Modular system of simulation modeling of conventional and robotic mining technologies

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Abstract. The paper describes the function chart of a simulation modeling system for the conventional or robotic mining technologies with drilling-and-blasting and cutting methods. The function chart is implemented using the evolutionary algorithm and simulation approach. The authors present the main program modules with generate simulation models and optimize the technology and management scenarios for the specific geological and geotechnical conditions. The structure of the data base on mining machines, their capacities, robotic automation alternatives and compatibility is presented.

1. Introduction
An integral part of selection of mining technologies is the synthesis and analysis of process flow management scenarios. Process flows are stochastic and dynamic, which complicates performance of conventional analytical approaches to project decision-making. Diverse robotic automation techniques [1–5], multi-choice organizational management and high cost of technological risk even more complicate the problem of process design. Moreover, it is as a rule difficult or impossible to find explicit analytical formulation of optimization criteria and constraints for process design variable. All this predetermines the need to apply optimization algorithms which enable evaluation of criteria for each variant using simulation models [6–9] and development of program tools toward detailed optimization studies. Thus, it is an urgent problem to create a simulation modeling system to optimize selection of process flow management scenarios for mining technologies in mining. The Institute of Coal has developed a flow chart for the simulation modeling of mining with conventional technologies and with robotic process automation in blasting and in cutting (Figure 1). The flow chart includes various operating modules.

2. Simulation modeling system
A user enters geological and geotechnical conditions via interface and sets measures of efficiency (price of mining machines, mining advance rate, number of miners per face) to be taken into account in optimized selection of the technology and management scenario of mining. These data are transmitted to the optimization modulus running without participation of a user. The key task of the optimization modulus is identification of the optimal or sub-optimal technology and management scenario by the optimization criteria set by a user. Mining scenarios include different models of mining machines and methods of their robotic process automation; for this reason, their number is limited, and the optimization problem is solved as the discrete programming. The alternatives under
consideration can be hundreds of thousands in number [10], and, thus, one more task of the optimization module is to avoid exhaustive search. The optimization modulus runs an evolutionary algorithm capable to solve the discrete programming problems without exhaustive search.

**Figure 1.** Simulation modeling flowchart for mining operations with blasting and by cutting (GGC—geological and geotechnical conditions)

![Simulation modeling flowchart](image)

**Figure 2.** Mining cycle model algorithm

![Mining cycle model algorithm](image)
For estimating each drivage alternative, the optimization module sends the input data to the simulation modeling module for automatic arrangement of a mining cycle model using stock software modules displaying the processes of cutting, drilling, charging, loading, support installation and auxiliary works. Then, the model is run through the interpreter program of GPSS World, and a simulation modeling report is composed using the selected measures of efficiency sent back to the optimization module.

Arrangement of a model follows the algorithm in Figure 2.

At the first stage, depending on a technology in use, either drilling-and-blasting or cutting, a proper module is selected. Then, in case of the drilling-and-blasting technology, after the method of charging and the type of a loading machine are selected, the Charging and Loading modules are included in the function chart. After that, depending on the type of haulage, either the Haulage module or the Conveyor module are entered. At the last stage, as per the technology, one of the possible Support modules is included. In case of the cutting technology, the Cutting and Loading module is connected with the appropriate Haulage and Support modules are included in the chart. Furthermore, the modules of auxiliary operations connected with borehole pattern design, support design and communication extension are added. After the model arrangement, the program modules are interconnected in accordance with the selected mining technology.

In the evolutionary algorithm within a technology and management scenario of mining, parameters of mining equipment employed are coded as a genetic chain, and the scenario is presented as a species representing this genetic chain. At the first step of the algorithm, the first generation of such species is created, and the species are subjected to the following operations:

1) Crossing—in the whole generation, the species are randomly paired. In these pairs, the species exchange mining equipment units encoded in their genome. As a result, each pair has two new daughter species with mining equipment parameters different from the parent species. All daughter species are included in the generation.

2) Estimation—in each species, the measures of mining efficiency are determined to be then included in the optimization process. The estimation is performed by the simulation modeling module.

3) Selection—all daughter and parent species are ranked in decreasing order of utility. A half of species with the lowest utility are withdrawn from the generation, and a half of species with the higher utility participate in the modeling.

