Bożena SKOTNICKA-ZASADZIEŃ
Witold BIAŁY

AN ANALYSIS OF POSSIBILITIES TO USE A PARETO CHART FOR EVALUATING MINING MACHINES' FAILURE FREQUENCY

ANALIZA MOŻLIWOŚCI WYKORZYSTANIA NARZĘDZIA PARETO-LORENZA DO OCENY AWARYJNOŚCI URZĄDZEŃ GÓRNICZYCH*

The article presents a general classification of quality management tools applied in different industry branches. From among these tools the authors have chosen a pareto chart to present an analysis of mining machines participating in the mining process. The analysis covers mining machines such as: a roadheader, chain conveyor, belt conveyer, crusher and a support.

***Keywords**: quality management, Pareto chart, failure frequency.*

W artykule przedstawiono ogólną klasyfikację narzędzi zarządzania jakością stosowanych w różnych gałęziach przemysłu. Spośród tych narzędzi został wybrany diagram Pareto-Lorenza, za pomocą którego przestawiono analizę awaryjności urządzeń górniczych biorących udział w procesie wydobywczym kopalni. Analizie poddano kombajn, przenośnik zgrzebłowy, przenośnik taśmowy, kruszarkę oraz obudowę.

***Słowa kluczowe**: zarządzanie jakością, diagram Pareto-Lorenza, awaryjność urządzeń.*

1. Introduction

Most hard coal mines have an Integrated Quality Management System and only sometimes management tools imposed by the documentation are applied as part of the system evaluation in order to assess the improvement of quality in an enterprise. The changing economic situation in the state, competition as well as ever-growing requirements of coal-mine recipients (clients) make the managers search for new ways of improving the production (mining) process [10]. In the process of hard coal mining it is very important to monitor mining machines as well as to analyse the failure frequency of machines and equipment taking part in this process.

2. Characteristics of quality management tools

Quality management tools are used to collect and process data related to various quality aspects. Most frequently they are used to supervise (monitor) the whole production cycle, starting with a design, through manufacturing and finishing with the completed production process. Quality management tools fall into two categories: traditional (old) and new ones. tables 1 and 2 present the range of use for traditional and new quality management tools.

Table 1 presents traditional quality management tools and their range of use, while table 2 shows new quality management tools and their range of use.

In this article one of traditional quality management tools – a Pareto chart has been used to evaluate mining equipment failure frequency. A Pareto chart is a tool which enables factors influencing a particular phenomenon to be organised. By means of this graphic picture it is possible to present both relative and absolute distribution of the types of errors, problems and their causes (fig. 1) [5].

The field under the Pareto chart has been divided into three areas:

- Area A – in case of 20% of populations containing 80% of cumulatve feature values.
- Area B – in case of another 30% of populations containing another 10% of cumulative feature values
- Area C – in case of the remaining 50% of populations which contain 10% of cumulative feature values.

In practice a Pareto chart is used to group particular problems and their causes in order to solve crucial problems in a given enterprise [11].

3. Problem analysis

In the mining industry a Pareto chart is used to monitor and control mining machines (a cutter-loader, chain conveyor, belt conveyor, crushers as well as power supply and control equipment) which are an important element of the mining process. It is important to evaluate these machines' failure frequency and reliability as well as to find which of the discovered causes responsible for the high failure rate may be eliminated in the first place [4,16].

The construction of a Pareto chart for mining equipment control and monitoring is divided into the following stages:

- Information collection (collecting data on mining equipment failure frequency at particular stages of the mining process),
- Putting the collected data in order (assigning particular failures to particular mining equipment, such as a cutter-loader, chain conveyor, belt conveyor, crusher, mechanised support),
- Calculation of cumulative percentage values (establishing the cumulative percentage values for particular failures),
- Preparating a Pareto chart,
- Interpretation of the Pareto chart.

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

Tab. 1. Range of use for old quality management tools

Tool	Range of use
Cause-and-effect diagram of Ishikawa (fish bone diagram)	• To solve quality-related problems which involve an extended chain of causes • It is a method of recording ideas • Discovers unrevealed connections between causes • Helps to find the source of a problem
Check sheets	• Used when collecting date on the frequency of problems and defects during a production process and other processes • Used in data collection process • Used when standardising a list of activities
Histogram	• Pictorial presentation of processes and economic phenomena versus time • Visual presentation of information on the course of procesess • Shows the changeability of phenomena and states
Pareto chart	• Eliminating the most frequent phenomena • Eliminating the biggest cost sources • Analysis of a problem importance and frequency
Correlation diagrams	• Enables a graphic presentation of relationships between variables • For identifying potential sources of incosistence • Used to find whether the two effects may result from the same cause
Check cards	• To evaluate process stability over long periods of time • To assess whether the process is under control at a particular period of time • To identify areas of possible improvement • To prevent manufacture of defective products • To ensure systematic control over the process
Block diagram	• To illustrate the sequence of activities in a process • To find relations between activities • To easily specify the effects of undertaken activities • Provides a possibility of facilitating the analysis of the process course and eliminating unnecessary activities

Source: a study based on [9].

