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MODELING AND SIMULATION ANALYSIS OF MINE PRODUCTION IN 3D ENVIRONMENT

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Abstract: The article considers the problems posed by the application of 3D simulation analysis to the modeling of production processes in surface mining. The issues here focused on include the possibilities of creating the representations of mining exploitation elements in a three-dimensional environment as well as the description of the influence that spatial characteristics of surface mines has on simulation processes. The paper also discusses the sense for employing simulation techniques in the design of surface mining production processes and presents the results of analysis performed for a model production system. In conclusion the advantages and disadvantages of the described solutions are compared and the perspectives for their further development and popularization are described.

Keywords: simulations, mine production, FlexSim, analysis of scenarios, 3D models

INTRODUCTION

As is the case in any branch of heavy industry, production technologies in surface mining do not experience significant modifications during the life-cycle of the facility. This is mostly due to high purchase cost of machines, whose replacement during production is uneconomic. Any modifications of production parameters are therefore dependent on the options available for machine operation control, and as a result the key factor here is proper design of the complete production system. The fact that depending on terrain conditions, deposit location and kind of tools used the exploitation of minerals may be performed in a variety of manners leads to the question of what

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solutions are best for a particular deposit and how accurately it is possible to estimate the efficiency of the designed systems.

Presently this question is addressed by engineers who design exploitation systems and prepare deposit development plans. Nonetheless, even optimal determination of the parameters that a mining production system should meet does not limit the wide range of its specific elements. One illustration of that issue might be utilizing either motor or conveyor transport systems. In some cases, from the perspective of design quality both transport types are suitable for operation in the mine, and hence the selection of one of them will be determined by other factors, such as cost of operation, reliability, investment possibilities etc. (Witt, 2011). In this case, making the right choice from among various acceptable components that comprise the production system depends on correct illustration of the system's operation along with the advantages and disadvantages that may influence the decision-making process. Simulation techniques are a useful solution in this case, being first and foremost a source of information on the dynamics of the analyzed system, and at the same time allowing to trace the historical dynamics of changes, study those dynamics and effectively design the system's future operation (Beaverstock et al., 2011).

Simulation tools have been already used for more than half a century. The first application allowing for simulations, called the General Simulation Program, was created in 1960 (Kocher, Owen) and soon after, the first simulation programming language (GPSS - General Purpose Simulation System by G. Gordon). Allowing for fast and easy construction of basic simulation models, the techniques were soon adapted to aid solving production problems (Pawlewski, 2010).

It is worth mentioning at this point that production in a surface mining plant is largely dependent on the space, in which it occurs. This applies to deposit geometry, designing of mining faces progress, as well as to the location of processing plant, which directly impacts transport distances. That scope of spatial variability dynamics, as compared to other production systems, entails the necessity to employ tools that would allow for such dynamics in the calculations, so that the potential of simulation technologies can be maximized.

Taylor ED – the first application enabling simulations to be performed in full three-dimensional environment – was created relatively recently, in 1998 in the United States (Beaverstock et al., 2011). This event commenced the period of continuous evolution and popularization of such tools, further intensified by the dynamic development of computer technology and wider access to PC computers. The fact that new simulation tools enable spatial variables to be included in the calculations allows for a suggestion that problems of mining production may well be addressed using computational capabilities of the here described solutions. The first attempt at Wroclaw University of Technology to model mining production in 3D environment was made in 2014. It was aimed at analyzing the distribution of truck traffic generated by mining plants (Chęciński, 2014).

MODELING OF MINING PRODUCTION

To meet the demand for effective mining production design solutions, the Research Centre for Economics of Industry and Geoeconomics together with “Poltegor-Instytut” Institute Of Open Cast Mining undertook an initiative to build a 3D-environment simulation model of a schematic production system in a surface mine.

Until now simulation analyses and employment of optimization techniques in mining (including 3D environment) have remained within the area of research concerning optimal deposit extraction. The key objective of the research has been to define adequate mining exploitation procedures from the perspective of changing quality parameters and geological and mining conditions (Jurdziak & Kawalec, 2007). The applications employed for that purpose aid modeling of deposit variability (e.g. CAE Studio), or optimal scheduling of exploitation works progress (e.g. NPV Scheduler). The production modeling and simulation technology here described go a step further in that they aim at selecting the best production system for a predefined progress of mining faces. Ability of use three dimensional simulation system seems to have an essential value, mostly because of the fact that mining production environment is changing dynamically. It is caused not only by deposits exploitation, which impacts on haulage distances, but also by changing location of some system elements (for example place of unloading the trucks).

