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USE OF THE METHOD FMEA FOR HAZARD IDENTIFICATION AND RISK ASSESSMENT IN A COAL MINE

Adam Duda
Silesian University of Technology

Tymoteusz Juzek
Polish Mining Group Joint-Stock Company

Abstract:
One of the basic stages of mining operations is development work. During them there can occur the events that affect the process of development work as well as the safety of workers. This article conducts a process risk assessment using the Failure Modes and Effects Analysis (FMEA) method to identify events that disrupt the development work process, along with the causes of the occurrence of these events. The study covered the process of development work i.e. the execution of the M-2 roadway in seam 502/1 realized at a depth of about 550 m with an assumed length of about 500 m. As a result of the study, those risks for which countermeasures should be applied were identified, and measures were proposed to minimize the risks involved. As part of the research, an FMEA evaluation form was created to assess process risks in the execution of similar work. The highest process risk was identified for the drivage of the excavation with a road header, and is related to the possibility of frequent failure of hydraulic systems. Similar process risk results were obtained for the risk associated with improper execution of mining with explosives and the need to perform additional blasting work in the excavated roadway. The results can contribute to reducing the time of coal face stoppage during development work, and thus improve the process of them and reduce the costs incurred during this process.

Key words: *development work, risk assessment, process, threat*

INTRODUCTION

The coal mining sector has a huge impact on both economic, environmental, social aspects and ensuring the energy security of the country, especially in the case of countries whose energy is based on coal. How great this influence is has been shown in recent years where, as a result of the outbreak of armed conflict in Ukraine, there have been many changes in the approach to the mining sector and ensuring energy security on raw materials that are available and allow a country to maintain as much energy independence as possible. Many commentators showed surprise at the lack of sufficient hard coal in Poland and the fact that it has to be imported. Such a situation came as no surprise to those who have knowledge of the mining industry other than that gleaned from media reports. Concepts appearing in the public space regarding a rapid increase in mining had to be confronted with the facts, i.e. the time needed, the amount of costs, the amount of work and manpower required to make new seams available, the cutting of new longwalls to increase coal production in the final stage.

The proper selection of winning machines for specific mining and geological conditions requires the development of an appropriate algorithm. The appropriate selection of a machine is closely related to acquiring a high concentration of exploitation from the given longwall. That is indispensable, especially taking into consideration the growing cost of mining, as well as the depth of coal seams.

The analysis of the mining process, especially in difficult conditions, indicates that in order to determine the extent of failure-free operation of machines, it is necessary to determine the coal/rock properties that have a significant impact on the mining process.

The above affects the technique, technology and efficiency of mining – it affects the efficiency of mining machines.

LITERATURE REVIEW

The process of longwall coal extraction is one of the final processes of seam mining, before the start of which it is necessary to carry out preparatory works. These works have a huge impact on both - the planned start of the longwall and ensuring the safe conduct of mining, which is more difficult and complicated in conditions of mining at lower and lower levels [1, 2, 3, 4]. One of the very important factor defining the ability to apply a certain winning machine in certain conditions, as well as achieving the assumed production goals with minimal costs (economic effect) is the susceptibility of coal to cutting, which is a property of the coal solid [5, 6, 7].

Many authors make analyses related to hazards occurring in the mining process, however, most often these analyses co-ncern individual natural hazards such as methane hazards [8, 9, 10, 11, 12], gas and rock blasting hazards [13, 14, 15, 16], rock burst hazards [17, 18, 19, 20, 21], or water hazards [22, 23, 24, 25].

Natural hazards as well as existing mechanical hazards cause occupational accidents with injuries or death of workers [26, 27, 28] despite the protection in place and the occupational risk assessment carried out at workplaces. Authors of publications often refer to individual hazards and the possibility of occurrence of events associated with them much less is the analysis of risk assessments of the entire process of mining works, i.e. process risk assessment. Among the publications on process risk analysis in mining, the studies presented in publications can be mentioned [15, 29, 30, 31, 32, 33].

