https://doi.org/10.7494/miag.2023.4.556.19

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Decision-making in hard coal mines with the support of selected stochastic methods

The article presents selected methods of stochastic process modeling that can support decision-makers in Polish hard coal mines. It outlines the classification of determinants that have a significant impact on the processes carried out in the mines. The article also distinguishes between programmed and non-programmed decisions made by the management in the mines. In the following sections, three selected methods are presented, enabling decision-makers to make more effective decisions that may be crucial for the processes implemented in hard coal mines.

Key words: *hard coal mining, decision making, stochastic methods*

1. INTRODUCTION

Decision-making is a process that should consistently be supported by the most reliable analysis, both of the available data regarding the process and of the conditions surrounding it. This influences the properly planned organization of the process and allows for appropriate responses in case of changes.

To be effective, any human activity should be properly organized. This is the fundamental assumption that serves as the starting point for the implementation of the production process [1]. In the case of mining, work organization was not adequately implemented from its inception. There were two reasons for the delayed introduction of work organization into the mining production process. The first was the complexity of the natural conditions associated with the production process in mining, which for many years fostered the belief that mining experience and practice were more suitable than scientific methods of organization. The second reason was the attempt to transfer scientific theories of work organization directly to mining without any modification or adaptation [2–3]. Over time, however, it became clear that by appropriately modifying general principles, work underground could be successfully improved. Credit in this area is attributed to Karol Adamiecki, who, by proving that "the methods employed by scientific organization lead to the economy of forces and resources," convinced miners to undertake efforts to determine the conditions for applying and introducing scientific organization into mining [2].

2. FACTORS DETERMINING PROCESSES IN HARD COAL MINES

In the case of hard coal mines, the factors determining the process fall into two groups: mining-geological conditions and technical-organizational conditions.

Mining-geological conditions include:
- type of roof,
- type of floor,
- coal workability,
- thickness and incline of the coal seam,
- natural hazards.

Technical-organizational conditions that significantly influence the production process include:

– mechanization system,
– technical parameters of machines,
– equipment failure rates,
– organization of the production cycle, which consists of the organization of tasks, the form of work organization, and the work system,
– the training and experience of the workers.

The occurrence of these factors causes the production cycle carried out in the longwall face to become destabilized. In the literature, methods can be found that determine the impact of these factors on the duration of activities carried out at the longwall face. These methods use, for example, regression and correlation analysis [4–5].

The phenomena occurring in the rock mass, due to its varied geological and hydrogeological structure, are complex and difficult to precisely determine. Improper mining operations can lead to areas of high pressure, sudden collapses of roof layers, rock bursts, or other hazards. Even correctly conducted operations carry the risk of natural hazards [6]. Therefore, to maintain the highest level of safety and minimize disruptions in the production cycle at the longwall face, efforts are made to fully understand the mining-geological conditions present in the exploited deposit.

3. PROGRAMMED AND NON-PROGRAMMED DECISIONS

Decision-making is a procedural and technological feature of the management process, influenced by multiple economic and psychosociological factors. Decision-making can be viewed in two senses [7]. There are many classifications and divisions of decision types, depending on the adopted criteria. However, in the decision-making process, especially in hard coal mining, one of the key distinctions is between programmed and non-programmed decisions.

The multitude of factors determining the coal extraction process means that both programmed and non-programmed decisions should be supported by the most accurate insights and available mathematical methods.

Programmed decisions, by definition, deal with routine problems, typically governed by rules, procedures, or guidelines. Non-programmed decisions, on the other hand, concern non-routine problems within the process and often lack a predefined structure.

Witold Kieżun suggests that the essence of the decision-making process lies in processing input information, along with existing knowledge and experience, into output information, which serves as the basis for making a non-random choice of action [8]. Therefore, utilizing available stochastic methods in the decision-making process in hard coal mines can bring decision-makers closer to success. In the following section, selected methods supporting decision-makers in mining will be highlighted and briefly presented.

