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Availability analysis of selected mining machinery

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Underground extraction of coal is characterized by high variability of mining and geological conditions in which it is conducted. Despite ever more effective methods and tools, used to identify the factors influencing this process, mining machinery, used in mining underground, work in difficult and not always foreseeable conditions, which means that these machines should be very universal and reliable. Additionally, a big competition, occurring on the coal market, causes that it is necessary to take action in order to reduce the cost of its production, e.g. by increasing the efficiency of utilization machines. To meet this objective it should be pro-ceed with analysis presented in this paper. The analysis concerns to availability of utilization selected mining machinery, conducted using the model of OEE, which is a tool for quantitative estimate strategy TPM. In this article we considered the machines being part of the mechanized longwall complex and the basis of analysis was the data recording by the industrial automation system. Using this data set we evaluated the availability of studied machines and the structure of registered breaks in their work. The results should be an important source of information for maintenance staff and management of mining plants, needed to improve the economic efficiency of underground mining.

Key words: OEE model, TPM strategy, effectiveness, mining machines.

1. Introduction

The process of the underground exploitation of the coal is very complicated and it is characterized by a huge changeability of mining and geological conditions in which it takes place. The globalization and the growing competition in the energy resources industry forces national mining companies, which want to remain on the market, to take actions one of which goal is higher level of resources use. In particular, it regards to all type of machines and devices.

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Concentration of extraction, realized by reducing the number of longwalls and, at the same time, increasing their performance, makes that the mine's activity is based mostly on one or two working longwalls. Therefore, it is obvious that the effectiveness of the entire mining company depends on efficiency and proper work organization in these longwalls. One of the factors having a significant impact on the effectiveness is optimal capacity utilization of machines, which directly translates into improvement of work efficiency and productivity in these companies. Taking any actions, it is necessary to take into account the specifics of mining companies, which belong to the group of the open plant and differ significantly from stationary enterprises in other industries. In the underground mining exploitation, there is a high risk which is the result of various types of natural hazards and specific work environment. During the exploitation, there are often disturbances of the production process and that generates losses and causes an increase in the cost of coal excavation. The causes of these disturbances are technological as well as technical and organizational factors [10]. Additional costs are generated not only by stopping the extraction process but these are also "lost profits", which are equal to the potential production volume at the time of the stoppage.

The process of coal production involves several stages of which the most important is the obtaining of useful mineral in the exploitation phase (Fig. 1). This exploitation is based on a mechanical cutting out the useful mineral from the rock mass and transporting it from the zone of direct exploitation. Currently, due to the fact that the exploitation process is mostly realized by the longwall system (long, easy for mechanization operational fronts), this zone is called the zone of the longwall face.

Shown in Figure 1 a simplified scheme of coal production process includes also horizontal transport of excavated material to the shaft zone, from which it is transported to the surface by devices using for vertical transport. Subsequently, the output goes to the processing plant and there after taking part with enrichment process the final product, in the form of the right coal with definite parameters, is obtained.

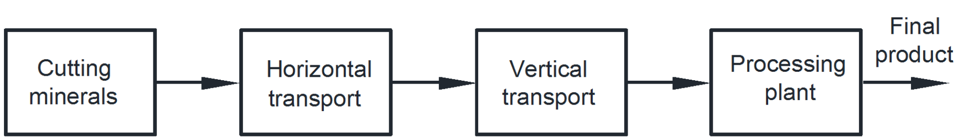

Figure 1: Simplified scheme of coal production process.

The coal cutting process is closely related to the life cycle of the excavation operation mining excavation (called the exploited longwall) and it is shown in Figure 2.

This cycle includes three phases, namely the exploited longwall preparation (so called the disarmament and start-up), the main exploitation and liquidation. All these phases are important for the effectiveness of exploitation process but the final economic result is mainly determined by the second phase, during which the main mineral exploitation is carried out. The proper run of this phase is strongly affected by any type of devices including mining machinery, which take part with the exploitation process and

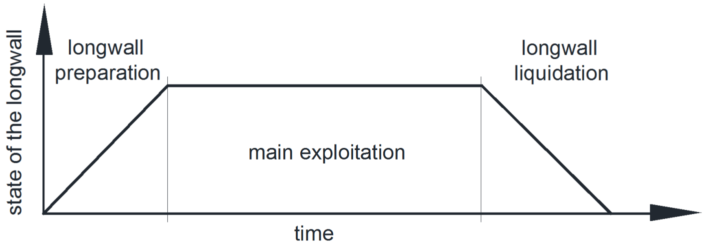

Figure 2: The life cycle of the exploited longwall.

