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SELECTED ASPECTS OF QUALITY ENGINEERING IN MANAGING THE OPERATION OF MACHINERY AND EQUIPMENT MINING – CASE STUDY

19.1 INTRODUCTION

Reducing the failure frequency of the mining machines and equipment is important because even brief interruptions in operation of those technical facilities can cause breaks in the entire production cycle and financial losses to the coal mines [6]. Evaluation of reliability and causes of failures of individual components involved in the process of mining can contribute to improving and increasing the efficiency of operation [5, 13]. Understanding the causes of failures of the mining machinery and equipment and analysis of their reliability will allow for better planning of the coal mining cycle [2].

The process of the coal mining in the mines is very complex and consists of several stages. It determines many factors such as the availability and size of a coal bed, geological conditions, coal mining system, as well as mining machinery and equipment involved in the mining of the coal. The technical condition of the facility is of great importance because of the continuity of the longwall faces exploitation, since the mining machines and equipment operate in an arrangement similar to the serial one, in which the failure of one unit can cause the downtime of the system. In the event of a failure of the mining machinery and equipment in a coal mine, the whole mining sequence is stopped, which generates losses and an increase in the cost of the coal mining.

The problems of evaluation of the technical facilities operation process has already been analyzed in many articles [4, 6, 10]. Most of them were primarily focused on the presentation of the analysis of reliability of the entire technical utility using statistical analysis [11, 13, 15]. An important problem associated with the mining equipment failure rate is also to identify the causes of interruptions in the operation of those machines, and in a later stage, to propose preventive measures and the measures that will increase the uptime [12].

In this study by using, in the first stage, the methods and tools of the quality engineering, such as Pareto-Lorenz ones, the percentages of individual failures were estimated, then a quantitative FMEA method was used to identify the causes of failures in the tested technical facility. In the second stage an assessment of reliability of the scraper conveyor as the serial system and of its individual components was presented.

The scraper conveyor is used for the excavated material haulage from the longwall face. The main task of the scraper conveyors is a continuous transport of the excavated material stacked in series on the gutters. The gutters create a special route of a specified distance. The route of the scraper conveyor is limited by the place of loading and unloading [1]. The scraper conveyors are divided into the longwall face conveyors used for the excavated material haulage and the transfer conveyors, and may cooperate with crushers. The longwall scraper conveyors are used for the haulage of excavated material from the longwall face, and cooperate with the combine. The individual assemblies and components of the scraper conveyor are illustrated in Figure 19.1.

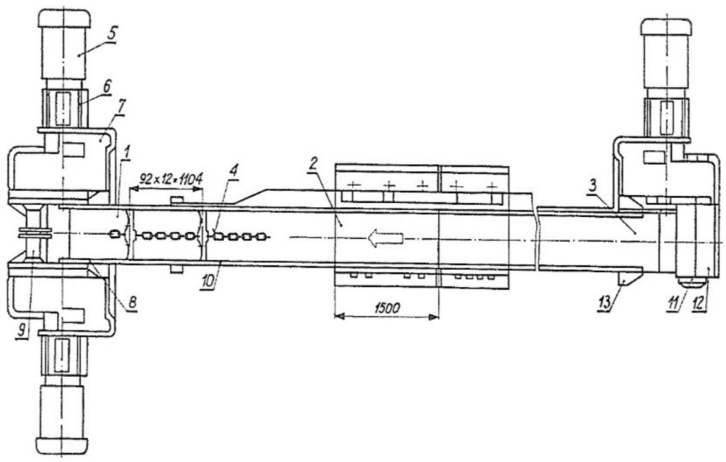

Fig. 19.1 Basic assemblies and scraper conveyor components

Souce: [1].

The scraper conveyors consist of the following components (Fig. 19.1) (this applies to each scraper conveyor) [1]:

1. main (front) drive,
2. gutters,
3. auxiliary drive (switch),
4. working tie,
5. electric engine,
6. Fluid coupling,
7. toothed gear,
8. drive enclosure,
9. drum with including socket wheel,
10. attached gutter,
11. blind bearing,
12. return cover,
13. bracket for mounting the chain combine compensator.