The proper conduct and execution of development work is of huge importance not only for these works but for the entire mining process, as it repeats itself cyclically with the preparation of the panelling of successive walls. Preventing the occurrence of events such as failures and accidents, which can lead to hindrances and even stoppage of the process of development work, contributes to proper, uninterrupted operation and both process safety and protection of life and health of workers. This article presents the use of the Failure Modes and Effects Analysis (FMEA) method for process risk assessment during development works for the excavation of the M-2 roadway in the seam 502/1 at a depth of about 550 m.

METHODOLOGY AND RESEARCH

The Failure Modes and Effects Analysis (FMEA) method was used to implement the process risk assessment of development work. Through the use of this method, it is possible to identify potential failure events, the hazards that may cause these failure events, as well as to determine the effects that may arise as a result of the occurrence of a given failure event [34, 35]. Identifying potential failure events also makes it possible to identify ways to minimize the risk of failure and/or mitigate the consequences of failure events.

The FMEA method identifies possible disturbances and failures at each stage of the process. During the assessment, ratings are assigned to each possible event (failure) for the following parameters Occurrence (*O*) – the probability of occurrence of the failure, Detection (*D*) the probability of failure not being detected, and Effect (*E*) the amount of damage or harm that the failure mode can cause to the entire system including workers, machinery and equipment. The product of these three ratings is the risk measure number (*RPN*) for the failure.

The terminologa used in FMEA is the following one [36]:

- Failure Mode: physical description of a failure. It is the manner in which the process fails to perform its intended function.
- Failure Effect: it is an impact of failure on process, equipment. it is an adverse consequence that the operator/user might experience.
- Failure Cause: it refers to the cause of failure.

For a given failure scenario, the *RPN* value is calculated from the assessment of variables:

- Effect (*E*): the effect of a failure mode. Effect categories are estimated using a 1 to 10 scale.
- Occurrence (*O*): occurrence is related to the probability of the failure mode and cause, scale from 1 to 10.
- Detection (*D*): the assessment of the ability of the „design controls" to identify a potential cause. Detection scores are generated on the basis of likelihood of detection by the relevant company design review, testing programs, or quality control measures, scale from 1 to 10.
- Risk Priority Number (*RPN*): the Risk Priority Number is calculated from dependence:

$$RPN = Effect\ (E) \times Occurrence(O) \times Detection(D) \quad (1)$$

Assessments of the individual parameters: Effect, Occurrence, Detection is done according to the scoring scale used in the method, which is shown in Table 1.

Conditions and parameters for conducting the assessed development work.

Natural hazards which can occur:

- Methane hazard – category III methane hazard, the excavation is included in the excavations with degree „c" of danger of methane explosion.
- Coal dust explosion hazard – class „B" coal dust explosion hazard.
- Water hazard – 1^{st} degree of water hazard.
- Endogenous fire hazard – II-III, self-ignition group.
- Rock burst hazard – 1^{st} degree of rock burst hazard.
- Gas and rock ejections hazard – not included.
- Climatic hazard – 1^{st} degree of climatic hazard.

It was assumed that the initial section of the roadway (about 12 meters) will be drilled with explosives, the rest of the excavation (about 490 meters) will be drilled with a road header. It is planned to use the following types of shoring: ŁPSp V32/4/6.85x3.8; ŁP12/V29/4/A; ŁP10/V29/4/A; ŁP9/V29/4/A. Heavy steel mesh will be applied between the lining and the roof. The raodway will be ventilated by separate ventilation in accordance with the lute ventilation design.

