Assessment of Risk in a Production System with the Use of the FMEA Analysis and Linguistic Variables

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Abstract. The paper describes a method for analysing and assessing the risk in production systems. A process of ore transportation process with the use of a belt conveyor was used as an example. Ishikawa diagram was used to identify the risk factors in the cause and effect analysis. In order to determine the extent of the impact of individual risk factors on the selected area of the production system, the FMEA analysis was used. When determining the values of the parameters needed for calculating the Risk Priority Number (RPN), defuzzified values of appropriate linguistic variables were used. The effect of the work is a reduction of the risk level in the analysed production system as well as the information about risk factors obtained on the basis of verbal communications from production workers.

Keywords: Risk, production system, transportation of excavated material, FMEA analysis.

1 Introduction

Nowadays, companies focus their attention primarily on operational and organizational problems. Risk, which is a natural and common phenomenon in enterprises, is a fundamental issue here. Elimination of risk is impossible, because it affects every decision.

Business activity is characterized by uncertainty. This condition is caused by many factors, which include, inter alia, a large number of elements making up a production system and the dynamics of the system. A measure of the uncertainty (ignorance) of the state is the average entropy of the state of the H(X) object defined by the equation (1):

$$H(X) = -\sum_i p(x_i)\log_a p(x_i) \tag{1}$$

where: X_i-th state of the x object, p(x_i) - probability of the occurrence of the x state, a- radix. Usually it is assumed that a = 2.

Planning and decision-making processes in contemporary companies generally use deterministic methods, without taking into account the conditions of uncertainty [2]. This increases the risk, because there is no information about the possible occurrence

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of threats and the resulting effects. To mitigate the risk and increase the probability of taking correct decisions, actions should be taken in order to identify the area of risk, its extent and the impact on the operations in the organization, as well to search for measures for eliminating the risk. The awareness of the omnipresence of various types of risk raises the need to identify it in terms of the place of its occurrence and the strength of its impact on the company.

In the case of mining processes it is particularly difficult to assess the impact of risk factors on a production system. This is caused by specific conditions, in which the processes run, as well as by the provisions of the mining law. The information about risk factors often comes from production workers and has a linguistic value determined without data from technical measuring instruments. In the further part of this study, a linguistic variable was used to assess the risk of a failure of a belt conveyor.

2 Identification and Assessment of Risk in Production Systems

In order to reduce the level of risk in a production system, a series of actions must be taken. The first of them is the risk identification, which determines the threats that might occur during realization of company's goals. Due to a potential possibility that many risk factors may occur, it is important to find the source risk, which is the key cause of the problems. During the identification, it is important to search for the answers to the following questions: in which area of the production system the risk occurs and which area is affected by the highest risk.

The next step in reducing the risk level is measuring the risk and determining the extent of the impact on the production system. Failure Mode and Effect Analysis (FMEA) is one of the methods which allow determining the extent of risk in the designated area of a production process or in a product, as well as the resulting effects. Thanks to this, corrective actions aiming at mitigation of the risk can be found subsequently [6]. "*One of the key factors in proper implementation of the FMEA program is to act before an event occurs and not to gain experience after the event. In order to obtain the best results, FMEA should be performed before a particular type of construction or process defect is "designed*" for a given product." [3].

2.1 Determination of the Risk Priority Number (RPN) in the FMEA Method

When assessing the risk in a production process with the use of the FMEA method, the first step is to detail the operations in the process, then to identify the risk factors present in the process, determine the effects caused by their presence, and to find possible causes. The next step in the analysis is to assign numerical values to the following parameters shown in Table 1.

Risk Priority Number (RPN), i.e. the extent of the risk, is calculated for each of the selected areas of the production system using the formula [5]:

$$RPN = (Z) \times (P) \times (T) \tag{2}$$

Table 1. Characteristics of the parameters used in the FMEA method for determining RPN

Parameter symbol	Parameter name	Description
Z	degree of threat	It determines the extent of the effects which arise as a result of the occurrence of a defect during a production process and during the use of a product.
P	probability	The probability of the occurrence of a defect
T	detection rate	It determines the probability that a potential defect or its cause will be detected later

This obtained value allows assessing the estimated risk and is used as a point of reference in relation to the corrective actions taken. The value of RPN may be in the range between 1 and 1000. So a high value of RPN corresponds to a high risk in the process. If the RPN value is high, efforts should be taken to mitigate the risk using corrective actions [3]. The corrective actions shall be taken first in the areas with the highest RPN level.