The analysis of the causes of failure and reliability of the scraper conveyor was based on data from three coal mines in the Upper Silesian Coal Basin. The data was collected between January 2013 and December 2014.

In terms of the types of failure the following are distinguished:

- mechanical failures, such as a broken chain, destroyed channel, chute failure,
- electrical failures including but not limited to driving engine damage, fuse-link damage and power cable damage.

19.2 ANALYSIS OF THE CAUSES AND CONSEQUENCES OF THE SCRAPER CONVEYOR FAILURE

Analysis of the causes and consequences of individual failures of the scraper conveyor was conducted using FMEA quantitative method. The FMEA method is used in industrial enterprises to analyze the process of operation of technical facilities and the entire, as well as finished products production process. Using this method, it may be determined what cause may result in damage to the scraper conveyor, and consequently failures and downtimes of the operation process. The advantage of this method is that it can be used directly by people involved in the production of a product, or participating in the production process. The individual steps of the FMEA method are presented in the algorithm (Figure 19.2).

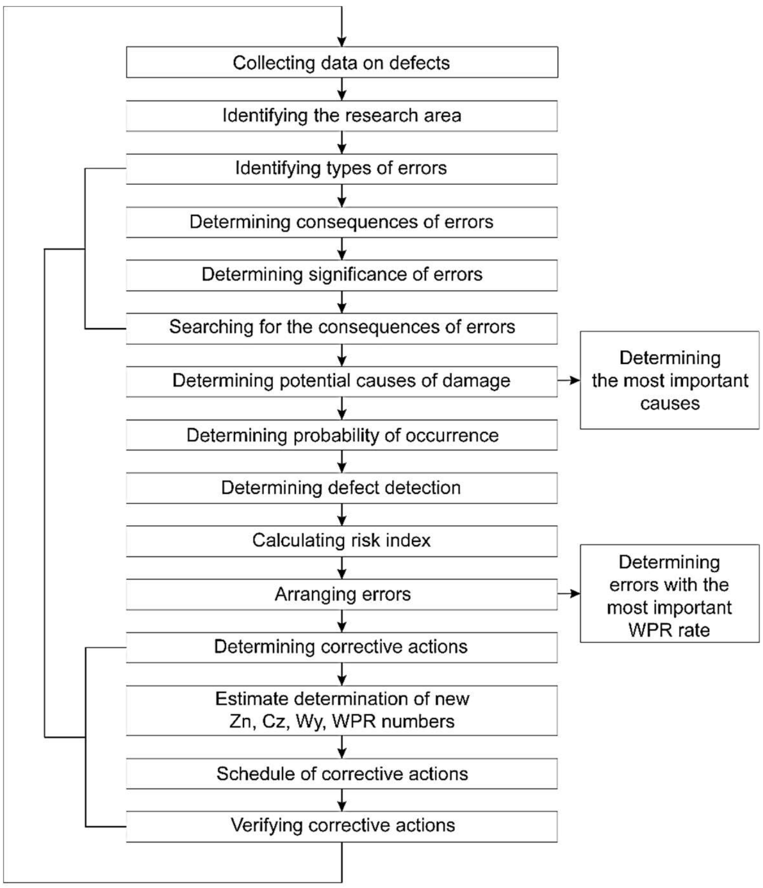

Fig. 19.2 Algorithm of the FMEA method procedure

Source: [13].

The FMEA method is a quantitative method in which the value of the risk of failure of a technical facility is estimated using the factor of risk of potential WPR damage:

$$WPR = Zn \times Cz \times Wy \tag{19.1}$$

where:
WPR – risk level,
Zn – importance of the damage [1-10],
Cz – frequency of occurrence of the damage [1-10],
Wy – detection of the damage [1-10].

After this analysis conducted with the use of the FMEA method, corrective and preventive action are introduced and then the risk level factor is re-calculated. After the WPR reassessment, that factor should be lower. In the literature, it is recommended that the level of risk of damage is less than 100 [7].

