The Use of Stochastic Modeling and Simulation to Optimize the Mining Processes

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Abstract

The article aims to study the possibilities and benefits of using the stochastic modeling and simulation method in the optimization of production processes. The article presents general characteristics of modelling and simulation and presents examples of stochastic models of selected production processes implemented in hard coal mines in Poland. The presented analysis led to the conclusion that the method of stochastic modelling and simulation is one of the methods worth using as a tool supporting process optimization. Its most important feature is enabling process analysis, which, regardless of the time range, can be verified within a few minutes. As a consequence, many variants of action can be analysed before their actual implementation in real conditions.

Keywords: *stochastic modelling and simulation, production process, mining process, optimization*

1. Introduction

There is no need to convince anyone about the need to optimize production processes. Over the years, we have learned a lot as scientists and practitioners about process optimization methods. We use methods and tools aimed at improving the functioning of enterprises of all types, improving processes to the optimal level, i.e. the one that is most beneficial for us given certain operating criteria.

There are many modeling and simulation methods that are implemented in various computer programs, which were mentioned in Chapter 2. However, this article is devoted to stochastic modeling and simulation, which, according to the authors, are useful in optimizing production processes, including mining processes. In addition to general information characterizing stochastic modeling and simulation, examples of their use are presented.

2. General characteristics of modeling and simulation

Modeling means "the act of matching the original with an acceptable substitute called a model, i.e. it is an approximate reproduction of the most important properties of the original" (Gościński 1982). In other words, it is building a model that „is a representation of the most important features of the tested or designed object from the point of view of the task it serves in a specific reality or abstraction" (Durlik 2000).

The literature talks about various models of the production process (Zdanowicz 2007; Wieczorek 2008; Matuszek, Kurczyk 2013). The most universal and used at all management levels are schematic models (block diagrams, business process maps in various notations, e.g. IDEF, BPMN, UML, etc.). These are the methods of notation used primarily to prepare process maps.

Their role is mainly to statically analyze the problem. They reflect the production process, its structure, elements and relationships between them and the way the production system functions, but they do not allow to determine the effects of the decisions made. Computer simulation models are used for this purpose (Vasudevan, Devikar 2011; Burduk 2013). They belong to the group of symbolic models in which reality is reflected using symbols and mathematical relations.

The computer simulation model captures the logic of behavior and mutual relations between the individual elements of the production process being tested, as well as the data that represent the characteristics of these elements. The course of the process can be presented graphically through animation, and after a simulation experiment, results are obtained in the form of charts, reports or a set of statistics describing specific elements of the process, with both the content and the form of presenting the results largely dependent on the approach used simulation (Maciąg in. 2013). The results of the experiments can be the basis for making decisions regarding the changes that should be made in the existing process (e.g. in terms of the number of machines, assembly stations, type of assortment, warehouse capacity, etc.) to achieve the assumed goal (e.g. increase in production efficiency, reduction of production costs or shortening the production cycle).

Modeling and simulation of the production process is carried out according to the general procedure presented in Figure 1.

Delving into this scheme, it can be said that the modeling and simulation procedure begins with formulating the problem and defining the research goal. Then, the simulation model is created in two steps: (1) determining its structure by deciding which elements and features of the process are important in the context of the defined problem and research goal; (2) collecting the data needed to determine the parameters of the model. The next step is to program the model using the selected simulation approach and an IT tool. The results obtained after the implementation of the initial simulation experiments on the software model are used to validate and approve the model. Validation consists in checking whether the model reflects the real production process with appropriate convergence and whether it can be used, with full confidence, to support decisions regarding the real process. The ap-

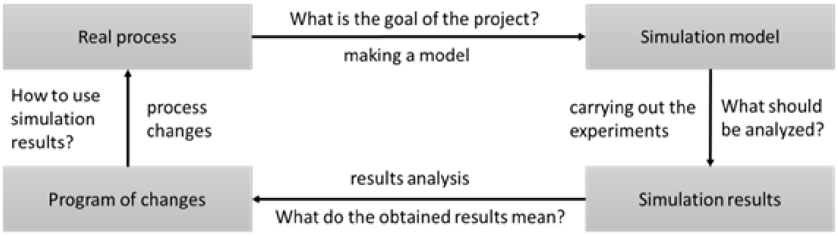

Fig. 1. Modeling and simulation of production processes. Source: (Maciąg i in. 2013)
Rys. 1. Modelowanie i symulacja procesów produkcyjnych. Źródło: (Maciąg i in. 2013)

proval of the model is usually carried out by people from the enterprise where the project is carried out. This stage forces many times to revise the previous assumptions and repeat the previous activities. The next phases of the discussed procedure consist in designing experiment scenarios that meet the research objective, conducting experiments and interpreting their results. The analysis of the results can be the basis for defining a program of changes to improve the examined process. This procedure can be continuous (Gordon 1974; Gregor i in. 1998; Burduk 2013). The main problem areas in which modeling and simulation of the production process are used are: (Łatuszyńska, 2015):

- forecasting the financial result,
- forecasting and planning material needs,
- planning the execution of production orders,
- designing production systems,
- comparing alternative manufacturing processes,
- production scheduling,
- analysis and comparison of different manufacturing strategies,
- analysis of the use of production resources (e.g. identification of bottlenecks),
- improving production systems and eliminating waste,
- visualization of the effects of activities related to production management,
- conducting presentations and trainings for staff.