minerals transport, and devices, which protect the whole operational zone (for example mining roof support). Their reliability, availability and performance largely determine the economic efficiency of the whole longwall exploitation. In order to achieve the best results, it is necessary to take actions aimed at optimum use of operated machines by for instance their proper selection to mining and geological conditions, in which they work, providing adequate preventive maintenance, control, etc. A tool that successfully stabilizes machinery's work and at the same time optimizes the cost of its operation is methodology, originating from Japan, for the comprehensive management of machinery and equipment effectiveness, called TPM (Total Productive Maintenance) [1, 2, 5, 7]. To take effective actions in this area it is necessary to conduct research and analysis that are aimed at determining the real utilization of machines on the basis of credible information. For this purpose research, which are described in this paper, has been conducted.

So far, research, which has been carried out in this area, was based only on failure analysis of mining equipment and it was leaned on notes made in the dispatcher's registers. The relatively low reliability of the data made it impossible to determine the actual use of mining equipment and identify the structure and reasons of downtime occurring during working.

In this paper, the data obtained from the industrial automation system was the basis of availability analysis of chosen mining machines. This system, independently from the machine's operators, registers number of machinery parameters in a discreet way. Based on obtained data, an effectiveness analysis of the use of a set of mining equipment belonging to the mechanized longwall system, which is used for direct coal cutting and transporting excavated material from the zone of a longwall face, was conducted. This system also includes mining roof support, which protects mining excavation, and a set of devices that are necessary to carried out the exploitation. Research involved the work of the longwall shearer, the armoured face conveyor, the beam stage loader and the crusher. Machines availabilities and structure of registered breaks in their work were determined on the basis of the obtained data. The study was conducted based on the Total Productive Maintenance strategy (TPM) using the assumptions of the Overall Equipment Effectiveness (OEE) model, which is a tool used for quantitative evaluation of this strategy [1, 3, 4, 6, 8, 9, 11].

2. The TPM strategy and the OEE model

One of the areas where there are opportunities to effectively reduce the cost of mining production is the effectiveness of the use of resources, especially, the mining machinery. Recent years, in Polish underground mining thanks to dynamic technical progress, better and better machines are designed, produced and operated and thus these machines are also more expensive. The increase in technical capabilities of these machines, which are, in many cases, highly modern and powerful, and whose level of reliability is very high, does not always make the benefits linked with their use [10, 12].

The strategy, which is successfully used by stationary production plants to analyze the effectiveness of the equipment use, is Total Productive Maintenance (TPM) [1, 2, 5, 7]. According to the strategy, improvement of the economic efficiency can be achieved through a set of actions and activities aimed at machinery, equipment and other technical measures (renewable resources) maintaining in a failure-free and faultless state, reducing the number of failures, unplanned downtime and lack. This strategy also refers to the human factor, assuming that the effectiveness increasing process of machines and devices has to include changes in the perception of particular technical and organizational activities by employees, to be efficient. Therefore, it is justified to take measures aimed at making employees aware that their knowledge, skills, engagement, responsibility and awareness of their role in the machine maintenance are necessary condition to succeed in this field. Identification of employees with the company, in which they work, is one the assumptions of the TPM strategy. Its application is aimed at reducing failures, unplanned downtime, including so-called micro-downtime, and increasing performance and improving production quality. [2, 5, 7].

In order to effectively make organizational and technical changes, which can result in the improvement of effectiveness of the use of the production resources, it is necessary to analyze the initial state. A tool that allows carrying out such analysis and, at the same time, quantifying the effectiveness of the TPM strategy is the Overall Equipment Effectiveness indicator. [4, 6, 8, 9, 11]. This indicator is the product of three components which include availability and performance of the studied machine and the quality of the obtained product. The values of the partial indicators and the OEE indicator are determined based on the following formula:

$$OEE = A \cdot P \cdot Q \tag{1}$$

where: A – availability, P – performance, Q – quality.

$$D = \frac{D_o - D_t}{D_o} \cdot 100\% \tag{2}$$

where: D_t – downtime, D_o – total time available.

$$W = \frac{W_r}{W_n} \cdot 100\% \tag{3}$$

where: W_r – the real performance during the work shift in tons of excavated material, W_n – the performance founded in the technological plan for the very longwall in tons.

$$J = \frac{J_a}{J_c} \cdot 100\% \tag{4}$$

where: J_a – the real quality of excavated material (that includes the amount of gangue content and sortiment of excavated material), J_c – the quality founded in the technological plan.