In the case of the analyzed technical facility, the causes and consequences of damage of the scraper conveyor and its individual components were defined. The analysis conducted using the FMEA method, covered only those components of individual systems that represented more than 70% of all failures in the system [14].

To determine which components of the scraper conveyor systems represent over 70% of all failures, Pareto diagram was used [12]. Pareto-Lorenz diagram was constructed as follows: A cumulative percentages of each failure was calculated using the following formula [7]:

$$PIE_j = \frac{100}{IE} \tag{19.2}$$

$$SPIE_j = PIE_j + PIE_{j-1} \tag{19.3}$$

$$PIA_j = \frac{100 \times IA_j}{\sum_{i=1}^{IE} IA_j} \tag{19.4}$$

$$SPIA_j = PIA_j + PIA_{j-1} \tag{19.5}$$

where:
PIE_j – percentage number of components,
$SPIE_j$ – cumulative percentage number of components,
IE – number of components,
PIA_j – percentage number of failures
$SPIA_j$ – cumulative percentage number of failures,
IA – number of failures.

Subsequently, percentages of failures and the cumulative percentages of failures of individual systems were shown in Table 19.1 (mechanical system) and Table 19.2 (electric system) as well as a Pareto-Lorenz diagram was shown in Figures 19.3 and 19.4.

Table 19.1 Cumulative percentage numbers of the mechanical system failures

Type of failure	Number of failures	Percentage number of failures	Cumulative percentage number of failures
Broken chain	7	77.8	77.8
Damaged channel	1	11.1	88.9
Chute failure	1	11.1	100.00

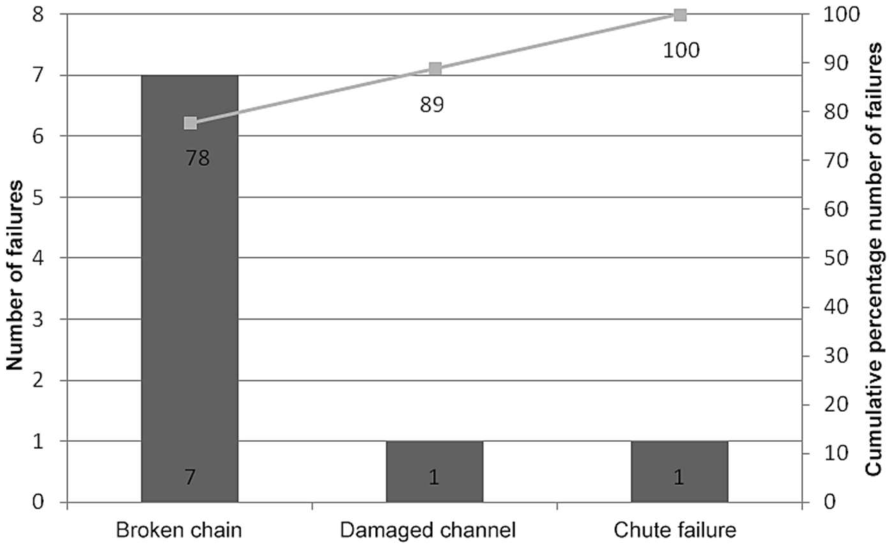

Fig. 19.3 Pareto-Lorenz diagram for mechanical failures of the scraper conveyor

Table 19.2 Cumulative percentage numbers of the electrical system failures

Type of failure	Number of failures	Percentage number of failures	Cumulative percentage number of failures
Damage to the drive motor	23	95.8	95.8
Damaged cable	1	4.2	100.00