Table 1
Scoring scale used in the FMEA method

Score	Description
Parameter: Effect (*E*)	
1	None. No effect.
2	Very slight. Slight disruption to work. The condition does not affect the safety and the process flow.
3	Slight disruption to work. The condition does not affect the safety and the process flow.
4	Very small. Slight disruption to work. Low impact on safety and process flow.
5	Small. Slight disruption to work. Low impact on security. Low impact on safety and process flow. The process is disrupted without reducing system functionality.
6	Medium. Slight disruption to work. The condition affects less than 100% of the safety and the course of the process. The process is disrupted without reducing system functionality.
7	Large. Disruptions in work. The condition affects less than 100% of the safety and the course of the process. The process is disrupted and the functionality of the system is reduced.
8	Very big. Significant disruption to work. The condition affects the safety and course of the process in 100%. The process is disturbed by loss of system functionality.
9	Dangerous with warning. It endangers the employee. It significantly affects the safety and course of the process. State inconsistent with regulations and standards. The hazard comes with a warning.
10	Dangerous without warning. It endangers the employee. It significantly affects the safety and course of the process. State inconsistent with regulations and standards. The hazard occurs without warning.
Parametr: Occurrence (*O*)	
Score	Description
1	Unbelievable. There were no events in similar processes.
2	Very rarely. In similar processes, events occurred sporadically.
3	Rarely. In similar processes, events occurred accidentally.
4-6	Average. In similar processes, events were rare.
7-8	Often. In similar processes, events occurred frequently.
9-10	Very often. Loss is almost unavoidable.
Parametr: Detection (*D*)	
Score	Description
1-2	Detection of defects certain. An automated test is used for detection.
3-4	The chances of detecting a defect are high, a functional test/control is used with a high probability of detection.
5-6	Inspection can detect defects, average detection rate. Optical inspection by the operator (defect relatively easy to detect visually).
7-8	Defect detection is difficult. Visual inspection by the operator and the defect is hard to detect.
9-10	Detection of a defect is extremely difficult or impossible, or there is no control that could detect a given defect.

Source: [36].

The cycle of execution of work with explosives consists of the following stages:

- excavation of the rock mass (drilling of blast holes, loading of the explosives, dismantling of the working face protection, withdrawal of the crew and firing of the explosives,
- building of temporary casing (rebuilding of temporary lining rails, building of temporary lining, protection of the working face, transportation, bolting and building of the roof of the final lining on the rails of temporary lining, making the lagging and lining of the roof).
- excavation (manual excavation of excavated material, usually on a short scraper conveyor the length of the entire excavation),
- installing the final lining (transporting the elements of the lining, bolting the roof arches to the roof support, making the lagging and lining the roof supports, setting the doors to the direction and leveling with the installation of multi-element struts).
- The cycle of work execution when mining with a road header consists of the following stages:
- mining of the rock mass (entry and setting of the road header, mining of the center of the working face, passage of the road header for processing, processing of the first side, passage of the road header for processing, processing of the second side of the excavation, departure of the road header from the face),
- installation of timber frame (transport, bolting and fastening of roof panel arches on the road header's arm, passage with the road header to the installation of timber frame, construction of lagging, which together with the twisted roof panel constitutes a temporary lining, transport and bolting of roof panel arches, construction of roof lagging, alignment of roof panels to the direction and leveling with the installation of multi-element struts, construction of lining and wedging).

Due to the high frequency of repetition of cycles in mechanical mining, compared to mining with explosives, a very important complementary element to the above stages is the transport, haulage and reconstruction of haulage equipment and equipment at the face, following the progress with the installation of electrical systems, as well as firefighting, compressed air and drainage pipelines.

RESULTS OF RESEARCH

The application of the FMEA method for process risk assessment was carried out according to the diagram shown in Figure 1.