Therefore, it is justified to claim that the final indicator (OEE) shows the level of use of the basic time which is needed to achieve a full production.

To determine the value of this indicator for some machine or production system it is very important to identify the causes because of which time losses occur. The most important causes are following [6, 8, 11]:

- failures which are defined as unplanned and often impossible to predict stoppage of the machine for technical reasons, and they make a value of availability indicator decrease as in case of pipeline production process (Fig. 1).
- unplanned downtimes whose the most common causes are logistical problems. Losses resulting from this cause make the value of availability decrease but it is relatively easy to reduce them by, for example, appropriate organizational activities.
- minor failures and stoppages which are most often the result of technical problems and they are removed by operators. They are treated as speed losses and affect a reduction of the performance indicator.
- rearming understood as a change of machine's equipment. In general, it is assumed that rearming is preparing a machine for production process but when the normative time intended to carry out this operation is exceeded, the excess is treated as a loss that make the availability value decrease.
- setting which is treated similarly as rearming.
- loss of performance that are a result from the slowdown of a machine or a system. Errors resulting from improper control, preventive stoppages or exceeded operating parameters (for instance temperature or pressure) can be reasons.
- defective product that causes loss of time which has to be designed to produce a new good product. It reduces the OEE value in the area of quality.

According to the overall equipment effectiveness model for each of studied machines and the entire set of the machines it is necessary to determine the partial indicators in the area of availability, performance and product quality (carbon).

Presented example is focused on the first partial indicator of the OEE model which is the availability indictor of studied equipment. In the next stages of conducted studies it is necessary to expand this analysis because it should include other indicators as well in order to determine the Overall Equipment Effectiveness indicator for each of examined machines and for the whole set of mining machines.

3. Characteristics of the tested set of machines

The tested set of machines is a part of the mechanized longwall system which is used for underground coal exploitation in the longwall. The longwall system is based on cutting a useful mineral (in this case coal) in the zone of the longwall face whose length can vary from approx. 60 meters to approx. 300 meters. Such long longwall makes great opportunity to make cutting and transporting process mechanized and automated.

Figure 3 shows a scheme of a longwall excavation with the selected main parts [12]. Figure 4 shows its view during exploitation [3].

A set of mining machines, belonging to the mechanized longwall system, which is presented in this analysis concludes the longwall shearer, the armoured face conveyor, the beam stage loader and the crusher designed for crushing large parts of excavated material.

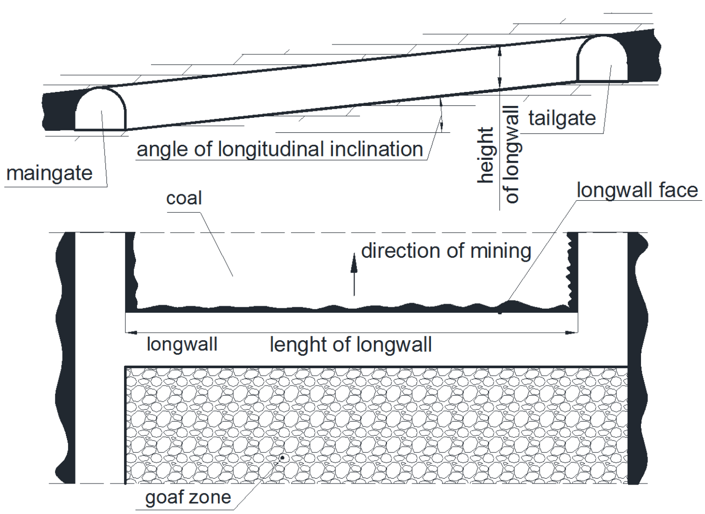

Figure 3: A scheme of a longwall excavation.

The basic machine that is a part of the mechanized longwall system is the longwall shearer. Its task is to cut the coal and load excavated material onto the armoured face conveyor. The shearer is very important for the whole analyzed set of machines because it is the first link in the technological exploitation process. The effectiveness of the analyzed set of machines, as well as of the entire operation process depends on the shearer's reliability. Coal cut by a longwall shearer is transported by an armoured face conveyor from the longwall to a bottom gate and then it is reloaded onto the beam stage loader and transported out of the zone of the longwall face. The analyzed set of machines includes also crusher whose task is to break large parts of coal to make it possible to transport it further. Inefficiency of a crusher can cause that the exploitation will have to be stopped due to the fact that the coal transport is then impossible.