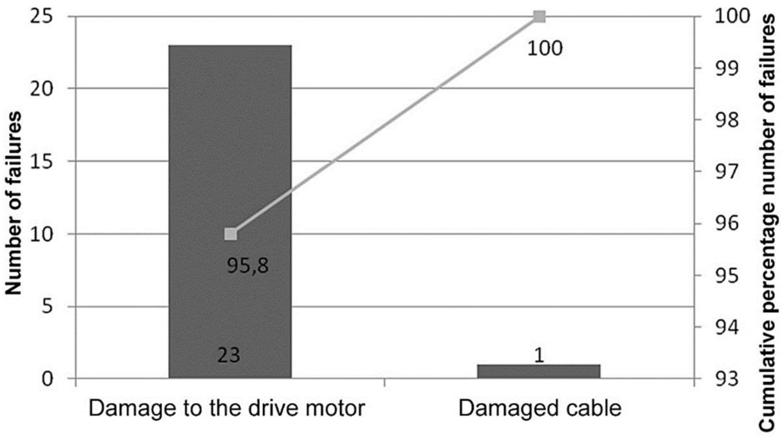

Fig. 19.4 Pareto-Lorenz diagram for electrical failures of the scraper conveyor

The following was analyzed using the FMEA method: broken chain for the mechanical system, and damaged drive motor component for the electrical system.

The FMEA analysis was conducted in accordance with the illustrated algorithm (Fig. 19.2). First the causes and consequences of failure of the scraper conveyor, and its mechanical and electrical systems were determined. Subsequently, the WPR risk level factor for the individual causes of failures was calculated. In the second stage, corrective and preventive actions to reduce WPR were developed. In the last stage, the risk level factor was recalculated and it was estimated of how much it decreased and reached the expected level. The results of the FMEA analysis are shown in Table 19.3 for the mechanical system and in Table 19.4 for the electrical system.

Table 19.3 EMEA for mechanical system of scraper conveyor components

Technical facility subjected to the analysis: mechanical system of the scraper conveyor							**Date of FMEA analysis implementation**				
Person conducting the analysis: X											
Potential failure	Potential consequences of failure	Potential causes of the failure	Zn	Cz	Wy	WPR	Results of acting				
							Measures to improve	Zn	Cz	Wy	WPR
broken chain	stoppage of the conveyor operation	too large amplitudes of dynamic load, the conveyor overloading with dredged materials	10	3	7	210	control of quantity of the excavated material on the conveyor, introduction of periodical control of the chain conditions before starting to work, more frequent maintenance	10	2	6	120

After analyzing the causes and consequences of failures – broken chain in the scraper conveyor, it can be noted that the risk factor of failure before the introduction of the corrective actions was well above the required level. The introduced measures helped to reduce the risk factor to 120.

The introduced activities used to remedy the failure – damage to the drive motor helped significantly to reduce the rate of risk occurrence from the original 240 to 60.

Table 19.4 EMEA analysis for electrical system of scraper conveyor components

Technical facility subjected to the analysis: electrical system of the scraper conveyor							**Date of FMEA analysis implementation**				
Person conducting the analysis: X											
Potential failure	Potential consequences of failure	Potential causes of the failure	Zn	Cz	Wy	WPR	Results of acting				
							Measures to improve	Zn	Cz	Wy	WPR
damaged drive motor	stopping operation of the scraper conveyor	winding burning	10	2	8	240	do not overload the conveyor, control the engine operation	10	1	6	60

The FMEA method can be a complementary analysis in determining the causes of damage in the mining machines, which can be performed by each employee after earlier reading of the algorithm of the proceedings. All data from the FMEA method are archived in the event of a recurrence of the problem, they can be used and verification can be conducted.

19.3 MEASURES OF RELIABILITY OF THE SCRAPER CONVEYOR COMPONENTS

First, the Mean Time Between Failure – MTBF was calculated, both of the entire conveyor and the mechanical and electrical systems. According to the definition of the serial system, the system is suitable for operation if all of its components are operable. According this assumption, reliability indicators of the scraper conveyor both as a system and its various mechanical and electrical systems were calculated in this study.

Mean Time To Failure (MTBF) for the scraper conveyor as a serial system was calculated using the following formula [3]:

$$MTBF_s = \left(\sum_{i=1}^{n} \frac{1}{MTBF_i}\right)^{-1} \quad (19.6)$$

where:

$MTBF_s$ – average time between the damages to the conveyor as a serial system.

$MTBF_i$ – subsequent average times between the damages to the conveyor.