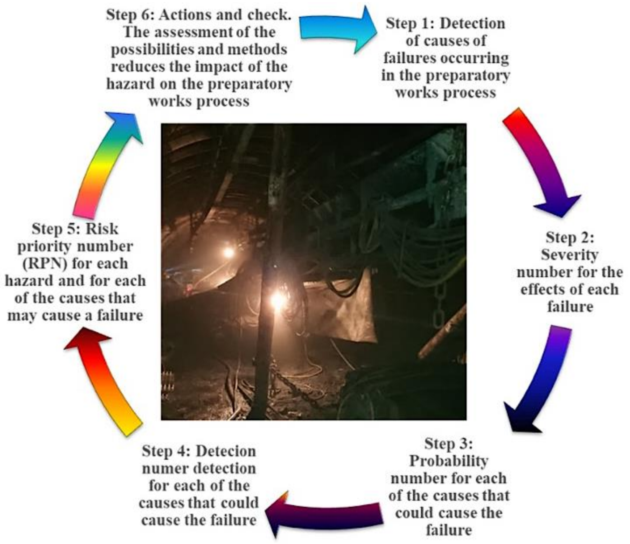

Fig. 1 FMEA cycle for process risk assessment

The evaluation process began by selecting the composition of the evaluation team. This team consisted of six people, i.e. two workers of supervision staff, three physical workers and one researcher. After familiarizing all team members with the FMEA method, the team identified incidents and the hazards that could occur in them. The process of identifying the hazards was based on the extensive experience of the team members in the execution of preparatory works and on reports of previous incidents occurring during the execution of roadway excavations.

To carry out the assessment, a spreadsheet was prepared to assign the following ratings to individual causes of process hazards (emergency events): effect, occurrence and detection, and to automatically calculate the RPN index. The assessment results obtained are shown in Table 2.

Table 2
FMEA assessment results

Name of the process	Hazard in the process	Potential causes of the hazard	Local effect	Effect on the system	*RPN*
Excavation with explosives	Lack of required spatial parameters of the breach of the working face	Blasting holes made improperly	Necessity of additional excavation (additional blasting work). Withdrawal of the crew. Provision of additional explosive	Delay in the process execution	112
		Improperly loaded holes with explosive, improper condition of explosives	Necessity of additional excavation (additional blasting work). Withdrawal of the crew. Provision of additional explosive	Delay in the process execution	168
		Damaged blast line (fuse breakage)	Necessity of additional excavation (additional blasting work). Withdrawal of the crew. Provision of additional explosive	Delay in the process execution.	126
	Methane explosion	Sudden outflow of methane and occurrence of an initiation	Damage to the excavation, casualties among workers	Temporary suspension or termination of the process execution	40
	Rock burst	Change in stresses in the rock mass as a result of the work being carried out	Damage to the excavation, casualties among workers	Temporary suspension or termination of the process execution	40
	Uncontrolled explosion of explosives	Errors in the use of explosives	Damage to the excavation, casualties among workers	Temporary suspension or termination of the process execution	60
Excavation with a road header	Stoppage of the road header	Failure of the power hydraulics	Stopping the roadheader, stopping the work. Need for repair	Delay in the process execution	294
		Failure of apparatus and control box	Control errors (loss of communication). Necessity of repair	Delay in the process execution.	294
		No power supply	Stopping the road header. Restoration of power supply (repair of the transformer station)	Delay in the process execution	147
		Failure of the scraper feeder	Stopping the road header. Repair of the scraper feeder	Delay in the process execution	140
		Failure of the road header feed system	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	126
		Lack of cooling of the road header	Stopping the road header, stopping the work	Delay in the process execution	108