Figure 4: A view of longwall excavation with equipment during exploitation [3].

Selection of such a set of machines used in this analysis is justified because the quantitative analyses of machines and devices failure that are conducted in mines indicate that most of failures are caused by a cutting machine and conveyors [1, 3, 10]. Therefore, it can be assumed that machines included in the longwall system together with a beam stage loader and a crusher have the greatest impact on the effectiveness of the entire exploitation process.

From the reliability point of view, the studied set of machines is a serial structure system and it means that it properly works when all its components are efficient (Fig. 5).

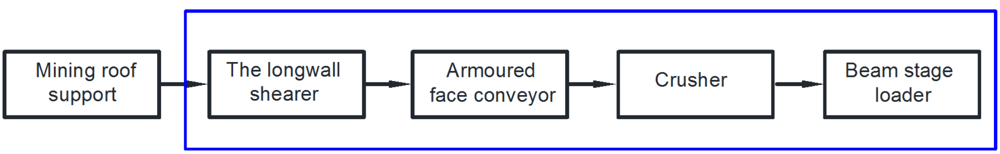

Figure 5: A scheme of reliability structure of the studied system.

Selected parameters of the tested machines are summarized in Table 1. It is important to noticed that some of these parameters are given in two versions: as nominal values and as values that can be achieved by the specific machine in the conditions which are characteristic for the particular longwall.

Table 1: Selected technical parameters of the studied machines

Machine	Parameter	Value of parameter	Value of parameter in longwall conditions
The longwall shearer	Maximum installed power: – cutting heads – feed – hydraulic	 2×375 kW 2×60 kW 2×13 kW	 2×375 kW 2×60 kW 2×13 kW
	Work speed	0–12 m/min	0–12 m/min
Armoured face conveyor	Engines power	3 × 400 kW	3 × 400 kW
	Conveyor's performance	1200 t/h	1200 t/h
Beam stage loader	Installed power	1 × 300 kW	1 × 300 kW
	Maximum performance	2000 t/h	1200 t/h
Crusher	Engines power	1 × 200 kW	1 × 200 kW
	Maximum performance	4000 t/h	1200 t/h

4. Determination of availability of the studied set of machines

The specificity of mining industry was taken into consideration during preparing the methodology for determining the OEE for mining machinery. Data collected by an industrial automation system were used to calculate availability of these machines. It was assumed that real work time is difference between total time available included in standard (normative time) and unplanned downtime. This is the time when machines did not work (current consumption of their motors was zero) and there were no problems related to the difficult mining conditions. Thus, the methodology for determining this OEE index included a thorough analysis of registered downtimes and their causes. The specificity of mining exploitation allows for occurrence of such cases that breaks at work of machines are caused by objective factors which are independent of these machines. Performance and quality indicators were also specified using different approach than in case of closed companies. The mass of disintegrated rock related to the value provided in standard was taken into account when calculating performance index. However, in the case of determining the quality index, amount of waste rock in production and sortiment of coal were included.

The whole methodology for determining OEE is therefore based on data not used for other production companies. Its originality results from its adaptation to the mining specificity.

The basis for determining the indicators of availability of each of the studied machine was data which was recorded in the zero-one system. Figure 6 shows an example of temporal waveform of longwall shearer's work in during work shift (lasting 360 minutes).

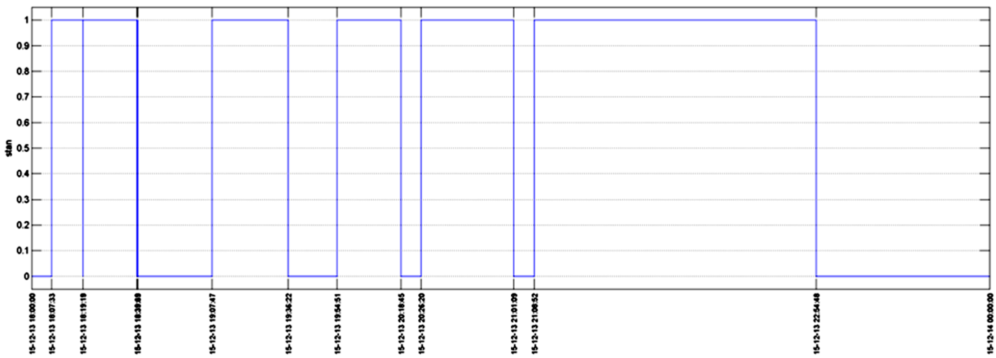

Figure 6: Temporal waveform of longwall shearer's work during one work shift.