Due to the fact that basic editions of applications used in 3D simulations are not equipped with models illustrating the elements of mining production systems (trucks, intake hoppers etc.), it was necessary to build appropriate 3D models (Fig. 1). Testing the ability to simulate production was performed in FlexSim application environment. In case of FlexSim environment, modeling particular elements of mining production system, as well as accurate reproduction of the excavation may be performed in any three-dimensional graphic environment. As the manufacturer’s instructions require the models to be adequately simplified (FlexSim’s User Manual), the construction was performed with Trimble SketchUp application, which is sufficient even for building very complex 3D mining models (Chęciński, 2014). During the preparation of individual system elements, basic object class were used (TaskExecuter, Separator, Queue, Conveyor), available at standard FlexSim application library.

The first stage of simulation model construction was to prepare a general outline of surface mine production system (Fig. 2). It has been assumed that the constructed model would be based on a system designed with intake hopper and pre-crusher, as well as a second-stage crushing system with a screen. The exploitation technology model includes loosening of the rock material with explosives, transporting it to the first crusher, and then using conveyor belts to pass it to the next crushing stage. Crushed material is fed to a set of screens, which directs the streams of material on conveyor belts to the place where separate fractions are stored (Fig. 1). Due to FlexSim limitations, it's quite hard to build a mechanism of sending material between two running vehicles (excavator - truck). Because of the problem, this element of the system was simplified, and represented just by using the variable time of loading process (truck object parameter).

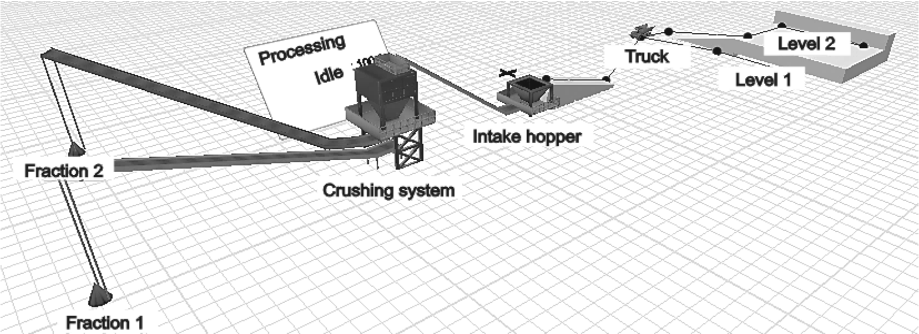


Fig. 1. 3D view of schematic production system in mineral aggregates mine

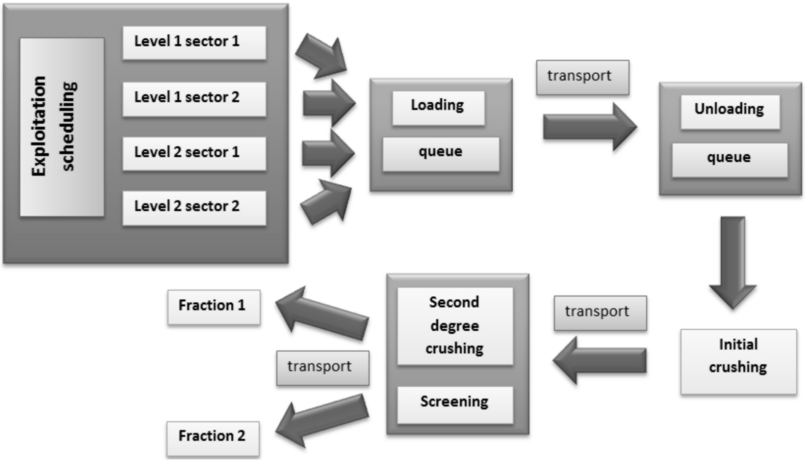


Fig. 2. Diagram of material flow in modeled production system

During modeling stage, the exploitation pit area was simplified to have only two excavation levels together with approach ramp. The analysis covered loosening of four sectors in two shortwalls (Fig. 3). The construction of the model includes changing the illustration of the sectors from the monolithic block layout to loosened rock layout, which is represented by a set of packets intended for transportation. Employing such mechanism allows to illustrate the movement of the mining face and the reduction of deposit resources.

