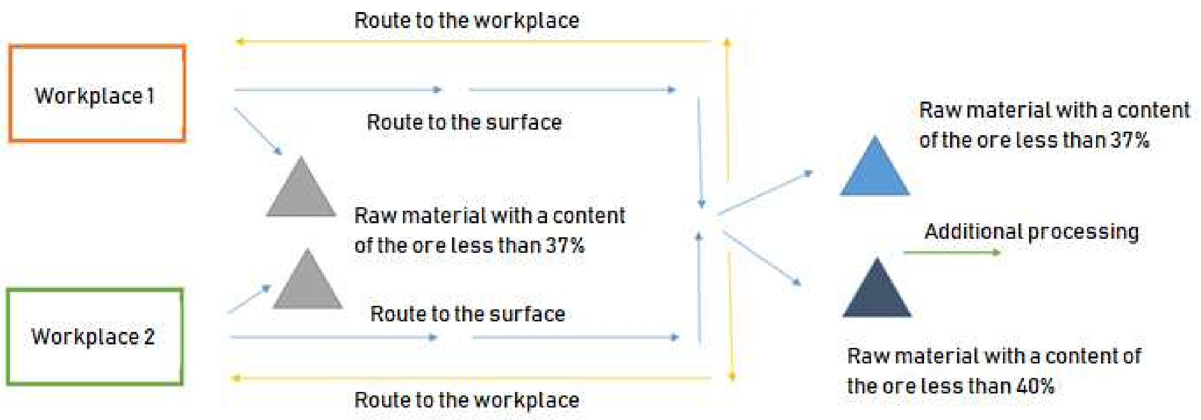

Fig. 2. Scheme of the model situation (Janič et al., 2018).

The basic software (Fig. 3) for creating the planning model is ESRI ArcGIS software and MATLAB software with the Simulink add-on. ArcGIS software is used to work with the geostationary model and its visualization, block selection, and also to visualize output data on the mining process. It will therefore mainly serve for the preparation of mineral deposit data, respectively about individual mines. The MATLAB software will be used for the main part of the modeling process, in which the mining process itself will be modeled, and the ArcGIS data and other input data will then be imported (Fig. 4).

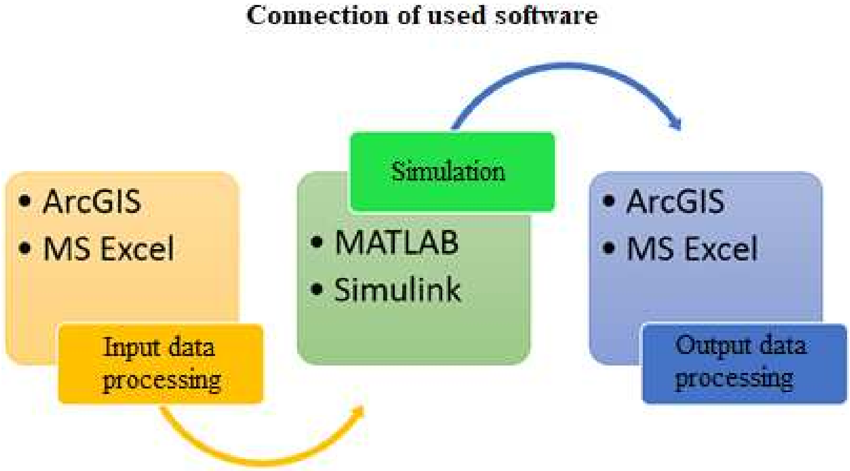

Fig. 3. Connection of used software (Janič et al., 2018).

Modeling process

The simulation model is based on the Stateflow toolbox. Stateflow is an environment for modeling and simulation of combinatorial and sequential decision-making based on logical events using state automata and flowcharts. Stateflow allows to combine graphical and table representation, also includes transition diagrams, flowcharts, transition tables and truth tables for modeling as the system responds to events, time conditions, and external input signals (Novák et al., 2005).