Analyzed work shift's real (actual) time in case of the longwall shearer was 13590 seconds and downtime amounted to 8010 seconds. For this change availability rate was therefore 58.9

Figure 7 shows the calculated values of availability indicator of the studied longwall shearer for 64 work shifts and the average value of this indicator during analyzed period (work shift availability and average availability).

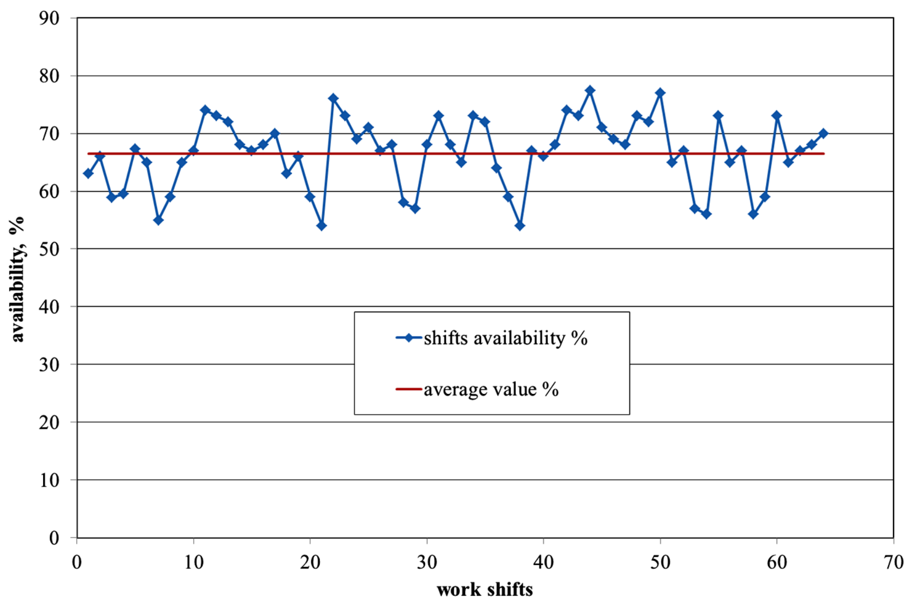

Figure 7: The values of availability indicator of the longwall shearer.

In the similar way, the values of availability indicator of the other studied machines, which are the parts of the longwall system, were determined. (Fig. 8).

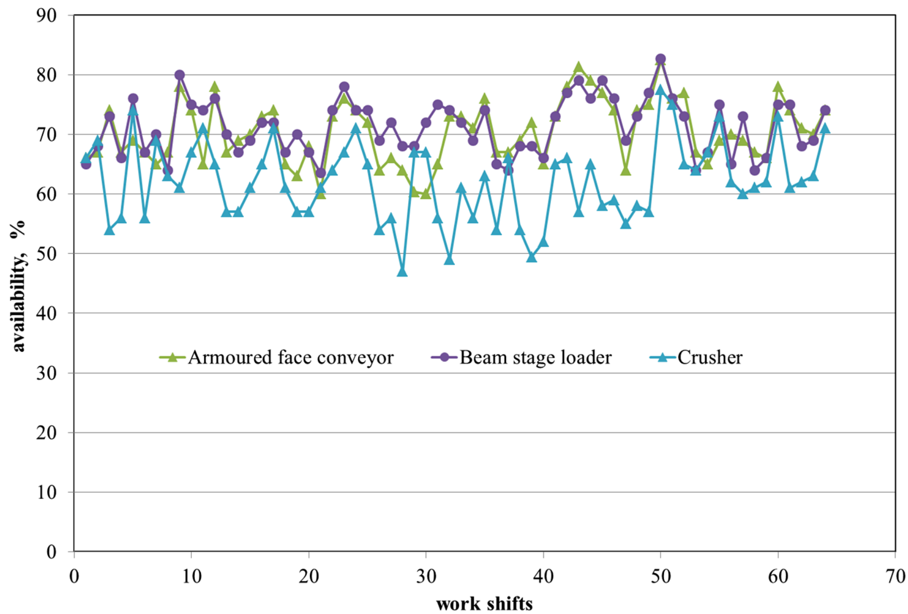

Figure 8: The values of availability indicator of particular machines of the examined set.

