Production Risk – Selected Aspects of its Occurrence and Management on the Example of a Longwall

Ryszard SNOPKOWSKI[1], Marta SUKIENNIK[2], Aneta NAPIERAJ[3]

[1] AGH University of Science and Technology, Faculty of Mining and Geoengineering; email: snopkows@agh.edu.pl
[2] AGH University of Science and Technology, Faculty of Mining and Geoengineering; email: marta.sukiennik@agh.edu.pl
[3] AGH University of Science and Technology, Faculty of Mining and Geoengineering; email: aneta.napieraj@agh.edu.pl

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Abstract

The production process carried out in longwall faces of hard coal mines is characterized by a high production risk due to a number of factors determining it. Therefore, it is necessary to recognize this risk and then reduce its occurrence. This article presents the mining and geological as well as technical and organizational conditions of the process carried out in the longwall face. The possibilities of risk assessment and its quantification in the production process implemented in the longwall face of hard coal mines for the selected mining technology are also presented. It was found that the constantly evolving BI class tools are intended to support the decision-making process based on the knowledge derived from the events that take place every day in the enterprise, including longwall faces. The use of appropriate computational tools and methodologies to analyze collected data may contribute to reduce the negative effects of the risk that occurs in the mining process.

Keywords: *production risk, longwall face, mining process, mine, mining industry*

1. Risk management as a process

The concept of risk is inherent in every human activity. The risk defined as an unwanted event which may or may not happen often determines the course of many of the so-called production cycles. In the case of analysis of the risk present in the production process, we can speak of the so-called production risk. It includes all possible (both positive and negative) deviations and fluctuations in the area of the assumed goals and achieved results of the company [1].

Risk management itself can be defined in a broad and narrow sense. In a broad sense, it is a system of methods and actions aimed at reducing the degree of risk impact on the functioning of an economic entity and at making optimal decisions to this end. In a narrow sense, risk management consists in taking actions aimed at limiting external influences, unpredictable factors on the organization [5].

The production process carried out in longwalls of hard coal mines is characterised by high production risk, due to a number of factors that determine it. The factors influencing the mining process can be divided into two groups: geological and mining conditions, and technical and organisational conditions. Geological and mining conditions constitute a number of obstacles in the course of the production process, which is carried out in specific conditions, i.e. underground. Technical and organisational conditions are specific in the sense that they, among other things, rely on the use of machines and equipment that work together in a certain way, depending on the technology used, as well as on the need to include the time wasted on getting to the longwall in the total working time. The occurrence of the above mentioned factors may cause the destabilisation of the production cycle in the longwall. The decisions made in this process are therefore closely related to the conditions of uncertainty and the risk that can be understood as the effects of that uncertainty. The authors have already addressed the subject of optimisation of the processes carried out in the longwall, with respect to production itself [2,3,6, 9, 11, 12, 14] or process organisation. [4, 15,16].

2. General identification of the risk in the longwall

The deposits currently exploited in Poland are in the form of seams, i.e. layers lying on a large area that are limited from the bottom and top by two more or less parallel planes [7]. In order to extract a coal deposit, it is necessary to make it accessible, i.e. to make the opening-out heading. Then, the field designated for mining is cut by means of gates (top and bottom), along which the operation is carried out.

In the Polish hard coal mining industry, the vast majority of longwalls are led with fall of roof, in which the shearer operates as a mining machine. Bidirectional mining is the most commonly used technology. The production cycle then includes a single passage of the shearer along the wall and consists of the following activities: the shearer sumps into the face, the support is moved, the drive is moved, the conveyor is moved, the shearer starts mining, the conveyor is moved (Fig1.) [8].

The course of the production process carried out in the longwall of hard coal is determined by a number of factors (regardless of the adopted technology of uni- or bidirectional mining). The decisions made within this process are therefore closely related to the conditions of uncertainty and the risk that can be understood as the effects of that uncertainty. The factors influencing the mining process can be mainly divided into two groups: mining and geological conditions (Table 1) and technical and organisational conditions (Table 2).