Table 2 continued
FMEA assessment results

Name of the process	Hazard in the process	Potential causes of the hazard	Local effect	Effect on the system	RPN
Excavation with a road header	Failure of power hydraulics	Damaged power hydraulics hose	Stopping the roadheader, stopping the work. Need for repair Possible injury to workers	Delay in the process execution	294
		Failure of the control block-hose connection	Stopping the road header, stopping the work. Need for repair Possible injury to workers	Delay in the process execution	210
		Hydraulic cylinder failure	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	140
		High pressure pump failure	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	168
	Failure of apparatus and control box.	Mechanical failure	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	126
		Failure of electronic system	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	147
		Contamination of electronic and/or mechanical components	Stopping the road header, stopping the work. Need for cleaning	Delay in the process execution	147
		Improper use, operating and maintenance errors	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	147
	Lack of power supply (electric voltage)	Triggering of the power-off system at the face due to exceeding the permissible CH_4 concentration	Stopping the road header, stopping the work. Withdrawal of the crew, ventilating the excavation.	Delay in the process execution	140
		Failure of the power supply line to the face	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	147
		Failure of the transformer supplying power to the working face	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	168
		Loss of power supply to the entire region	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	168
	Failure of the scraper feeder	Damaged chain of the scraper feeder	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	140
		Damaged reversing mechanism of scraper feeder	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	140
		Defective scraper feeder driving gear	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	126
		Defective scraper feeder drive motor	Stopping the roadheader, stopping the work. Need for repair	Delay in the process execution	126
	Loss of combine feeder advance capability	Damaged road header tracks	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	105
		Damaged road header driving system motor	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	98
		Damaged power cable of the road header driving system	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	168
	Methane explosion	Sudden outflow of methane and occurrence of an initiation	Damage to the excavation, casualties among workers	Temporary suspension or termination of the process execution	40
	Rock burst	Change in stresses in the rock mass as a result of the work being carried out	Damage to the excavation, casualties among workers	Temporary suspension or termination of the process execution	40
	Lack of cooling	Damage to the hose supplying water to the road header	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	90
		Low pressure in the fire pipeline	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	126
		Lack of sufficient flow through the cooling system (contamination)	Stopping the road header, stopping the work. Need for repair	Delay in the process execution	126

Table 2 continued
FMEA assessment results

Name of the process	Hazard in the process	Potential causes of the hazard	Local effect	Effect on the system	RPN
Lining execution	Lack of transport of input materials (elements of roadway lining)	Failure of transport system	Lack of materials at the site of work. Suspension of works. The need to wait for the execution of the order	Delay in the process execution	252
		Failure to order the required lining elements	Lack of materials at the site of work. Suspension of works. The need to wait for the execution of the order	Delay in the process execution	105
		Delays in delivery of required lining elements	Lack of materials at the site of work. Suspension of works. The need to wait for the execution of the order	Delay in the process execution	120
		Incorrect marking of the destination of the required shoring elements	Lack of materials at the site of work. Suspension of works. The need to wait for the execution of the order	Delay in the process execution	144
	Methane explosion	Sudden outflow of methane and occurrence of an initiation	Damage to the excavation, casualties among workers	Temporary suspension or termination of the process execution	20
	Rock burst	Change in stresses in the rock mass as a result of the work being carried out	Damage to the excavation, casualties among workers	Temporary suspension or termination of the process execution	40
	Prolonged time of building the doors – lack of required spatial parameters of the breakout of the working face	Errors during mining of the working face with explosives (incorrectly drilled holes, incorrectly loaded holes, defective explosives)	Necessity to perform additional mining (additional blasting work). Withdrawal of the crew. Provision of additional explosives	Temporary suspension or termination of the process execution	210
		Failure of workers (shearer and his helper) to maintain sufficient attention. Errors in the technology of performing the work	Re-entering the breach	Temporary suspension or termination of the process execution	112
	Failure of output	Failure to make the equipment or tools for excavating fully operational	Stopping the progress of the working face. Accumulation of excavated material at the face	Delays in the process	108
		Faulty haulage conveyor	Stopping the progress of the working face. Accumulation of excavated material at the face	Delays in the process	120
		Lack of required operation of the haulage conveyor	Stopping the progress of the working face. Accumulation of excavated material at the face	Delays in the process	108
		Insufficient length of spoil haulage conveyor	Stopping the progress of the working face. Accumulation of excavated material at the face	Delays in the process	105

DISCUSSION

Within the framework of the evaluations obtained, it was found that among all the risks and the causes that can cause them, the vast majority concern the process of mining the working face with a road header (Figure 2), which, among the analyzed processes, lasts the longest on the scale of tunnelling the entire length of the excavation.

The highest *RPN* was 294 for an emergency stoppage of the road header caused by failure of the power hydraulics or failure of the apparatus and control box and for damaged power hydraulics hose. Figure 3 presents a graph showing the *RPN* indices with lines for median, average, and significance level.