Tab. 2. Range of use for new quality management tools

Tool	Range of use
Relationship diagram	• Solving problems connected with determining the cause and effect dependence. • Showing the co-dependence between causes leading to a particular effect. • Attempts to find dependences between causes outlined in a relation diagram.
Relation diagram	• Issues subjected to analysis are too thorough or to chaotic to be defined in a simple way. • It is necessary to support a particular solution, concept, design. • The aim is to explain and justify a stance. • A useful tool after a brainstorming session is sought.
Systematic diagram	• We want to solve a specific problem (then it resembles the diagram of Ishikawa). • We present subsequent stages of activities in the process subjected to analysis.
Matrix diagram	• Helps to understand the relationships between particular groups in the diagram. • Is used to communicate these relationships.
Matrix data analysis	• Searching for market niches. • Marketing analyses. • Shows important dependencies with regard to selected features of a product.
Process Decision Programme Chart (PDPC)	• To evaluate any situations which may occur after implementing a new plan of activities which involves a risk of failure. • When implementing complicated plans of action. • When implementing plans with deadlines.
Arrow diagram	• Comprehensive planning of a project or process, taking the tasks and resources into consideration. • Project implementation time analysis. • Project implementation monitoring. • Re-planning the course of a project while taking the changes into account.

Source: a study based on [9].

3.1. Characteristics of mining equipment failure frequency

Breakdowns in hard coal mines may be divided according to their causes as follows:

- mining causes, where the main causes include: rock mass shocks, roof collapse (odpad stropu), water pumping, lump crushing, exceeding the level of CH_4 etc. In general these causes are not man-made.
- technical causes occur when the equipment and machines used in the mining process are damaged. Such equipment includes: heading machines, conveyors, mechanised supports and crushers;
- organisational causes which are independent from the mining conditions and conditions of machine operation. Such failures include: lack of water supply or lack of power supply.

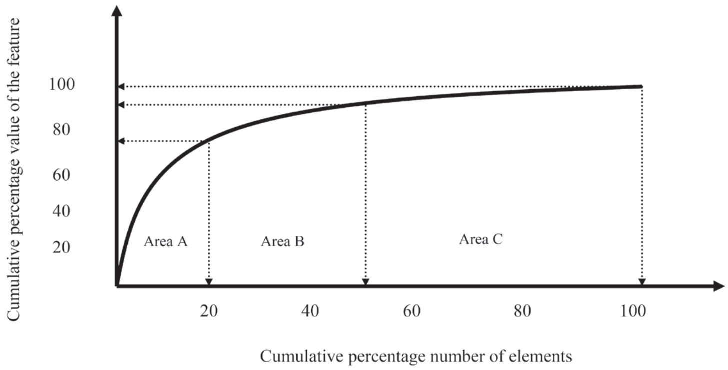

Fig. 1. Pareto chart

According to the type of failure, we distinguish the following:

- mechanical,
- electrical,
- hydraulic causes.

In order to obtain a more detailed analysis, mining equipment failures may be further divided according to the area of their occurrence, e.g..: arms and cutting heads, traction systems, hydraulic systems, electrical system or the body [3].

In Polish coal mining industry, coal beds are mined using the longwall method by means of winning equipment which works on a machine cutting basis [1,7,8]. For this reason, one of major areas of a coal-mine activity is the use of equipment (machines) [6]. Among others this should involve control over rational and effective use of equipment in the mining process [14].

Technical systems used in a hard coal mine are characterised by:

- considerable scattering,
- complexity,
- working area limitation by the size of underground excavations.

The main task for maintenance teams is to ensure continuous work of machines and equipment (at a given moment). As a result of such actions, the costs of machines and equipment maintenance, and thus production costs, i.e. the costs of a mining plant functioning are reduced. If this process is disturbed, huge losses are generated [13].

The main element in the mining process is the sequence of getting, which consists of the following stages [2,3]:

- the process of getting,
- horizontal transport,
- vertical transport.

When following the sequence of getting we may find that it is a series system. A failure of one of the above listed links results in "switching off" the remaining elements of this sequence.

As the sequence of getting in the process of coal mining (the mining of useful minerals) is a basic element influencing the size of output, and in consequence the costs related to this process, the failure frequency of this basic element has been subjected to analysis [2,3]. The failure frequency of all the faces working in one of the hard coal mines belonging to Kompania Węglowa S.A. in 2009 has been analysed. More than 400 types of failures have been found. Table 3 presents examples of mining machine failures.

3.2. Practical use of a Pareto chart for evaluating mining equipment failure frequency

Mining equipment failure frequency has benn analysed using one of the traditional quality management tools – a Pareto chart.