3. Possibilities of risk assessment and its quantification in the production process carried out in longwall of hard coal mines

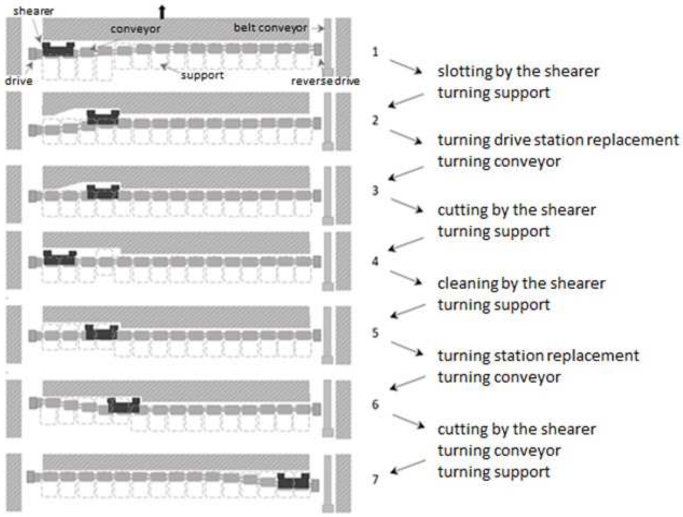

Fig. 1. General pattern of the production cycle realised in the longwall. Source: based on [8]
Rys. 1. Ogólny schemat cyklu produkcyjnego realizowanego w przodku ścianowym. Źródło: opracowano na podstawie [8]

One of the methods widely used for the risk assessment of the production process is the FMEA method. Based on the analysis of production cycles carried out in longwall of hard coal mines, it is possible to assess the risk of the production process using the FMEA method.

The FMEA (Failure Mode and Effect Analysis) method is also known under other names, i.e. FMECA (Failure Mode and Criticality Analysis) or AMDEC (Analyses des Modes de Deffaillace et Leurs Effects). It started to be used in the 60s in the USA in projects related to astronautics (elements of spacecraft, etc.). FMEA has become so popular and effective that it has been implemented in the nuclear, chemical, aerospace, electronics and automotive industries. Already in the 90's, it was included in the ISO 9000 or QS 9000 standards for the automotive industry. This is an analysis of the types of errors and their effects and consists in determining the cause and effect relationships of potential product defects taking into account the criticality factor. The main objectives of FMEA are to continuously identify potential product or process defects, eliminate them and reduce the risk of their occurrence to a minimum. This makes it possible to successively improve the studied phenomena [20].

The method consists in examining all possible faults before the design solution is approved, thus avoiding errors at a later stage. FMEA analysis is used in both unit and mass production. It may concern a single component or the whole product, several operations or the whole technological process. Conducting the FMEA of a product is advisable if the newly implemented material, part or technology poses a high risk to humans or the environment. Conducting the FMEA of the process, on the other hand, is justified when it is necessary to identify factors that may have led to manufacturing interruptions. They may be related to processing methods or parameters, measuring tools or machines [19].

The quantitative analysis aims to determine the criticality factor (LPR), i.e. the risk factor associated with the occurrence of a defect. The numerical evaluation is on a scale from 1 to 10 and is conducted on the basis of three criteria:

- frequency of defects (P),
- the significance of the defect for the customer, i.e. the extent to which the defect is important to them (Z),
- level of detection, i.e. the probability that a given defect will not be detected by the manufacturer and will be delivered to the customer, the so-called possibility of detection (W). The product of these three variables creates a priority number, determining it according to the formula:

$$LPR = Z \times P \times W$$

The LPR number that can take values from 1 to 1000 is of great importance. The higher the value, the greater the risk associated with the defect. It is therefore common to establish a specific criticality level above which all errors are analysed [19].

In order to conduct FMEA analysis of the production process carried out in longwall of hard coal mines in Poland, a list of potential failures of particular activities in the production process was drawn up. The anticipated effects of these events, the reasons for the failure and available prevention methods were determined. The methodology and results of the method are described in detail in the publication [18].

According to the FMEA method, if the LPR value is less than 100, it is assumed that the given failure does not pose a significant threat to the process, it is the so-called threshold of acceptability. Special attention should be paid to failures for which the LPR value is much higher than 100. In the case of the analysed process, these are failures causing the shearer to stop working, which, in turn, halts the mining of the wall. The reasons for these situations are as follows: lack of power supply (caused by various types of failures or natural hazards such as exceeding the permitted concentrations of gases (e.g. methane), burying the conveyor or support with output, as well as unfavorable geological conditions (overgrowth, low parameters of coal, roof falls, etc.). The greatest impact on the process disturbance has the occurrence of the above-mentioned failures during the shearer's operation, i.e. during the mining, cleaning and sumping of the shearer.