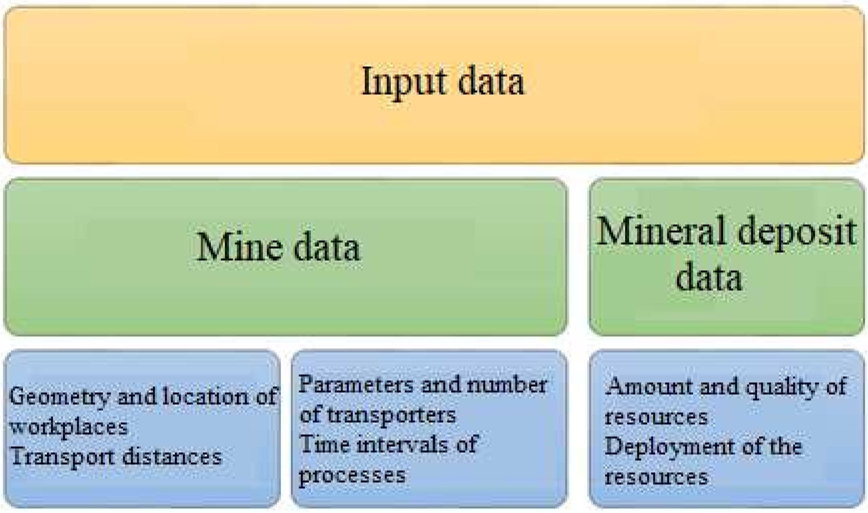

Fig. 4. Input data for the model (Janič et al., 2018).

With the Stateflow toolbox, it is possible to model the logic for supervisory control, task planning, and error management. Stateflow includes state-of-the-art animation, static and run-time control for design consistency testing and assembly before implementation. Using the Stateflow toolbox, we modeled the mining process by simulating discrete events. Each block created by the Stateflow toolbox represents one mining site (Fig. 5), with multiple blocks in the simulation scheme representing the same number of workplaces working on the same mining blocks. The mining input data can be set programmatically, using the mine_param.m script; the amount to be exploited is stored in the 1_pracovisko.xlsx and 2_pracovisko.xlsx files. Simulation is 60 times faster than real time, which means that 1 second in a simulation is 1 minute in real time.