A Pareto chart has been constructed according to the following stages:

1. Data on the type of failures of the following mining equipment has been collected: cutter-loaders, chain conveyors, belt conveyors, curshers and mechanised supports,
2. Particular failures have been assigned to particular mining machines,
3. Cumulative percentage values have been calculated (cumulative percentage values for particular failures) by means of the following formulas:

$$PIE_j = \frac{100}{IE} \quad (1)$$

$$SPIE_j = PIE_j + PIE_{j-1} \quad (2)$$

$$\frac{100 \cdot IA_j}{\sum_{i=1}^{IE} IA_j} \quad (3)$$

$$SPIA_j = PIA_j + PIA_{j-1} \quad (4)$$

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

Table 4 presents data on the type of mining equipment, a cumulative percantage number of particular machines, a number of failures in a particular machine, a percentage number of failures and a cumulative percentage number of failures.

Figure 2 presents a Pareto chart for the failure frequency of the sequence of getting in one of the mines belonging to Kompania Węglowa S.A.

Tab. 3. Examples of the types of failures and their causes

Type of failure	Machine	Examples of damage
Mechanical failures	Cutter-loader	Damaged cutter-loader cable
		Damaged cable layer
		Protection system exchange
		Damaged cooler of the cutter-loader lower arm
		Damaged water cable
Electrical failures	Cutter-loader	No control
		Electrical damage of the cutter-loader cable
		Burnt fuse of the hydraulic pump
Hydraulic failures	Cutter-loader	Damaged cutter-loader water hose
		Damaged sealing of the cutter-loader upper head
		Water hose exchange
Organisational failures	Cutter-loader	No water for the cutter-loader
		No power supply on the face
		No pressure on the face
Mechanical failures	Chain conveyor	No control
		Damaged coupling insert
		Seized bearing of the right gear
Electrical failures	Chain conveyor	Damaged set of chokes on the upper drive contactor
		Damaged control panel
		No control – damaged fuse
Organisational failures	Chain conveyor	No water
		No power supply
Mechanical failures	Belt conveyor	Damaged coupling
		Gear exchange
Electrical failures	Belt conveyor	No control
		Fuse exchange
		No brake control
Organisational failures	Belt conveyor	No power supply on transport equipemnt
		No power supply
Mechanical failures	Crushers	Flux exchange
		Broken ram
Electrical failures	Crushers	No control
		No power supply
Mechanical failures	Support	Exchange of hose in pressure conduit
		Damaged hose
Electrical failures	Support	No pump control
Organisational failures	Support	Pipeline sealing

Tab. 4. Mining equipment failure frequency

Number of equipment	Type of equip-ment	Cumulative percentage number of elements	Number of failures	Percentage number of failures	Cumulative percentage number of failures
j		SPIE	IA	PIA	SPIA
1	Cutter-loader	20	193	43	43
2	Chain conveyor	40	110	24	67
3	Belt conveyor	60	94	21	88
4	Crusher	80	28	6	94
5	Support	100	27	6	100

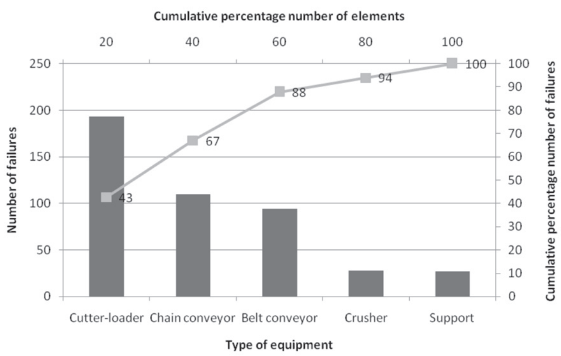

Fig. 2. Pareto chart

4. Summary

The Pareto chart indicates that the highest number of failures (88%) are caused by three mining machines:
- cutter-loaders,
- chain conveyors,
- belt conveyors.

The remaining machines, such as crushers and mechanised supports cause only 12% of failures.

Taking into consideration the percentage share of the three important mining machines (cutter-loaders, chain conveyors and belt conveyors) it may be concluded that the total of 60% of machines cause as much as 88% of failures.

Longwall equipment failures affect the effectiveness and concentration of output and in consequence, translate into the financial result of a mine.

Preliminary analyses (table 3) and studies [2, 3] indicate that most failures found in the above mentioned three types of machines are mechanical ones. This leads to the conclusion that the above mentioned three types of mining machines should be subjected to thorough analysis. Such analysis should specify the main causes of failures, methods and preventive measures which should be taken in order to drastically reduce the failure frequency of these elements of mining equipment. Persons monitoring and controlling the work of cutter-loaders, chain conveyors, belt conveyors should take special care of these machines' technical condition and try to prevent any failures.

In their further studies, the authors will present the causes and effects of these machines' failures which have the biggest impact on the mining sequence delays, i.e. winning machines (cutter-loaders) and transport equipment (chain and belt conveyors).

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Dr inż. Bożena SKOTNICKA-ZASADZIEŃ
Dr hab. inż. Witold BIAŁY, prof. nzw. w Pol. Śl.
Institute of the Production Engineering
Silesian University of Technology
Ul. Roosevelta nr 26, 41-800 Zabrze, Polska
e-mail: bozena.skotnicka@polsl.pl; wbialy@polsl.pl