Fig. 1 shows 4 areas representing an area of high losses and risk. These areas are presented together with the parameters described above.

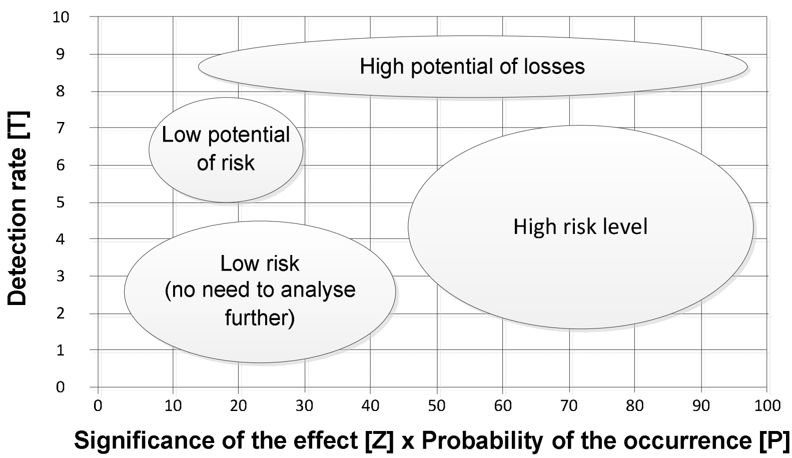

Fig. 1. The results of the RPN analysis depending on values of the parameter

Determination of a general limit for a high RPN value is not easy. Each FMEA analysis is unique and the risk estimation in this method cannot be compared with other analyses. This is caused by some sort of subjectivity, the dependence during the assessment, and the decisions made by the person performing the analysis. Therefore for each FMEA analysis a system of criteria should be developed and it should be determined from which values of RPN the corrective actions should be taken [5].

3 Determination of Risk in the Process of Haulage of Excavated Material by Belt Conveyors, Using Linguistic Variables

In the "Rudna" Mining Enterprise, located in the Lubin Copper Basin, haulage of excavated material is carried out with the use of belt conveyors. The belt conveyor transport system consists of 65 conveyors with a total length of approx. 46 km. The conveyors are connected with holding tanks in nodal points.

Belt conveyors are mechanical means of transport with a limited range and continuous movement. Typically they are used for conveying bulk materials. Material is transported on a specific route limited by the distance between the loading and unloading stations. Depending on the construction, material can be transported along a straight line or a curve, at any angle. Belt conveyors are characterized by simple construction, high reliability and safety. More and more often they are used also for transporting people.

The main components of a belt conveyor ate shown in Fig. 2. These parts form a serial structure, which means that the correct operation of each subassembly has a direct effect on the functioning of the conveyor [1].

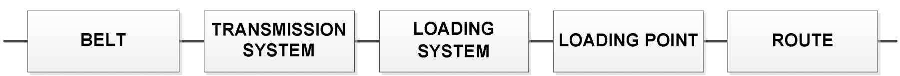

Fig. 2. Diagram showing the reliability structure of a belt conveyor

The problem of failures of belt conveyors was subjected to an analysis. This is a very important issue in respect of transportation of excavated material in a mine, because failures lead to unplanned downtimes and thus to stopping the haulage of excavated material for several shifts. On the other hand, the information about a failure may come from production workers only, which results from the conditions occurring in a mine, the length of the transport system and provisions of the mining law. Information about a failure was verbal and depended on individual impressions of workers.

Fig. 3 presents a cause and effect analysis of belt conveyor failures in the form of Ishikawa diagram. A failure of a belt conveyor, i.e. an interruption in its operation, was assumed as an effect. Risk factors were divided into the main factors and presented in boxes. Then the causes of their occurrence were analysed and were decomposed to the third level on this basis.