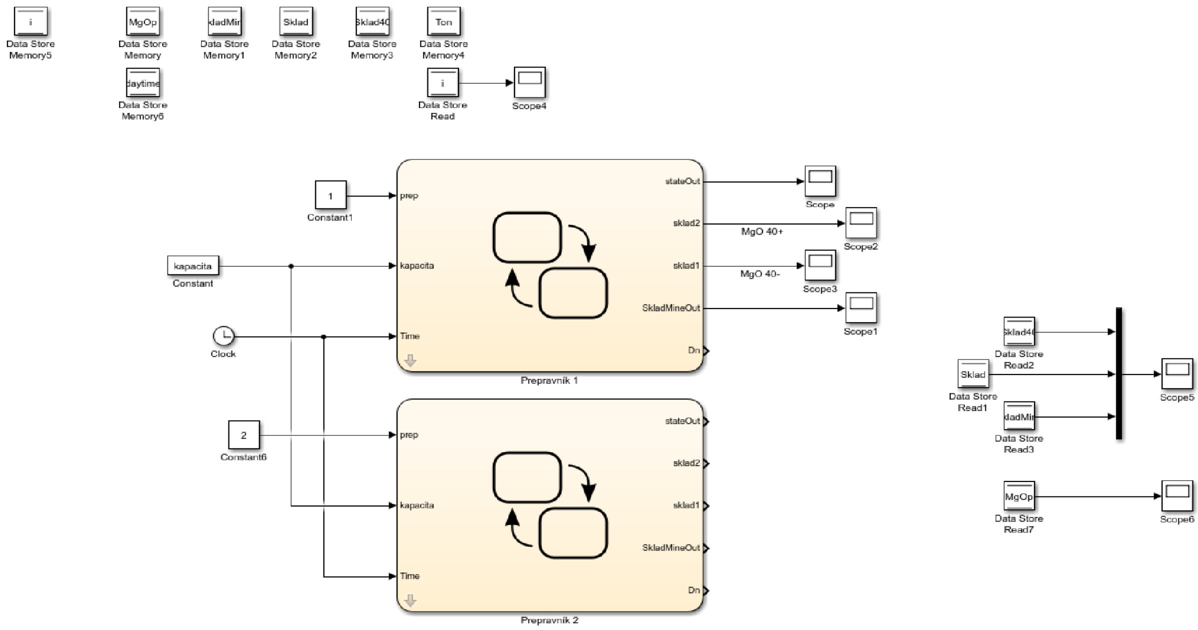

Fig. 5. Illustration of the first workplace in MATLAB / Simulink (Janič et al., 2018).

The result of the simulation is the time course of filling of the warehouses, which are according to the content of the utility component sorted into three categories. These data can be displayed directly in the MATLAB environment or can be exported to .xlsx for MS Excel. The simulation parameters can be set for the user in the mine_param.m script. As shown in the variable names, the capacity of the conveyor, the transportation time of fully loaded conveyor to the surface, the transportation time of empty conveyor to the underground, the loading time and the unload time. After changing the values, it is necessary to execute this script to save changes to the variables and also repeat the simulations. The mine_param.m script uses the import_s1.m and import_s2.m scripts that are loading and preparing the data.

The simulations themselves are stored in Simulink simulations in the mine.slx and mine2.slx files. Before running the simulation, run the mine_param.m file with the appropriate parameters. Once the simulation has finished, the data can be exported (Fig. 6). The export is executed by running the dataProcessing.m script which performs the preprocessing of the acquired data and stores the data in the .xlsx file.

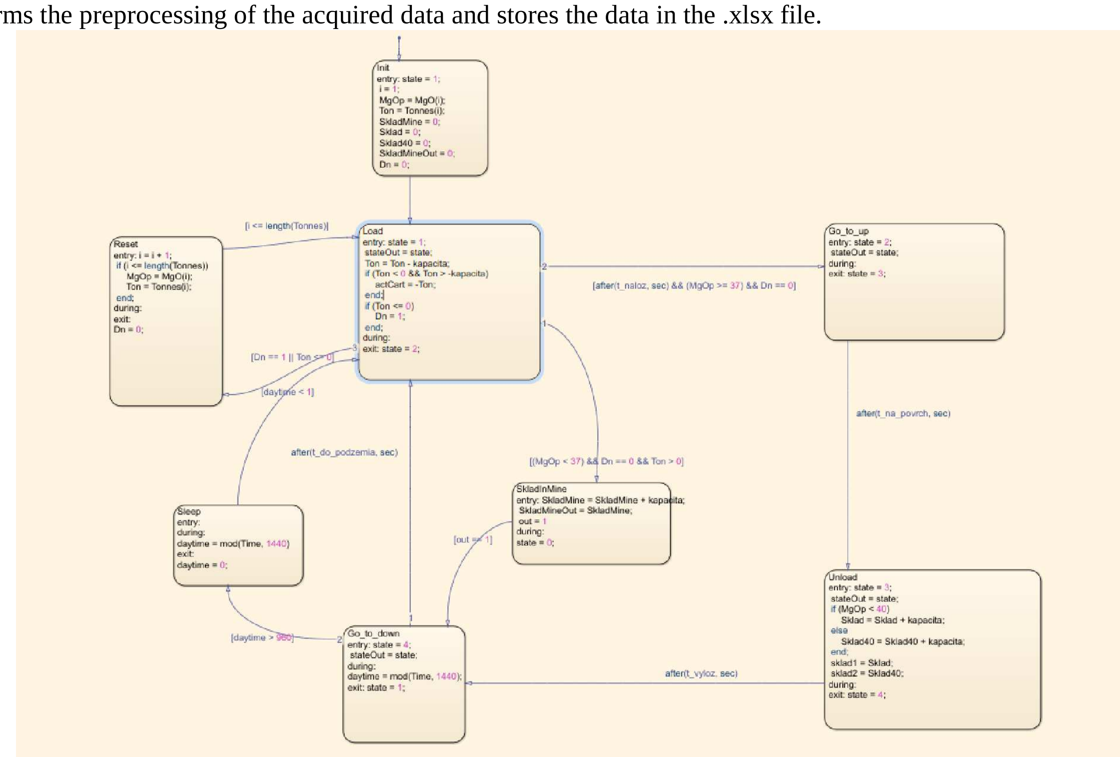

Fig. 6. Graph of transitions between states of the workplace (Janič et al., 2018).