Tab. 1. Mining and geological conditions influencing the occurrence of risks and uncertainties in the process carried out in longwall of hard coal mines. Source: [18]

Tab. 1. Uwarunkowania górniczo-geologiczne wpływające na występowanie ryzyka i niepewności w procesie realizowanym w przodkach ścianowych kopalń węgla kamiennego. Źródło: [18]

Factor	*Description*
Type of roof and type of floor	It depends mainly on the class of roof and floor rocks, but also on the thickness of the mined seam and the tendency of coal to self-ignite.
Coal workability	A feature closely related to the compactness of coal. The higher the compactness indicator, the more difficult the rock is to work. The workability of a rock is understood as its susceptibility to being separated from the face by tools, mining machines or explosives. The workability is related to the hardness and compactness of the rock, but also to the pressure of the rock mass and the transverse dimensions of the longwall and its progress. There are three groups of seam, depending on the value of the workability indicator, marked with the letter "*f*".
Seam thickness	This is the shortest distance between the roof and the floor. Depending on the thickness of the deposit, a division of hard coal seams into thin and thick seams is assumed.
Inclination of seam	Overlie of the seam can be horizontal or at a certain angle of inclination to the horizontal plane. The angle formed by the plane of the floor or roof of the seam with the horizontal plane is called the angle of seam inclination. Seams are divided into four groups depending on the angle of seam inclination.
Natural hazards	Natural hazards, including those related to rock and gas ejection, are one of the most dangerous hazards in underground mining. The risk of methane and rock ejection increases with increasing depth. As a result of mining at deeper and deeper depths, an increase in the seams' methane content is observed, which at the same time reduces the gaseous permeability of coal, contributing to the increase of this threat. Factors determining the occurrence of the threat are, among others: gas-bearing capacity of the deposit (methane content), compactness of rocks, pressure and intensity of gas desorption and conducting works in the vicinity of geological disturbances.

Tab. 2. Technical and organisational conditions influencing the occurrence of risks and uncertainties in the process carried out in longwall of hard coal mines. Source: [18]

Tab. 2. Uwarunkowania techniczno-organizacyjne wpływające na występowanie ryzyka i niepewności w procesie realizowanym w przodkach ścianowych kopalń węgla kamiennego. Źródło: [18]

Factor	Description
Mechanical system	Rational selection of the shearer-conveyor-support system usually results in shorter cycle times.
Technical parameters of machines	Despite the fact that today's shearers show an increasing work speed and, consequently, can theoretically show higher productivity, their actual performance is determined by mining and geological factors, in particular the degree of coal workability and roof conditions.
Equipment failure frequency	It can be assumed that the longer machines and equipment are used, the more often they can fail. Therefore, it seems important to carry out timely maintenance and quick repairs.
Organisation of the production cycle	Operation method, the form of work organisation and the system of work, and the training and experience of employees are the factors that seem to be the most predictable. It is possible to manage the properly trained staff in the longwall in an optimal way.

The process is slightly less affected by the occurrence of these failures when moving the conveyor or support. The methods of prevention for failures that carry the greatest risk include shearer's supervision, employee supervision, maintenance of correct geological documentation and support condition control. After conducting analysis, the recommended prevention should be implemented and a deadline should be set for recalculating the LPR in order to compare the results and take steps to eliminate or minimise the impact of failures on the production process. Nevertheless, taking into account the specific nature of mining production, it will be difficult to eliminate the risk associated with these failures, due to the high unpredictability of these events [18].

On the basis of the analyses of production cycles carried out in longwall of hard coal mines, a process map was developed for various mining technologies. Figure 2 shows unidirectional mining technology.

Distortions destabilising the process may and do occur in each of the elements of the process presented on the map. Therefore, it is important to identify the risk of their occurrence and to determine and take preventive measures as accurately as possible.

Within the framework of the production process diagram presented in Figure 2, 4 modules can be distinguished:

- Module 1: preparatory work (m1)
- Module 2: cutting (m2)
- Module 3: final works (m3)
- Module 4: cleaning (m4)

In each of these four modules, it is possible to distinguish the risk that may arise from technical and organisational, as well as geological and mining conditions, and which stops the realisation of the process, which in consequence leads to no extraction. Qualitative (descriptive) risk assessment - e.g. carried out on the basis of FMEA methodology, can be quantified using e.g. the method described in detail in the following publication [13]. It concerns the risk assessment for the implementation of the production plan.