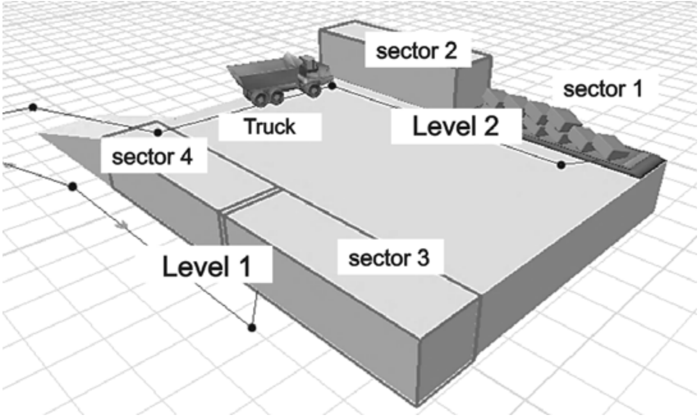
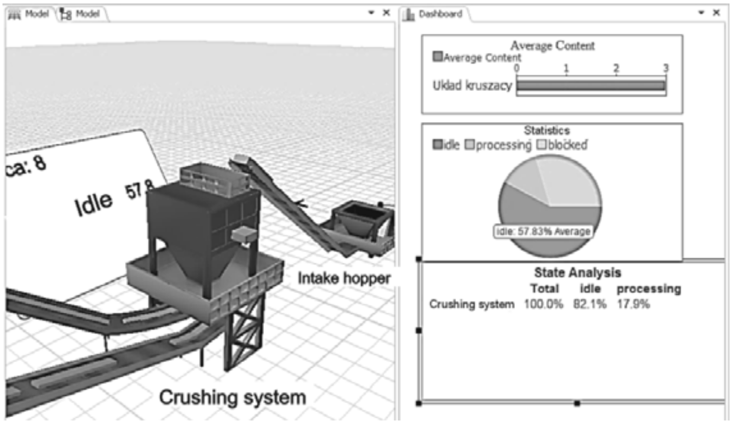


Fig. 3. Schematic model of the mining face

SIMULATION ANALYSIS PARAMETERS

In order to test the applicability of simulation analyses to mining production environment it was necessary to choose an appropriate parameter, whose value for each of the production scenarios would allow for assessing goal achievement. The chosen parameter was the percentage share of the kinds of work performed by screen system. Production practice proves this parameter to have direct impact on the operating effectiveness of the whole production system. The screen is activated at the beginning of production shift and is deactivated at its end. It is desired that the machine could screen material continuously with possibly short idle operation periods caused by material shortage. Elimination of idle operation is one of the key elements of process approach in logistics, which itself defines the most advanced level of the company's process maturity (Pawlewski, 2011). It may be safely assumed that proper machine operation management will depend on the amount of material supplied. The analysis result will be therefore dependent on the number of transportation cycles performed by trucks supplying the material, load-capacity of the trucks or their single run time, which in turn will largely depend on transportation distances. Simulation scenarios were prepared on the basis of the capacities of truck transport boxes.

In order to ensure effective monitoring of the searched parameter's variations depending on the configuration of other system's elements, in addition to 3D objects the model was equipped with 2 information panels (Fig.4). The first one is located directly in three dimensional space, as a 3D object next to the crusher system, the second one is the program's separate window functioning as a dashboard. Such solution allowed for manual setting of any parameters of the production system and observing the results, but it did not allow for simultaneous automatic analyzing of multiple variants.



State Analysis

	Total	idle	processing
Crushing system	100.0%	82.1%	17.9%

Fig. 4. Crusher model, with chart showing its work type during processing

The simulation analysis proper of the influence of truck's varying load-capacity was performed with "experimenter" tool, which is available in FlexSim application. This tool allows to create any number of configuration variants for the searched parameters and also to calculate the effects that the changes cause. The described model had 6 different transportation scenarios, with available load-capacities defined in ascending order. The volume of material transported was expressed as the number of packets transported in one run and hence as non-dimensional unit (1-6). The described packets may however be expressed in units compatible with the assumed workings of the process and outcome demand (e.g. 1 packet = 1 Tonne or 1 packet = 10 Tonnes). In addition the global number of execution repetitions for a single variant was defined, which aided the determination of the limits between resulting value ranges which are the effect of using random variables in the model. Each scenario was executed 5 times (Fig. 5).

ANALYSIS RESULTS

At described analysis, every scenario was focused only on the different values of truck capacity. All other parameters were the same (number of trucks, maximum speed, schedule of exploitation, production value, crushing systems efficiency etc.). Production schedule contains creation of four equal sets of 10 packages (equivalent of four mining sectors), at equal time intervals. The generated report of scenarios analysis results (Table 1) shows explicitly that the crusher performs most of idle work at the time when the truck's transport box is set to minimum capacity. The obtained values are within the range from 95.36% to 95.39% of the crusher's total work. The best results were obtained with the truck's transport box set to maximum capacity; they were within the range from 73.76% to 74.62% of the crusher's total work.