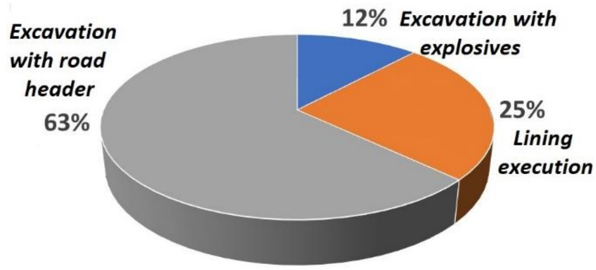

Fig. 2 Percentage of risks in the various stages of the works

Since the main purpose of the FMEA assessment was to evaluate process risks and not to evaluate occupational risks, the *RPN* values for natural hazards such as methane hazards and rockburst hazards received low values due to the rare occurrence and existing high detection levels of the possibility of these hazards.

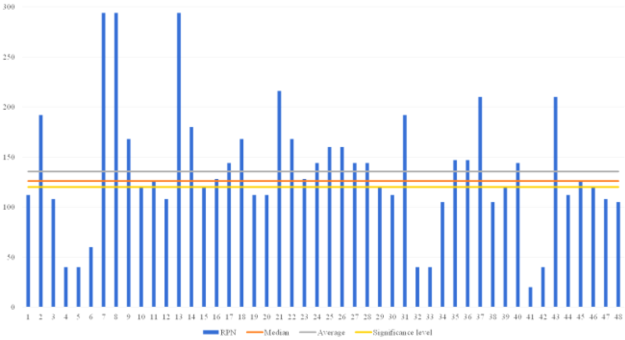

Fig. 3 RPN indicator graph

The hazards associated with the process of excavation with explosives mainly resulted in the improper execution of the breach of the face, and consequently the need to repeat the blasting work which significantly extends the process of execution of the work due to the need to withdraw the crew, execute the blasting work, ventilate the excavation and return the crew to the excavation. Often the need for additional blasting work, is identified only during the execution of the process of building the final lining. This often involves the impossibility of implementing measures to minimize the suspension or delay of the excavation process. In order to reduce the possibility of emergency events caused by this hazard, it was proposed to take measures to reduce the risk, among which we can mention: increased supervision of the blasting supervisor over the work performed by subordinate miners additional training in effective mining with explosives and the use of drilling equipment for blasting holes as intended. The measures introduced made it possible to reduce the maximum *RPN* in the process to a value of 105.

The largest number of identified hazards and potential causes of their occurrence and thus the occurrence of emergency events occur during the process of excavation with a road header. The ratings obtained for events such as failure of the power hydraulics or failure of the apparatus and control box (Figure 4) are not due to the large negative effect on the health of workers, but to the high frequency of their occurrence and the effect they cause on the proces.

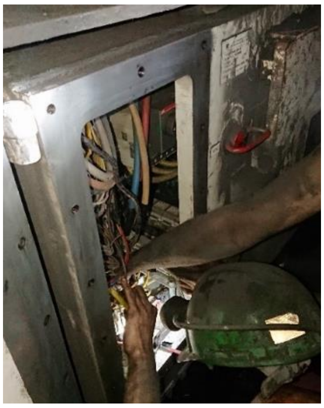

Fig. 4 Repair of apparatus box failures

Sometimes damage to the pressure hose in a hard-to-reach place can cause a long stoppage of the road header due to long-term repair, which causes delays in the execution of work and involves incurring additional costs associated with the stoppage of the working face. In order to avoid emergencies, solutions were presented to reduce the risk by using hoses with higher strength, more frequent inspection of visible pressure hoses and their connections, and, where possible, using covers on hydraulic components to prevent mechanical damage. These measures allowed to reduce the *RPN* index to 140, however, even after the implementation of these measures it was not possible to achieve a risk assessment below the significant level, i.e. 120 *RPN*, which indicates that the risk associated with the failure of hydraulic connections (Figure 5) and high-pressure hoses is significant for the process.