4) Mutation—the value of genome is changed in each species at a preset (low) probability, i.e. mining equipment parameters are varied.

After mutation, all species go to a new generation, and operations 1–4 are run in it. As the best species in a generation survive while the worst species vanish, the average measure of mining efficiency improved in each next generation. The evolutionary algorithm is terminated when no improvement is observed in the measures of efficiency for a few generations. Finally, the last generation holds one or a few best species which, together with the parameters of animation, are transmitted to the Visualization module for the visual presentation of mining in accordance with the optimized technology and management scenario as an animation with specified mining parameters.

The characteristics of mining machines available on the market and the robotic automation proposals are stored in the relational data base. It includes 153 units of mining machines and a set of procedures to compose the mining machines into robotic systems to be used in mining operations. The data base composition is depicted in Figure 3.

The data base is composed of:

—Table_Processes*—table of processes (drilling, loading, etc.) for different mining technologies;
—Table_Operations*—table of operations (drilling tool guidance, digging, etc.) and their connection with production processes (for instance, the drilling tool guidance is connected with drilling process, digging—with loading process, etc.);
—Table_Equipment*— table of mining machines, their capacities, price and operators, as well as robotic automation alternatives;
—Table_Restriction*— table of compatibility of mining machines. It allows excluding equipment physically incompatible (for example, it is impossible to use computer-aided control if a mining machine is unequipped with computer vision), or inefficient as modern automatic systems are multi-functional (for instance, when a roof bolter is selected, it is irrational to employ miners to be lifted to the roof for installation of mesh strapping);
—Table_KB, _KO, _KK, _KP, _CZ—table of mining machine systems for various processes; it automatically composes machine systems for each production processes using procedures from the data base and the tables of mining machines and their compatibility.

3. Conclusions
The developed simulation modeling flow chart implements two program modules. The first is the Simulation Modeling module which, using the information on geological and geotechnical conditions entered by a user, automatically generates possible technology and management scenarios for mining with drilling-and-blasting or with cutting. The second module enables automatic optimization of the technology and management scenario of mining for the preset geological and geotechnical conditions.

The implementation of these program modules and upgrading of the Visualization and Animation module can produce an interactive simulation modeling system. The latter can accelerate and improve the design of both conventional and robotic mining technologies, and eliminate expensive risks.

References
[1] Rusin EP, Freidin AM and Tapsiev AP 2007 About mining processes automatization in underground ore mines GIAB Vol 10 No 12 pp 235–244
[2] Martin Magnusson 2006 3D Scan Matching for Mobile Robots with Application to Mine Mapping Department of Technology at Orebro University 17 Orebro
[3] Vaganov VS and Urusov LV 2016 Analysis of networks organization ways for constructing a modern multi safety system in coalmines Vestn. Nauch. Tsentr. Bezop. Rabot Ugoln. Prom. No 3 pp 72–81
[4] Zhuravlev AG 2014 Tendency of career transport system progress with robotizing vehicles using *Problm. Nedropolz.* No 3 pp 164–175

[5] Ovcharenko AV and Udoratin VV 2015 Operative research of underground caves by dint of laser 3D-scanning *Vestn. Inst. Geol. Komi NTS UrO RAN* No 4 pp 20–25

[6] Kelton W and Law A 2000 *A Simulation Modeling and Analysis* McGraw Hill Education

[7] Zitzler Eckart, Deb Kalyanmoy and Thiele Lothar 2000 Comparison of multiobjective evolutionary algorithms: empirical results *Evolutionary Computation* Vol 8 Issue 2 pp 173–195

[8] Zhang Qingfu and Li Hui 2007 MOEA/D: A multiobjective evolutionary algorithm based on decomposition *IEEE Transactions on Evolutionary Computation* Vol 11 Issue 6 pp 712–731

[9] Fonseca Carlos M and Fleming Peter J 1995 An Overview of evolutionary algorithms in multiobjective optimization *Evolutionary Computation* Vol 3 Issue 1 pp 1–16

[10] Nikolaev PI and Zinoviev VV 2016 Methodic of rationale of underground robotic geotechnologies without permanent human presence in mine face *Vestn/ KuzGTU* No 4 (116) pp 26–33