In the scraper conveyor the mean time between the damages amounted to 20535 minutes. Using the same formula (6) $MTBF_m$ (for the mechanical system) and $MTBF_e$ (for electrical system) were calculated. The values are shown in Table 19.5.

Table 19.5 MTBF for mechanical and electrical systems of the scraper conveyor

Type of the scraper conveyor system	MTBF
Mechanical system	41026 minutes
Electrical system	41113 minutes

MTBF (Table 19.5) for the respective systems are comparable. The mean time between the damages in case of the mechanical system components was smaller than in case of the electric system components. Greater differences can be seen, when comparing the mean time between damages of the scraper conveyor and two of its most failing electrical and mechanical systems Mean time between the failures of the scraper conveyor operating as a serial system amounted to 20535 minutes and for each system it was twice as much (Table 19.5). It appears advisable to analyze the average time of individual systems and their components.

Also time of suitability – MTTF as well as downtime for internal reasons – MTTR were calculated. The data is presented in Table 19.6, Figure 19.4.

In the case of the analyzed technical facility its durability is an important parameter. The durability is defined as its useful life and the ability of the technical facility to fulfill a particular function until the first damage [9].

Table 19.6 Measures of the reliability of the scraper conveyor and components of its mechanical and electrical systems

Measure	Scraper conveyor	Mechanical system components of the scraper conveyor	Electrical system components of the scraper conveyor
MTTR	57 minutes	35 minutes	79 minutes
MTTF	20478 minutes	40991 minutes	41034 minutes

In the present case, the durability (calculated according to the formula shown below) amounted to 40.992 minutes.

$$T_s = \min(T_m, T_e) \tag{19.7}$$

Also the factor of readiness of both the scraper conveyor and its individual mechanical and electrical systems was calculated. The readiness indicator parameter is required to determine the performance of the system of the scraper conveyor, in this case. Also readiness of the analyzed mechanical and electrical systems was determined.

The system readiness (G_s) was described by formula [3]:

$$G_s = \frac{MTBF_s}{MTTR_s + MTB\ _s} \tag{19.8}$$

For the tested scraper conveyor amounted to 0.997.

Also the readiness of the mechanical system components (G_m) was calculated using the following formula:

$$G_m = \frac{MTBF_m}{MTTR_m + MTB\ _m} \tag{19.9}$$

Readiness for mechanical system components of the scraper conveyor amounted to 0.999.

To calculate the electrical system readiness (G_e) the following formula was used:

$$G_e = \frac{MTBF_e}{MTTR_e + MTBF_e} \tag{19.10}$$

Readiness for electrical system components of the scraper conveyor amounted to 0.998.

The above readiness index is the lowest in the case of the analyzed system or the entire scraper conveyor, it is associated with the number of components that can fail in the system.

The highest rate of readiness is available in the case of the electric system components. In this system the least failing components were determined.

The parameter that was used to present the scraper conveyor reliability function as a system and its mechanical and the electrical systems was the number of components (Figure 19.5).

The reliability function was calculated using the following formulas:

- reliability function for the scraper conveyor system [9].

$$R(T) = \exp(-\lambda t) \tag{19.11}$$

$$\lambda = \frac{1}{MTBF} \tag{19.12}$$

$$R(t_s(-\frac{t}{MTBF_s}) \tag{19.13}$$

- reliability function for the mechanical system components:

$$R(t_m) = \exp(-\frac{t}{MTBF_m}) \quad (19.14)$$

- reliability function for the electrical system components:

$$R(t_e) = \exp(-\frac{t}{MTBF_e}) \quad (19.15)$$

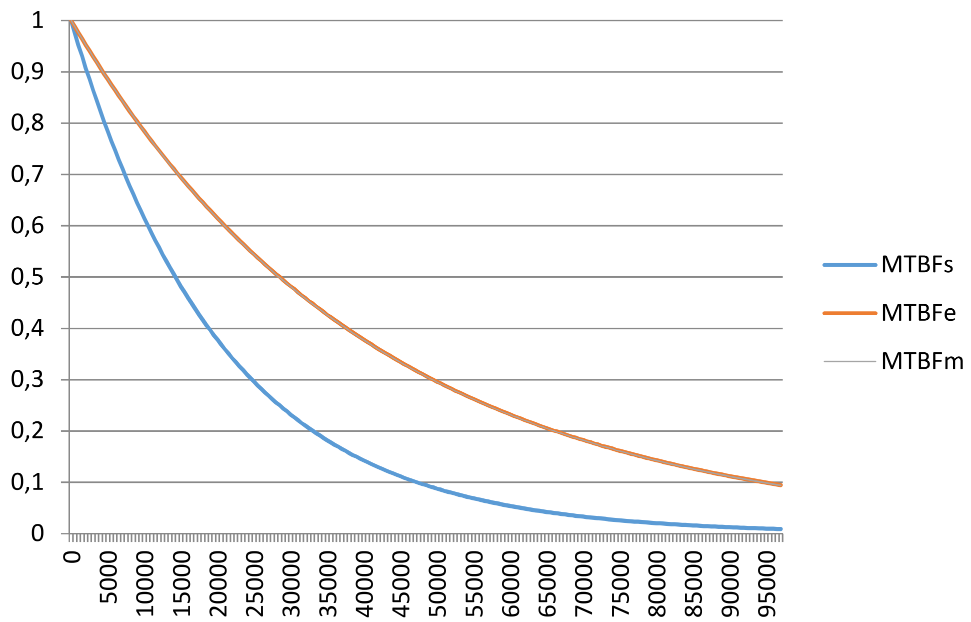

Fig. 19.5 Function of the reliability of the scraper conveyor and components of its mechanical and electrical systems

19.4 CONCLUSIONS

The analysis aimed to demonstrate the possibility of linking components of reliability and quality engineering to assess the reliability of technical facilities in a coal mining.

The results obtained allowed for the following conclusions:

– Using the Pareto-Lorenz diagram and FMEA method it was determined which parts of the scraper conveyor most commonly are subject to failures, and what is their percentage in the failures, and the causes and consequences of failures of those components were determined.
– Using elements of the reliability theory it was estimated that the scraper conveyor components are mostly subjected to failures and the duration of those failures was determined.
– The combination of quality engineering and reliability measures will allow for better monitoring and control of individual critical components of the mining machinery and equipment.
– Based on this analysis, a procedure relating to proper maintenance and repair individual more failing components of the mining machinery may be created.

– Using the presented studies a database can be created that would contain information about the number and causes of damages to the mining machines and equipment.

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Abstract: In the article elements of quality engineering have been presented, such as: Pareto chart and FMEA method for evaluating the scraper conveyor's failure frequency. A percentage share of particular failures in the scraper conveyor has been estimated by means of the Pareto chart. FMEA was used to identify the causes of failures and their effects. Quality engineering elements can be widely applied in an initial analysis of technical facilities' failure frequency in various industry branches.

Key words: quality engineering, diagram Pareto, FMEA, scraper conveyor, failure

WYBRANE ASPEKTY INŻYNIERII JAKOŚCI W ZARZĄDZANIU EKSPLOATACJĄ MASZYN I URZĄDZEŃ GÓRNICZYCH – STUDIUM PRZYPADKU

Streszczenie: W artykule przedstawiono zastosowanie elementów inżynierii jakości takich jak: diagram Pareto-Lorenza oraz metoda FMEA do oceny awaryjności przenośnika zgrzebłowego. Za pomocą diagramu Pareto-Lorenza oszacowano procentowy udział poszczególnych awarii w przenośniku zgrzebłowym. Metoda FMEA posłużyła do wskazania przyczyn wystąpienia awarii oraz określenia ich skutków. Wykorzystane elementów inżynierii jakości do wstępnej analizy awaryjności obiektów technicznych może znaleźć szerokie zastosowanie w różnych gałęziach przemysłu.

Słowa kluczowe: inżynieria jakości, diagram Pareto, metoda FMEA, przenośnik zgrzebłowy, awaryjność

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