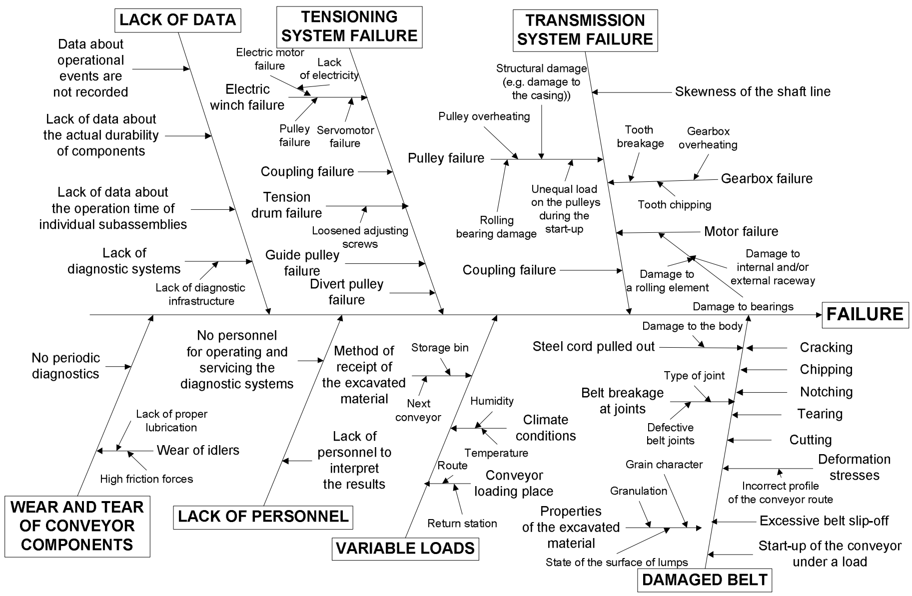

Fig. 3. Risk factors causing failures of belt conveyors

As a result of preparing the Ishikawa diagram, a summary of causes of the problem (risk factors), divided into groups, was obtained, but it does not result from it, which causes contribute to the highest extent to the effect, i.e. a failure. In order to determine the extent of the impact of individual risk factors on the process of transporting excavated material by a belt conveyor, it is required to perform the FMEA analysis.

The values of the linguistic variables used to calculate the Risk Priority Number (RPN) are shown in Table 2, Table 3 and Table 4. The interval values of the variables P, Z and T represent defuzzified values of respective linguistic variables.

Table 2. Linguistic variable and its defuzzified values for the occurrence of the risk factor

Linguistic variable for the occurrence of the risk factor	Characteristics	P [rank]
Remote	A failure is improbable	1
Low	Single occurrences	2 - 3
Moderate	A failure occurs occasionally	4 - 6
High	A failure occurs with a high frequency	7 - 8
Very high	A failure is almost inevitable	9 - 10

Table 3. Linguistic variable and its defuzzified values for the effect of the occurrence of the risk factor

Effect rate	Characteristics	Z [rank]
None	No effect	1
Minor	Minor disturbances in the operation; nuisances are noticed only by some workers	2 - 3
Low	Minor disturbances in the operation; minor impact on safety; some activities are burdensome without reduction in the performance	4 - 5
Moderate	Minor disturbances in the operation, the condition affects the safety in less than 100%; working is burdensome without reduction in the performance	6
High	Minor disturbances in the operation, the condition affects the safety in less than 100%; a reduction in the performance without a loss of the equipment function	7
Very high	Significant disturbances in the operation, the condition affects the safety in 100%; a loss of the equipment function	8
Hazardous with warning	Hazardous to workers, significantly affects the safety, the condition is inconsistent with regulations and standards, the hazard occurs with a warning	9
Hazardous without warning	Hazardous to workers, significantly affects the safety, the condition is inconsistent with regulations and standards, the hazard occurs without warning	10

Table 4. Linguistic variable and its defuzzified values for the detection rate of the risk factor

Detection rate	Probability of detection of a failure by control	T [rank]
Almost certain	The process is protected against the occurrence of a failure; failures are always detected	1
Very high	Controlling and finding a failure stops the process; failures are almost always detected	2
High	High probability that the failure will be detected	3 - 4
Moderate	Control may detect the occurrence of the failure	5 - 6
Low	Control has a low chance to detect the failure	7 - 8
Very low	Control probably will not detect the failure	9
Absolute uncertainty	Control will not detect the failure	10

The FMEA analysis was prepared on the basis of the stages of the process of transportation by a belt conveyor and the risk factors presented in Fig. 3. Table 5 shows the FMEA analysis performed for two first stages of the belt conveyor operation.