4. EXAMPLES OF THE USE OF STOCHASTIC METHODS TO SUPPORT DECISION-MAKING PROCESSES IN HARD COAL MINES

4.1. Selection of longwall crew based on the stochastic nature of the production process

Work organization in a hard coal mine is a challenging task due to the high unpredictability of extraction conditions. Geological surveys of the deposit allow for estimating production parameters, but these estimates do not always serve as a precise basis for calculations during production planning. The presence of heterogeneity in the geological structure of the deposit, natural hazards, or machine failures are just some of the factors that can contribute to the stochastic nature of the production process in mines. One of the most important aspects of work organization is staffing. Production efficiency largely depends on the rational assignment of workers to specific tasks. The very high costs of purchasing machines and equipment installed at the longwall face, as well as energy and labor costs, mean that any downtime results in significant economic losses. Downtime caused by random events, such as machine failures, can be mitigated only through preventive measures related to repairs and maintenance. However, downtimes resulting from poor work organization should be decisively eliminated. One of the main causes of such downtime can be the improper allocation of the number of workers to tasks. The use of appropriate mathematical tools, combined with data obtained through repeated observations of actual task durations, allows for the identification of the nature of random events and the determination of staffing levels, taking into account the stochastic nature of the production process. This methodology consists of the following steps:

- Identification of key activities in the production process.
- Division of the production process into characteristic modules, based on the simultaneity of actions
- Identification of the probability density functions for task durations in the separate modules.
- Selection of initial staffing variants for individual modules.
- Optimization of staffing in the modules by considering the probability of task execution with the given staffing levels, taking into account the characteristics of the modules.

A detailed description of this procedure is provided in the following works [9–10].

As mentioned, decision-making processes in hard coal mines are determined by many factors. The proposed decision support method can be useful both in routine decision-making processes and in emergency situations, where quick action is required due to sudden risk factors. The development of this method has led to the following conclusions and statements regarding its potential application:

- Replacing deterministic variables with random variables allowed for the simultaneous consideration of many factors influencing task completion time in the form of probability density functions.
- Every production process can be divided into a finite number of modules, differing in the simultaneity of task execution.
- Isolating modules from the production process enables easier analysis of the production process and, as a result, simplifies staffing decisions.
- The criterion of the probability of achieving the assumed module completion time used in the method allows for rational staffing, as the completion of the module as a whole takes precedence over the completion of individual tasks.
- The results of the calculations support the validity of the hypothesis presented at the beginning of the study, that using the probability criterion in the method for determining the staffing of the longwall face in coal mines allows for consideration of the stochastic nature of the production process carried out at the face.

4.2. Probabilistic modelling method for task duration in the production cycle at longwall faces in hard coal mines

The production process carried out at the longwall faces of hard coal mines is influenced by factors described in Section 2. The production cycle in the longwall face of a coal mine is defined as a set of operations repeated in a specific sequence and time, necessary to move the longwall face by the distance of one cut [11]. The production process involves the continuous repetition of such cycles until the production potential is exhausted (programmed decisions) or until an event occurs that prevents the process from continuing (non-programmed decisions).

The execution of the production cycle includes performing a series of tasks directly related to coal extraction, as well as managing the longwall face space while maintaining the proper condition of the roadway intersections, i.e., the gallery with the longwall face. All the tasks are necessary due to the technology applied; however, not all of them directly affect the duration of the production cycle. In the proposed decision support methodology, the first step was to select those actions that directly influence the production cycle duration, define the factors contributing to the instability of the task duration, and determine a set of probability density functions that best describe the selected tasks in the production cycle [12].