As previously indicated, factors destabilising the process carried out in longwall of hard coal mines are divided into two groups: geological and mining, and technical and organisational. Their unpredictability and impact on the production cycle is so significant that it may result in, for example, variable (unstable) shearer's movement. Then, the assessment of the effectiveness of such a production process (e.g. through the assessment of the stream of rock mined in that process) should take into account its unstable (undetermined) character.

The risk associated with the possibility of failing to implement production plans is therefore significant and should be determined. To do that, the authors of the paper [7] have proposed to use an indicator of the intensity of the stream of mi-

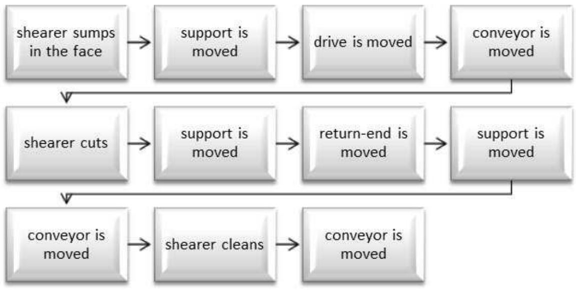

Fig. 2. Process map for unidirectional shearer mining. Source: Own study
Rys. 2. Mapa procesu dla technologii jednokierunkowego urabiania kombajnem. Źródło: Opracowanie własne

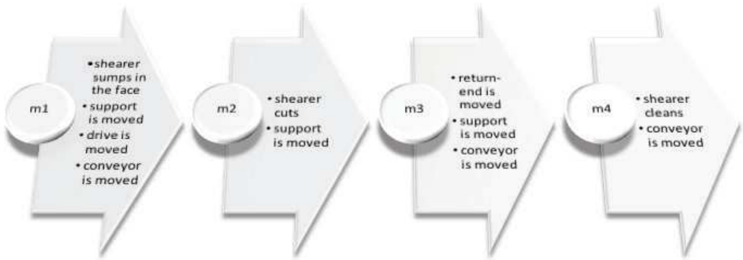

Fig. 3. Division of the production cycle in the longwall into modules. Source: [13]
Rys. 3. Podział cyklu produkcyjnego realizowanego w przodkach ścianowych na moduły. Źródło: [13]

ned rock in the function of probability. Assuming that some of the quantities describing this process are determined and some of them are described as random variables, it is possible to assess the probability of implementation of the assumed production plans.

Determined data, adopted in the proposed method, take the following values:

- longwall length
- longwall height
- web depth
- bulk density of coal
- web use index
- distance from the shearer stop position to the junction between the longwall and the gate road
- shearer length
- distance of the advancing conveyor from the supports
- minimum distance of the advancing conveyor from the shearer
- distance of the advancing roof supports from the shearer

On the other hand, the following values were treated as random variables:

- shearer maneuvering speed (shearer speed when clearing the shearer route)
- shearer working speed
- shearer working speed when cutting
- boot end movement time
- drive movement time

In the paper[10] the scheme of calculations to be made in order to obtain the characteristics of the stream of mined rock indicator has been described. For this purpose, it is necessary to perform a calculation procedure, divided into four stages.

The proposed method can be useful to evaluate the effectiveness of the production cycle in the longwall. In production risk assessment, it comes down to answering the following questions:

- What is the probability that the intensity of the stream of mined rock will not exceed a certain amount of extraction?
- What is the probability that the intensity of the stream of mined rock will be within the given limits?

4. Summary

Polish companies operating in the mining industry more and more often reach for modern solutions from the borderline of IT and communication. This is due to the continuous development of new philosophies of effective management, increasingly supported by Business Intelligence tools.

It is assumed that the idea of BI is to rely on huge amounts of information, which in itself may not be of any value or carry no information. However, using such fields or technologies as: statistics, econometrics, operational research, artificial intelligence, databases, business reporting, analytics, data mining or benchmarking can be a great help in management processes.

Polish mining companies systematically try to use the collected data for decision support processes.