3. Stochastic simulation

The stochastic simulation method is used for computer modeling of any processes (physical, economic, technological, etc.) or their fragments, the characteristic feature of which is the presence of at least one random variable in their description. The method was first used during the Manhattan Project research to build the American atomic bomb. The stochastic model developed at that time concerned the analysis of neutron propagation in a nuclear reactor. It was developed jointly by John von Neumann and the Polish mathematician Adam Ulman. The stochastic simulation method is also successfully used nowadays. The ability to create complex stochastic models, their recording in the form of a computer program in a language focused on solving such problems, as well as ever-faster computers - all this determines the frequent choice of stochastic simulation as a method of solving problems described by indeterminate models (Snopkowski 2005). Taking into account the nature of mining processes, as well as the participation of many undetermined factors in their course, it is justified to use this method also in mining.

The basis of stochastic simulation is the concept of a random number. According to what Knuth writes about it: “In a sense, there is no such thing as a random number; for example, is 2 a random number? On the other hand, we can talk about a sequence of independent random variables with a definite distribution, which means, roughly speaking, that each of the numbers was chosen completely randomly, with no connection to the selection of the other numbers in the sequence, and that each number falls into any fixed range. range of values with a certain probability” (Knuth 2002; Rolski 2013). Thus, a numerical value resulting from an experiment (e.g. the number of dice rolled) can vary from case to case, hence it is a variable. Since the outcome is decided by chance, so this variable is random.

The optimization methodology is based on a detailed analysis of the process (e.g. procurement, manufacturing, order fulfillment, etc.), or the production system (e.g. stations, cells, or production line) and visualization using one of the selected (depending on the needs and expected results) methods/tools, such as: Gantt chart (schedule), network of activities, modeling and simulation, virtualization – 3D scanning, process mapping, etc.

The next step is to optimize the analyzed process and evaluate the proposed solutions to improve its implementation.

From a practical point of view, the following facts speak for the use of stochastic simulation: it is a simple way to study random phenomena; closely related to stochastic simulations are computational methods called "Monte Carlo" (MC), which rely on the use of "artificially generated" randomness to solve deterministic tasks; moreover, it is available to everyone, in particular, the R "environment", which is a really powerful tool, is distributed for free.

4. Application examples

This chapter presents two methods, the construction of which is based on stochastic modeling and simulation. Possibilities of their application in mining practice were also indicated.

4.1 The method of probabilistic modeling of the duration of the production cycle activities carried out in longwall faces of hard coal mines

The production process carried out in longwall faces of hard coal mines is characterized by the influence of many factors that do not occur in other production processes. These factors are related to technical and organizational as well as geological and mining conditions. The production cycle performed in the longwall face of a hard coal mine is defined as a set of operations repeated in a specific order and time, necessary to advance the face of the longwall face to the distance of one (Kozdrój M., Kozdrój-Weigel M. 1993). After completing the cycle, the crew repeats the set of operations, i.e. performs the next cycle.

The implementation of the production cycle includes the performance of a number of activities directly related to the mining of the coal body, as well as the development of the face space, with the proper maintenance of intersections of the longwall with the longwall gallery and the longwall gallery, etc. All works are necessary due to the implemented technology, but not all of them affect the directly for the duration of the production cycle. In the discussed methodology, first, the selection of those activities that have a direct impact on the duration of the production cycle was made, the factors affecting the instability of the duration of the activities were defined, and a set of density functions was established that will best describe the selected activities of the production cycle.

Scheme of modeling and stochastic simulation of the duration of the production cycle activities carried out in the longwall face consists of the following stages:

1. Defining the density function of the duration of the production cycle activities in the conditions of a given longwall face
2. Generation of production cycle activity durations based on defined probability density functions
3. Determining the duration of the production cycle based on the generated values
4. Determination of shift mining from the longwall face
5. Checking the fulfillment of the probabilistic modeling termination condition (if the condition is not met, return to step 2)
6. Analysis of the results from the stochastic simulation of the duration of the production cycle activities.

A detailed description of the procedure is presented in (Napieraj, Snopkowski 2012). The practical benefit of the discussed model is the possibility to determine shift extraction, and to be precise, determination:

- the probability that production from a selected longwall will exceed a predetermined level W_0 during a work shift,
- the probability that the output from the selected longwall will vary fromW_1 to W_2,
- the level of shift extraction W_3, which is equally likely to be exceeded and not exceeded and amounts to 0.5.