Planning model features

The main features of the proposed planning model can be divided into three parts:
- determining the total amount of raw material extracted
- determining the amount of raw material extracted according to each set quality category
- determination of the mining process in individual mining places and workplaces

Together these features give an overall view of the mining process and its progress over time. Basic outputs from the model include spreadsheets, exported to .xlsx, and charts that can be viewed directly in MATLAB or can be created in MS Excel. A script that prevents data processing from simulation generates output:
- day-to-day mining and its breakdown by the quality of each workplace
- monthly mining and its distribution according to individual qualities for individual workplaces
- the number of mining blocks being used

After entering all input parameters of the model, it is possible to proceed to the simulations themselves (Fig.7). The length of the mining simulation for individual workplaces depends on the size of the individual mines and the time period to be simulated. Another factor influencing the length of the simulation is the performance of the workstation on which the simulation is running.

In the case of this model simulation, the simulation itself took place at the workstation with the following parameters:
- CPU – Intel Core i5 4670@3,4 GHz,
- RAM 16 GB,
- GPU NVIDIA GTX 1060 6GB,
- SSD 250 GB.

The duration of the simulation, in this case, lasted approximately 2 minutes for each workplace.

Outputs of mining simulations of individual workplaces were processed in MS Excel. Outputs are graphs and spreadsheets describing the progress of mining and the month-by-month mining scheme that was processed in AutoCAD software.

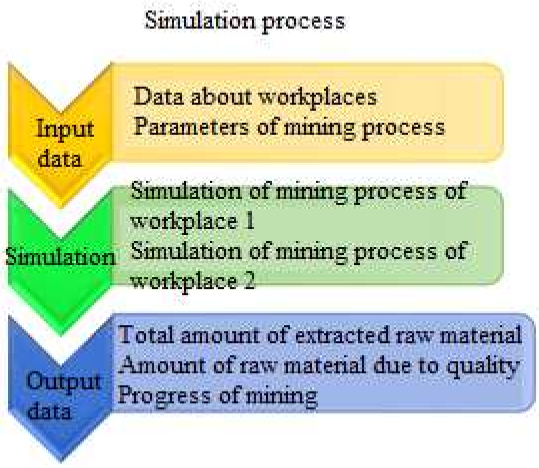

Fig. 7. Simulation process (Janič et al., 2018).

Outputs from the model

Fig. 8. is a schematic illustration of the process of each mining queue according to the months for the individual workplaces. These progress maps have been created based on the number of blocks to be mined in each month. The total number of blocks used is shown in Tab. 1 from where these values were used for the creation of the progress maps in AutoCAD software.