The scheme for modeling and stochastic simulation of task duration in the production cycle at the longwall face consists of the following stages, with a detailed description of the procedure found in [13]:

1) Defining the probability density functions for the task durations of the production cycle under the conditions of a given longwall face.
2) Generating task durations of the production cycle based on the defined probability density functions.
3) Determining the duration of the production cycle from the generated values.
4) Determining the shift production of the longwall face.
5) Checking the fulfillment of the probabilistic modeling completion condition (if the condition is not met, return to step 2).
6) Analyzing the results of the stochastic simulation of task duration in the production cycle.

The question arises as to what benefits the decision-maker may gain from using this method to make decisions (both programmed and non-programmed).

The practical benefit of the discussed model is the ability to determine:

- the probability that the production from a selected longwall will exceed a predetermined level during a work shift,
- the probability that the output from a selected longwall will vary within an accepted range,
- the accepted level of shift production, the exceedance and non-exceedance of which is equally probable at 0.5.

4.3. Use of marginal distribution to assess the duration of stochastic processes in underground mines

The method proposed in the article can also be used to analyze processes, including extraction processes, in which the resources (such as workforce and machinery) allocated for their execution are not quantitatively determined. Let's assume we are dealing with a process where the number of workers (i.e., the labor force of the process) assigned to carry out the process is unspecified. This example can also apply to varying numbers of machines, equipment, etc.

From a mathematical perspective, the "process workforce" in this case is a random variable, meaning we are not 100% certain how many workers will be available to carry out the process, perhaps due to absences or other reasons. We can consider the characteristic of the "process workforce" to be a probability distribution, in which the probability represents the likelihood of the process being executed by a specific workforce size.

The conditional distribution of the process duration is determined for each realization of the random variable "process workforce" according to the scheme shown in Figure 1.

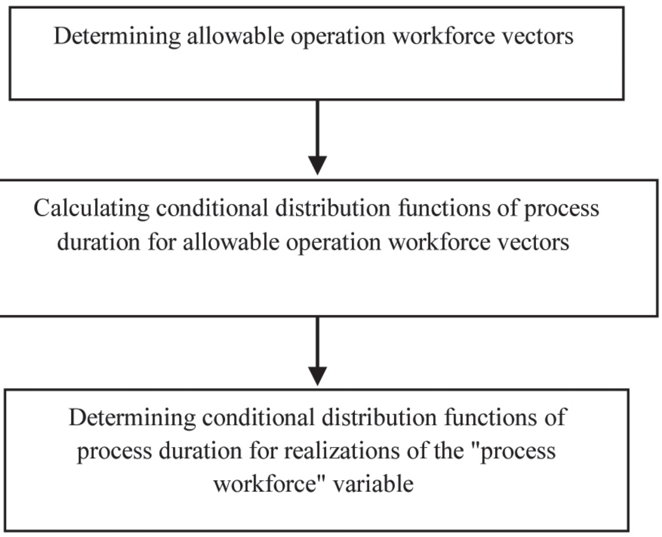

Fig. 1. Stages of the procedure for determining conditional distribution functions of process duration

A detailed description of the use of this method is the subject of a separate article, in which a selected example is presented step by step. This article is currently in the process of publication and will be available in both Polish and English.

The method of using the marginal distribution to assess the duration of stochastic processes in underground mines can serve as a complement to other process analysis and optimization methods. The assessment of stochastic process flows is a significant issue from the perspective of those managing these processes or investors who allocate their resources (e.g., in the case of an investment process). It is also important to emphasize that the application of the method described in this paper results in outcomes provided along with probability values. Therefore, the final assessment of these results always rests with the party conducting the process analysis.

5. CONCLUSION

The decision-making process is not easy, especially when it is influenced by many factors, both organizational and natural, as is often the case in coal mining. Supporting such a process with stochastic methods, which are designed to account for the random nature of the phenomenon under analysis, may prove helpful and effective. Both decision-makers responsible for programmed decisions and those making non-programmed decisions can use such methods. The article highlights only selected methods, which have been thoroughly analyzed by the authors and are the subject of separate publications. However, this does not exhaust the full scope of what can be supported in the mining industry.

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