Fig. 5 Hydraulic connections in working conditions

Also noteworthy is the *RPN* score for the hazard associated with the extended build time of the door - the lack of the required spatial parameters of the breach of the working face, caused by errors during the mining of the working face with explosives. Even after the introduction of measures to mitigate the risks associated with excavation with explosives, the *RPN* score for the hazard associated with extended development time remained at 140. Other hazards occurring in the process of making the casing are mainly related to delays in the execution of the work due to the lack of elements necessary for making the casing. Failure of the transportation system was identified as the main cause of such emergencies, of lesser importance were the lack of or insufficient execution of orders and the failure to deliver the required process materials to the casing excavation caused by an incorrectly indicated destination or a change of this destination during the transportation of materials in underground workings. To minimize the risks associated with the occurrence of these contingencies, the following were proposed: maintenance of transport equipment, periodic inspections of transport equipment, training of transport equipment operating personnel and increased supervision of planning and execution of orders, introduction of electronic monitoring of logistics support (tracking of transported items). The risks discussed above and the solutions introduced to minimize the risks associated with them refer to those risks for which the *RPN* indicator was the highest. Below in the Table 3 there are indicated risk minimization measures for all risks for which the *RPN* exceeded the value of 119, a description of the introduced measures is included in column 4, and column 8 of the table indicates the value of the *RPN* indicator after taking into account the risk minimization measures.

Table 3
Risk mitigation measures

Name of the process	Hazard in the process	Potential causes of the hazard	Measures to reduce the risk of an emergency event	*RPN*
Excavation with explosives	Lack of required spatial parameters of the breach of the working face	Improperly loaded holes with explosive, improper condition of explosives	Training in effective mining with explosives. Increased supervision of the blasting supervisor over the work performed by subordinate employees.	84
		Damaged blast line (fuse breakage)	Training in effective mining with explosives. Increased supervision of the blasting supervisor over the work performed by subordinate employees.	105
Excavation with a road header	Stoppage of the road header	Failure of the power hydraulics	Maintenance of equipment and machinery according to the manufacturer's guidelines, cleaning up high-pressure hoses	140
		Failure of apparatus and control box	Regular inspections, avoiding exceeding the amplitude and intensity of vibrations, regular maintenance	140
		No power supply	Proper ventilation of the working face, regular inspections and checks of electrical equipment	84
		Failure of the scraper feeder	Regular lubrication of feeder components, control of correct chain tension	63
		Failure of the road header feed system	Regular inspection of the feed system	70
	Failure of the power hydraulics	Damaged power hydraulics hose	Use of heavy-duty hoses. Inspection of the condition of hoses and connections	140
		Failure of the control block-hose connection	Use of hoses of proper length and strength. Inspection of the condition of hoses and connections	63
		Hydraulic cylinder failure	Proper inspection of supplied power hydraulics. Taking care to use in accordance with the intended use, use screens to protect hydraulic cylinders	63
		High pressure pump failure	Checking the condition of the oil filter and cleaning if necessary, filling the oil tank according to the manufacturer's guidelines	70
	Failure of apparatus and control box	Mechanical failure	Use of screens for electrical equipment and control panel, training of shearers on effective maneuvering of the road header	56
		Failure of electronic system	Use of the apparatus box in accordance with its intended use, including protection against vibration and moisture	56
		Contamination of electronic and/or mechanical components.	Use of apparatus box as intended, removal of excess dirt, inspection of components	98
		Improper use, operating and maintenance errors.	Training of crews using and maintaining the equipment	84
	Lack of power supply (electric voltage	Triggering of the power-off system at the face due to exceeding the permissible CH_4 concentration.	Proper ventilation of the excavation, control of the correct placement of gasometry sensors	42
		Failure of the power supply line to the face	Properly installed line - protected against overvoltage and possible damage. Inspection of the line and its condition	84
		Failure of the transformer supplying power to the working face	Use of long-life and reliable equipment. Inspection and maintenance of the transformer, taking care of the equipment during transportation	98
		Loss of power supply to the entire region	Preventing damage to the main power cables by properly placing and securing them. Adhering to the rigors of transporting large-size components	56