Table 5. FMEA analysis of two stages of the belt conveyor operation

Operation/Process stage	**Possible risk factors**	**Effects caused by the risk factors**	**Current state**			
			Risk factor assessment (P) [rank]	**Effect assessment Z [rank]**	**Hazard assessment T [rank]**	**RPN**
Start-up of the belt conveyor	Transmission system failure	Gearbox failure	5	8	2	80
		Coupling failure	5	8	3	120
		Motor failure	6	7	3	126
		Pulley failure	6	6	5	180
	Belt damage	Belt breakage	5	9	2	90
		Belt slip-off	5	9	7	315
Loading the belt conveyor	Excavated material blocked in the holding tank	Delay in transport	7	4	1	28
	Reduction in the clearance at the trays feeding the material	Delay in transport	6	5	2	60
	Faulty operation of the feeder drive	Delay in transport, belt damage	3	5	4	60
	Lack of excavated material	Delay in transport	1	8	1	8
	The chute is set improperly	Limited discharge to the belt	4	5	4	80

Basing on the FMEA analysis, corrective actions for the transport process were proposed in order to reduce the negative impact of the risk factors. For the first stage of the operation of a belt conveyor, the proposed corrective actions are as follows: regular inspections, minor repair activities performed every day before starting up of the conveyor, such as cleaning the belt or a visual inspection of conveyor condition. Additional activities which should be performed include: determining the actual time of operation of individual drive units, analysing the vibration, current and temperature signals, and inspecting the condition of wires and their connections in the electric motor. In addition it is recommended to take care of quality of the transported material, which means that the excavated material should be smaller in size and dry so that the clearance in the feeder is not reduced. The corrective actions performed at this stage include also taking care that the speed of feeding the excavated material onto the belt is constant. After the corrective actions has been implemented, the FMEA analysis was performed again and its part is shown in Table 6.

Table 6. The FMEA analysis after the implementation of the corrective actions

Operation/Process stage	**Possible risk factors**	**Effects caused by the risk factors**	**The state after the implementation of the corrective actions**			
			Risk factor assessment (P) [rank]	**Effect assessment Z [rank]**	**Hazard assessment T [rank]**	**RPN**
Start-up of the belt conveyor	Transmission system failure	Gearbox failure	4	8	2	64
		Coupling failure	3	7	3	63
		Motor failure	5	7	2	70
		Drum failure	5	5	4	100
	Belt damage	Belt breakage	3	8	2	48
		Belt slip-off	4	8	5	160
Loading the belt conveyor	Excavated material blocked in the holding tank	Delay in transport	6	4	1	24
	Reduction in the clearance at the trays feeding the material	Delay in transport	6	5	2	60
	Faulty operation of the feeder drive	Delay in transport, belt damage	3	5	4	60
	Lack of excavated material	Delay in transport	1	8	1	8
	The chute is set improperly	Limited discharge to the belt	4	5	3	60

After the corrective actions have been implemented, the risk of a failure in the analysed areas of the production system was reduced. The corrective actions consisted primarily in regular inspections and rigorous record-keeping, which was enough to mitigate the impact of the risk factors on the process.

4 Conclusion

Smooth operation of a production system is a phenomenon that occurs less and less often. It happens more and more frequently that the attention is drawn to the need of detecting the threats early and collecting the information concerning the cause-effect relationships occurring in the system. The FMEA analysis performed with the use of linguistic variables helped to determine the cause-effect relationships associated with the occurrence of risk factors and then minimize their impact on the production system. In the era of dynamic changes in the market environment, the FMEA method proved to be a good alternative solution that enables quick identification of potential risks for a company. When assessing a risk, linguistic variables are particularly useful, because it is possible to record the information about potential threats on the basis of verbal communications.

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