Table 2: Selected technical parameters of the studied machines

Machine	Average daily values of availability indicator, %	Maximum daily values of availability indicator, %	Maximum daily values of availability indicator, %
The longwall shearer	66,63 ± 5,97	77,36	54,21
Armoured face conveyor	70,36 ± 5,27	82,45	60,34
Beam stage loader	71,25 ± 4,61	82,65	63,53
Crusher	62,06 ± 6,65	77,43	49,45
The entire set of machines	67,55 ± 6,72	82,65	49,45

On the basis of calculations the average, maximum and minimum daily values of availability indicator of these machines and of the entire set of machines were determined (Table 2).

According to the analysis of the results, it can be claimed that the availability values of the machines are on the low level. Their average value did not exceed 75% for any of the tested machines. It is worth noticing that 75% is widely assumed to be the acceptable lower threshold.

Determined temporal waveforms of machines' work also enabled to determine the structure of the breaks during work. Figure 9 shows a summary of these breaks in case of the studied longwall shearer for all 64 work shifts. Percentage share of the particular breaks (divided into ten categories) was related to the total break time during all studied time.

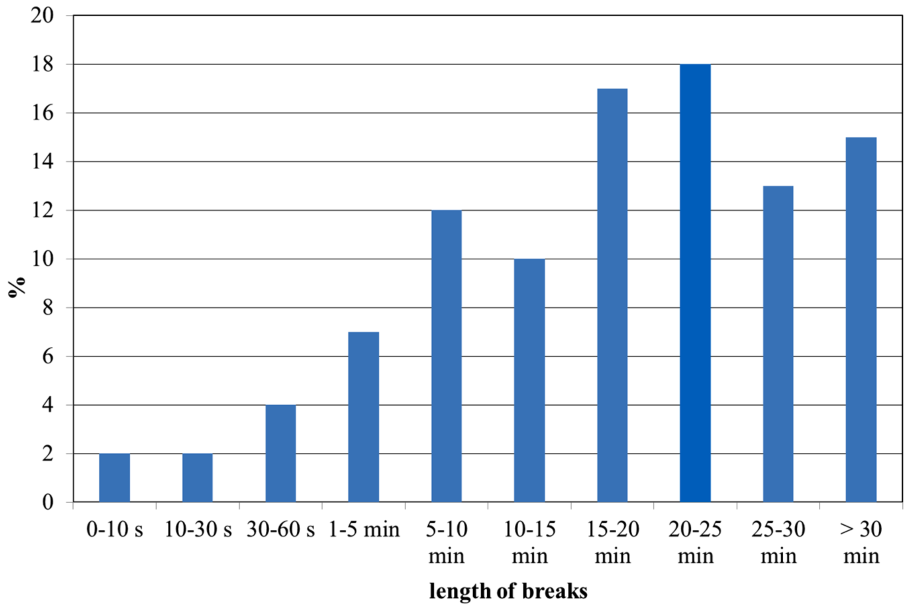

Figure 9: The structure of the breaks in longwall shearer's work.

It can be concluded, base on the results, that the breaks, the duration of which is in the range of 20 to 25 minutes (represent 18% of all time of the breaks), have the highest percentage share of the total breaks time during longwall shearer's work. The diagram clearly shows that the most important for work of this machine are the breaks whose duration is above 5 minutes and which represent approximately 85% of all registered breaks.

5. Conclusions

One of the areas, where there are opportunities to effectively reduce the cost in mining companies, is that one which includes a selection and a use of all types of technical equipment, in particular mining machinery. It is necessary to acquire adequate knowledge about the level of a technical resources use in these companies to make taken actions efficient.

Presented methodology for determining the indicator of effectiveness of the mining machines' use based on data obtained from a industrial automation system should be an important source of knowledge that is necessary to assess the state of machines' work. The conclusions coming from the analysis of the indicators and, in particular, from their variation referred to the taken actions should be the basis for decisions made by appropriate services in order to optimize the use of these machines.

In the present case, the data obtained from the industrial automation system was the primary source of information and based on it, availability indicators of the studied machines were determined. It guaranteed their credibility (and it eliminated the inaccuracy of the registration carried out by dispatchers) and it made the opportunity to register all types of downtime in real time. To identify the causes of the recorded breaks, especially unplanned ones, it is necessary to use the information gained from dispatchers of these machines, but in this area special actions (like trainings), which will raise awareness of the employees, should be taken. Implementation of both of these sources of information should guarantee to obtain reliable and credible information about the state of the studied machines which are essential for the services supervising their use.

The results of the study clearly indicate that there are a lot of reserves in the availability area of examined mining machines and the indicators values are unsatisfactory. In order to improve this situation, it is justified to continue a study and to more completely diagnose the causes resulting in such low values of these indicators.

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