Table 3 continued
Risk mitigation measures

Name of the process	Hazard in the process	Potential causes of the hazard	Measures to reduce the risk of an emergency event	*RPN*
	Failure of the scraper feeder	Damaged chain of the scraper feeder	Ensuring proper operating parameters including proper chain tension	56
		Damaged reversing mechanism of scraper feeder	Use of proper chain quality, regular inspection of chain tension condition	84
		Defective scraper feeder driving gear	Checking the correct installation of the gearbox. Lubrication in accordance with the manufacturer's recommendations.	105
		Defective scraper feeder drive motor	Proper exploitation. Training of workers who conduct the engine installation. Maintenance of the scraper feeder.	70
	Loss of combine feeder advance capability	Damaged power cable of the road header driving system	Correct installation and location of the motor power supply wiring, use of covers for cables	105
	Lack of cooling	Low pressure in the fire pipeline	Regular inspection of the condition and length of the road header's water supply hose	72
		Lack of sufficient flow through the cooling system (contamination)	Regular inspection of the performance of the water supply system, inspection of the state of contamination of water filters.	72
Lining execution	Lack of transport of input materials (elements of roadway lining)	Failure of transport system	Increased maintenance of the transport equipment. Periodic inspection of transport equipment. Training of employees operating transport equipment	120
		Delays in delivery of required lining elements	Execution of deliveries well in advance, supervision of planning and execution of orders	72
		Incorrect marking of the destination of the required shoring elements	Supervision of transportation execution, introduction of electronic monitoring of logistics support (tracking of transported items)	90
	Prolonged time of building the doors – lack of required spatial parameters of the breakout of the working face	Errors during mining of the working face with explosives (incorrectly drilled holes, incorrectly loaded holes, defective explosives)	Training in effective mining with explosives. Increased supervision of the blasting supervisor over the work performed by subordinate employees. Use of blast hole drilling equipment as intended	140
	Failure of output	Faulty haulage conveyor	Regular inspection of the conveyor route in accordance with the rules and regulations for output transport. Regular maintenance of the conveyor route and drives.	72

CONCLUSIONS

During the excavation of the M-2 roadway in the 502/1 seam, the process with the highest number of hazards was the excavation with a road header. This is a cyclically repeated process along the entire length of the excavation, so minimizing the occurrence of hazards by ensuring the efficiency of the road header and its cooperating equipment has a decisive impact on process safety during excavation tunnelling.

The use of the FMEA method to assess the process risk associated with the heading excavation in a very clear and transparent manner has made it possible to isolate individual hazards and the causes of emergency situations, thus confirming the effectiveness of the method for assessing risk in this process.

In many cases, measures to reduce the risk of occurring hazards are based on the training of employees and properly selected technology for carrying out the work, or, procedures and instructions for operating equipment and machinery. This conclusion implies that those responsible for safety and ensuring the continuity of the process should have the required knowledge and be motivated to carry out the works in accordance with applicable regulations and guidelines.

A comparison of the *RPN* values calculated before and after the application of risk minimisation measures allows the effectiveness of the risk reduction measures to be assessed.

The assessment process carried out with the participation of employees performing work at the working face, also made it possible to take advantage of their knowledge and experience acquired over many years of work during the excavation of dog headings.

Despite the application of risk minimisation measures, the assessment carried out showed that for four risks, the risk remained above the significant level i.e. the *RPN* is higher than or equal to 120. This means that these emergency situations have the highest impact on the implementation of the process and in future technologies for the execution of works, they will be described in detail, and the knowledge gained through the FMEA assessment will be able to be used to ensure the safety of the process during the implementation of subsequent developmnent work at the mining plant.

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Adam Duda
ORCID ID: 0000-0003-4952-828X
Silesian University of Technology
Faculty of Mining, Safety Engineering
and Industrial Automation
e-mail: a.duda@polsl.pl

Tymoteusz Juzek
Polish Mining Group Joint-Stock Company
KWK ROW Ruch Jankowice
e-mail: t.juzek@pgg.pl