Tab. 1. Final result of scenarios analysis for crushers idle scenarios

Separator's idle work, %					
Variants	Repetitions				
	1	2	3	4	5
Scenario 1	95.39	95.38	95.36	95.36	95.36
Scenario 2	89.98	89.92	89.84	89.87	89.82
Scenario 3	84.81	84.78	84.64	84.59	84.51
Scenario 4	78.22	77.93	77.59	77.66	77.38
Scenario 5	74.97	74.98	74.55	74.31	74.37
Scenario 6	74.62	74.51	74.04	73.94	73.76

The results of the analysis support a rather obvious conclusion that the greater the load-capacity of the truck's transport box, the more material is transported at a given time, which directly affects the crusher's effective operation time. However, for particular terrain conditions the direct influence of the truck's transport box capacity may be difficult to estimate, while the presented model allows for its precise estimation. By the fact that result of the analysis represents clearly an actual logic of mining production, it might be assumed that model was built correctly.

It is also worth to be mentioned (Fig. 5) that for the last two production configurations (Scenarios 5 and 6) the change of the truck's transport box did not have significant influence on the change of the amount of the separator's idle work (difference between 0.35% and 0.61%). This demonstrates clearly that the ability to use the transport box's capacity to control idle work has reached its maximum. Thus, other interruptions of the separator's operation depend solely on the scheduling of the shooting of individual sectors in the shortwall. Huge values of idle work in scenarios 5 and 6 shows that production intervals were probably scheduled too widely.

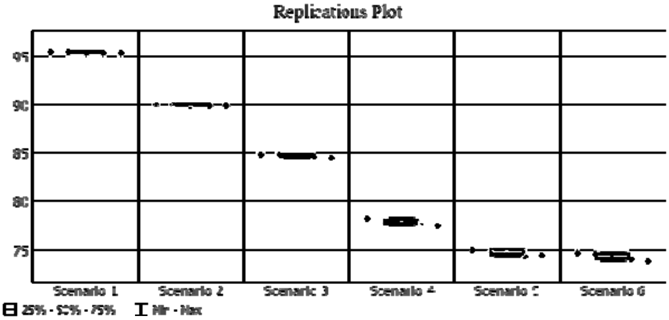


Fig. 5. Changeability diagram of searched parameter for every defined scenarios, in „Experimenter" tool window

CONCLUSIONS

Evaluation of the constructed simulation model of surface mining production allows for an opinion that such solutions may prove an effective aid not only in the process of mining production systems design, but also in deposit exploitation management. The ability to construct models that would be precisely adjusted to conditions existing in a given mine would enable on the one hand analyzing of exploitation system changes, and on the other hand forecasting production output in a volatile market. The ability to estimate production parameters accurately and to identify their components precisely may prove effective aiding decision making processes related to production systems. It must be stressed here that variant comparison as described in this article are not the only tools that aid decision making. A certainly more interesting component of FlexSim application seems to be the "optimizer" module, which assumedly is able to automatically find the best values of particular system's parameters (FlexSim User Manual). Unfortunately the module was not included in the version of the application provided to the authors and therefore testing its functionality was impossible.

Modeling of mining production in a virtual, 3D vector environment allows for precise identification of objects which dynamically change their position (e.g. vehicles). This in turn makes simulation results also applicable to other analytical environments, which operate on spatial data, for instance to GIS technologies (Chęciński, 2014). At the same time the possibility to create an accurate three-dimensional representation of the deposit and to illustrate the production processes makes possible further steps on the way to the idea of creating a virtual mine, which represents the newest trends in mining research and development worldwide (Jurdziak & Kawalec, 2013).

It should be stressed, however, that the technology presented is not flawless. Its greatest disadvantage is the prohibitive price of commercial version's license. Also the creation of simulation models requires the designer to be highly competent in areas such as modeling three-dimensional objects and object-oriented programming, to have extensive knowledge in the area of simulation and – in case of this subject – also in the area of mining. The above mentioned criteria limit the number of specialists potentially capable of designing such projects.

Thus, everything depends on first implementations of such applications in the industry and on rational evaluation of the benefits that arise result from such solutions. The evaluation of how effectively 3D simulation models are implemented seems particularly important for the prospective implementation of such solutions in mining industry.

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