In terms of reducing production risk, BI solutions can be very useful. The tools described above show how the available data can be used for analysis, the results of which can reduce or eliminate risk. The development of BI tools and the steadily growing computing power open wide doors for such analyses, even in a continuous system. It is assumed that in the field of knowledge management issues - knowledge bases (i.e. the

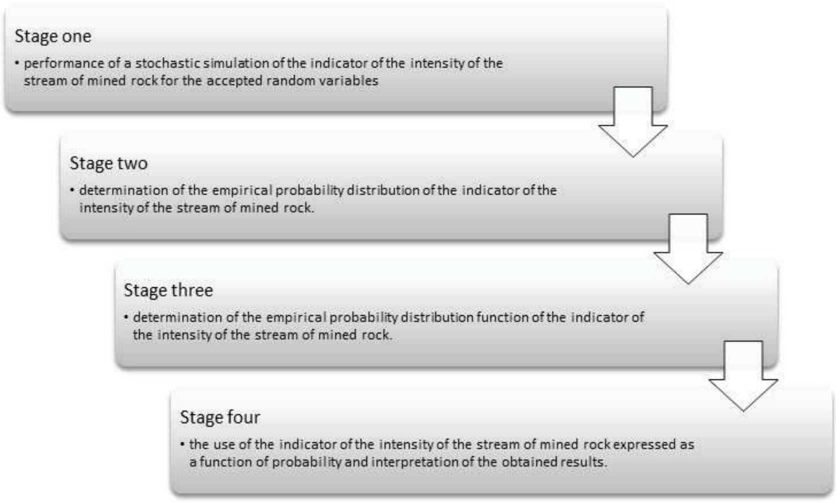

Fig. 4. Stages of obtaining a characteristic of the intensity of the stream of mined rock. Source: Own study
Rys. 4. Etapy uzyskania charakterystyki natężenia strugi urobku. Źródło: Opracowanie własne

basis of BI solutions) are a tool supporting knowledge identification, gathering, organising and sharing.

The knowledge bases collect data on the longwalls themselves. The data collected in them constitute a set of information about mining and geological as well as technical and organisational conditions that occurred during mining. So, those that influence the risk of the production process the most. In addition, it includes information related to technological interruptions, the reason for their occurrence and the way to eliminate the obstacle. There is also information on the duration of individual activities within the production cycle, data on the composition of the air, and all others that could and/or contributed to the way and quality of operation. Such a knowledge base is an important element when deciding to start mining a new wall. On the basis of the collected knowledge, the most similar longwall, which has already been mined, is searched for, and then decisions are made with respect to the way of operation. This is particularly important in terms of the overall functioning of a mine, because decisions made at this stage are crucial and binding during the functioning of a given longwall. Therefore, all financial expenses, the way people are hired, the management of the machine park and related costs and investments, the way the excavation is made available and, as a consequence, its aeration throughout the entire duration of exploitation and a number of other aspects typical of the production process, such as the selection of coal in an underground mine for activities and decisions, will systematically affect the entire mine. Therefore, it is extremely important and helpful to create and then use such a database [17].

Risk management is a current problem, not only for the mining industry. The best decision is a decision based on facts, which should be supported by appropriate and valid conclusions. It seems that the constantly expanding BI class tools are intended to support the decision-making process, and this is based on the knowledge coming from events that take place every day in the company. Appropriate equipping of collected data with computational tools and methodologies can contribute to reducing the negative effects of risks that occur in the mining process.

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Ryzyko produkcyjne – wybrane aspekty występowania oraz zarządzania na przykładzie przodka ścianowego

Proces produkcyjny realizowany w przodkach ścianowych kopalń węgla kamiennego charakteryzuje się występowaniem wysokiego ryzyka produkcyjnego, ze względu na szereg determinujących go czynników. Konieczne zatem jest rozpoznanie tego ryzyka a następnie ograniczanie jego występowania. W niniejszym artykule przedstawiono uwarunkowania geologiczno- górnicze oraz techniczno-organizacyjne procesu realizowanego w przodku ścianowym. Zaprezentowano także możliwości oceny ryzyka i jego kwantyfikacji w procesie produkcyjnym realizowanym w przodku ścianowym kopalń węgla kamiennego dla wybranej technologii urabiania. Stwierdzono, że stale rozbudowujące się narzędzia klasy BI z założenia mają wspierać proces decyzyjny i to właśnie w oparciu o wiedzę pochodzącą ze zdarzeń, które codziennie mają miejsce w przedsiębiorstwie, w tym także w przodkach ścianowych. Odpowiednie wyposażenie gromadzonych danych w narzędzia i metodyki obliczeniowe może przyczyniać się do ograniczania negatywnych skutków ryzyka, jakie występuje w procesie wydobywczym.

Słowa kluczowe: *ryzyko produkcyjne, przodek ścianowy, proces wydobywczy, kopalnia, przemysł wydobywczy*