4.2 The method of longwall face crew selection with respect to stochastic character of the production process

Organizing work in a hard coal mine is a difficult task due to the high unpredictability of mining conditions. Geological studies of the deposit allow for estimation of production parameters, but these approximations may not always be the basis for precise calculations at the stage of production organization. The occurrence of inhomogeneities in the geological structure of the deposit, natural hazards or machine failures are just some of the factors that may cause the stochastic nature of the production process carried out in mines. One of the most important aspects of organizing work is staffing. The efficiency of production and its effectiveness depend to a large extent on the rational allocation of employees to positions. Very high costs of purchase of machinery and equipment installed in the mining face, as well as energy and labor, mean that any downtime generates significant economic losses. There may be downtimes resulting from random events, such as machine failures, and only preventive measures related to their repairs and maintenance can be applied here. However, downtime resulting from poor work organization should be definitely eliminated. One of the main reasons for this type of downtime can be the wrong selection of the number of employees for the activities performed. The use of an appropriate mathematical apparatus, combined with data obtained as a result of repeated observations of actual times of performing activities, allows for identifying the nature of random phenomena and determining the staffing of positions, taking into account the stochastic nature of the production process. The methodology for determining the longwall face stock in hard coal mines, which takes into account the stochastic nature of the analyzed production process, consists of the following stages:

1. Identification of key activities in the production process
2. Division of the production process into characteristic modules, due to the simultaneity of the activities
3. Identification of the density function of activity durations in separate modules,
4. Adoption of initial cast variants for individual modules,
5. Optimization of staffing in modules by taking into account the probabilities of performing activities with the assumed staffing, taking into account the characteristics of the modules.

A detailed description of the procedure is included in the following works (Snopkowski, Sukiennik 2012; Snopkowski, Sukiennik 2013)

5. Discussion

The production process, carried out in the longwall face of hard coal mines, takes place underground, in specific geological and mining as well as technical and organizational conditions, which determine its specificity. The analysis of this process, in order to, for example, determine the level of achievable shift mining, can be carried out using determinate or stochastic models. The beginnings of the creation of determinate models date back to the 1960s and have been constantly developed since then. The disadvantage of these models is determinism, understood in such a way that for a specific set of data, the desired characteristic (e.g. extraction) is obtained in the form of points. However, the practice of longwall faces operation shows that the obtained extraction is not always constant - it may be subject to certain fluctuations. Therefore, it is worth using stochastic models in this case.

A similar situation accompanies the determination of the longwall face staffing, which is to ensure the continuity of the production process in this longwall face with the smallest number of employees needed. Each of the activities included in the production process is assigned an optimal staffing, and the staffing of the entire production process is determined by assigning specific employees to individual activities, taking into account the fact that some activities can be performed by the same employees. It can also be assumed that some modules can be implemented by the same staff, if there is no time conflict between these modules.

6. Conclusions

The considerations that accompanied the development of the method of probabilistic modeling of the duration of the production cycle activities and the method of longwall face crew selection make it possible to formulate the following conclusions:

- modeling the duration of the production cycle activities in the form of a probability density function makes it possible to take into account the influence of many factors on the course of these activities, and this influence results in variable time of their implementation in the conditions of a specific longwall face,
- analysis of the production cycle using the probability density function of the duration of activities allows to obtain the value of the duration of the production cycle in the modeling in the functional form,
- each production process can be divided into a finite number of modules differing in the simultaneity of the activities, which simplifies the analysis of the production process and, as a result, facilitates the selection of crew,
- the use of stochastic modeling and simulation in the described examples leads to the formulation of an objective assessment of the longwall face's production capacity level and the size of longwall face crew.

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Wykorzystanie modelowania i symulacji stochastycznej do optymalizacji procesów wydobywczych

Celem artykułu jest analiza możliwości i korzyści, jakie daje użycie metody modelowania i symulacji stochastycznej w optymalizacji procesów produkcyjnych. W artykule przedstawiono ogólną charakterystykę modelowania i symulacji oraz zaprezentowano przykłady modeli stochastycznych wybranych procesów produkcyjnych realizowanych w kopalniach węgla kamiennego w Polsce. Przedstawiona analiza pozwoliła na sformułowanie wniosku, że metoda modelowania i symulacji stochastycznej jest jedną z metod, którą warto stosować jako narzędzie wspomagające optymalizację procesów. Jej najważniejszą cechą jest umożliwianie analizy procesu, które bez względu na zakres czasowy trwania, mogą być weryfikowane w ciągu kilku minut. W konsekwencji można przeanalizować wiele wariantów działania przed właściwym wprowadzeniem ich do realizacji w warunkach rzeczywistych.

Słowa kluczowe: *modelowanie i symulacja stochastyczna, proces produkcyjny, proces wydobywczy, optymalizacja*