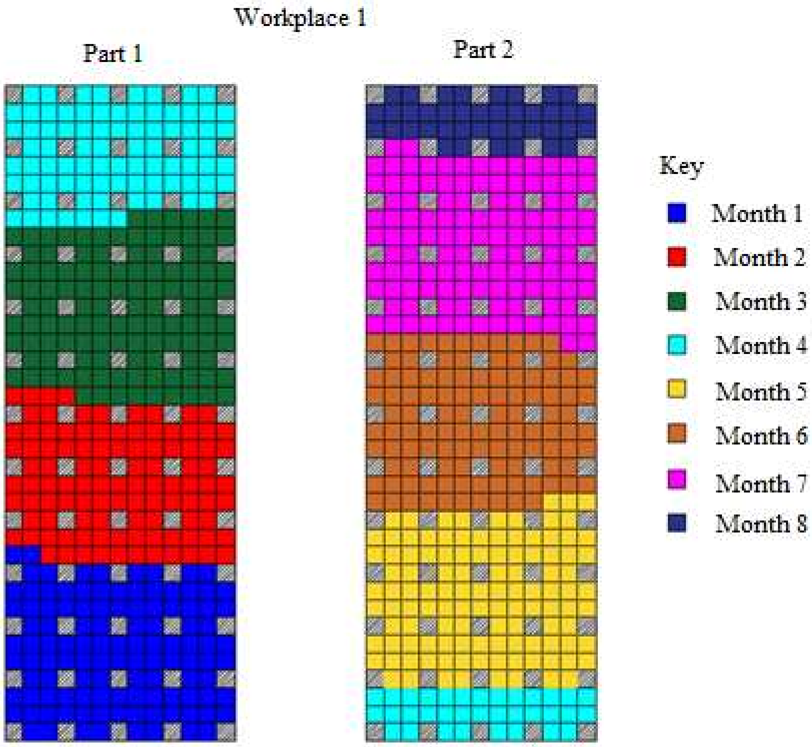

Fig. 8. Monthly progress of mining – Workplace 1divided into two parts (Janič et al., 2018).

Tab. 1. Summary of mining in workplace 1 (Janič et al., 2018).

Month	Product 1 [t]	Product 2 [t]	Product 3 [t]	Number of excavated blocks	Monthly mining of raw materials [t]	Total mining of raw materials [t]
1	24336	33984	5760	112	64080	64080
2	50688	64872	13824	225	65304	129384
3	85968	85248	25344	342	67176	196560
4	121536	105048	37440	459	67464	264024
5	147456	136368	45504	572	65304	329328
6	172800	169704	50112	682	63288	392616
7	207072	190080	63936	801	68472	461088
8	215424	195840	67392	832	17568	478656

Model evaluation and possibilities of use in practice

The model for the planning of the mining progress of the deposit, which is the main benefit of this article, also forms the basis for further development and gradual improvement to adapt to the conditions of the particular operation as much as possible. The proposed model could be summarized in terms of advantages and disadvantages as follows:

Advantages of the proposed model

- simple input of basic mining parameters
- import of the mining data is in .xlsx format, which is supported by most geo-statistical models,
- simulation speed
- possibility to adapt to any requirements of the user.

Disadvantages of the proposed model

- in actual version is necessary to run the model from MATLAB,
- a more complicated changing procedure of some parameters (working time, number of workplaces),

- not generating graphical output automatically (mining progress).

Possibilities of the model improvement to match most of the needs of

- adding a higher number of the input data,
- adding possibilities of optimization of mining parameters with a genetic algorithm,
- creation of a model as a separated software without the need to run a model in MATLAB,
- the possibility of creation version for a mobile phone or web app,
- adding a fully graphical interface.

The proposed model can be used in practice not only in the mining planning process and its progress but also in the design process, determination of the optimum size of the transporters as well as sufficient power of mechanisms or design and choice of mining routes. The benefit of the model for practice is the rapid simulation of various variants of mining plans.

Conclusion

The article focuses on the design and creation of a computer model for the mining planning process, which should be a supporting tool in the planning process. The introduction of such advanced tools into the mining industry is justified, and abroad, these software tools are used as standard and are applied to all areas of mining. However, they are rarely used in the conditions in Slovakia and practice at all in the mining planning process. This article aimed to analyze the currently available commercial planning software, to evaluate its advantages and disadvantages. Based on this analysis, the criteria and requirements for the computerized planning model itself and the appropriate tools for its design were determined. The article also deals with the preparation and processing of data that will be used in models as input data. The main emphasis of the article is on the creation of the model itself and its use in solving the planning of the mining process in the deposit. A designed model was created in MATLAB and Simulink, which serves as a universal tool for a wide range of technical calculations. The created model was subsequently tested on a model situation, which simulated deep mining using selected mining method and mining machinery. The parameters of this simulation tried to approach the real mining conditions as closely as possible within the capabilities and functions of the proposed computer model. The proposed computer model also forms the basis for further extending its functions and gradual improvement to meet the conditions of a particular operation, eventually serving as a springboard for another version of such a computer model. A model can also be used in the process of education of future mining engineers and as a learning tool for subjects dealing with the mining of raw materials.

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