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THE OEE MODEL AS A TOOL FOR EFFECTIVENESS ASSESSMENT OF THE USE OF EQUIPMENT

Summary. In order to increase economic effectiveness, manufacturing companies have to improve maintenance and develop a system of inspecting machine work. Data from these systems should be the basis to make full use of machines and devices and achieve effectiveness at a high level. One of the effective methods to increase the maintenance efficiency is the implementation of the Total Productive Maintenance strategy. The article presents a practical example of using of a fundamental tool used in the quantitative evaluation of the TPM strategy, OEE model, to analyze the use of mining machines.

Keywords: TPM, OEE, mining machines, maintenance.

MODEL OEE JAKO NARZĘDZIE DO OCENY EFEKTYWNOŚCI WYKORZYSTANIA SPRZĘTU

Streszczenie. W celu zwiększania efektywności ekonomicznej przedsiębiorstwa produkcyjne muszą usprawniać procesy utrzymania ruchu oraz rozwijać systemy nadzorujące pracę maszyn. Dane z systemów powinny stanowić podstawę do pełnego wykorzystania maszyn i urządzeń oraz uzyskiwania efektywności na wysokim poziomie. Jednym ze skutecznych sposobów na zwiększanie potencjału wykorzystania sprzętu jest wdrożenie strategii Total Productive Maintenance. W artykule przedstawiono praktyczny przykład wykorzystania podstawowego narzędzia do ilościowej oceny TPM, czyli modelu OEE, do analizy stopnia wykorzystania maszyn górniczych.

Słowa kluczowe: TPM, OEE, maszyny górnicze, utrzymanie ruchu.

1. Introduction

In recent years, underground mining has experienced serious problems mainly due to falling coal prices. This problem is related to the global drop in the prices of all energy resources. This trend means that many mining companies have big financial problems and moreover, the economic efficiency of coal production has significantly worsened. The companies are forced to take various measures to improve the situation. One of the areas, in which it is possible to improve the efficiency of the mining industry, is the exploitation of equipment used for the production and transporting of coal. Many of the mining specialists claim that modern, complicated and expensive mining machines are used improperly and that their high potential is used only partially. Unfortunately, only a few of those comments were supported by quantitative research results [2, 3, 4]. However, issues related to the effective use of the machine park are an important subject of research in other areas of the economy [7, 13, 14].

Relevant research was conducted to determine the actual status of use of mining machines in Polish coal mines. The aim of this research was to determine the overall effectiveness of set of machines which belong to the mechanized longwall system. Machines, which were analyzed, include: longwall shearer, armored face conveyor (scraper) and beam stage loader (belt conveyor).

The analysis was conducted using the Overall Equipment Effectiveness (OEE) model which is a quantitative tool for assessing the effectiveness of the TPM strategy. In this model, the overall efficiency of each of the studied machines was determined on the basis of partitive indicators: availability and performance. The product (carbon) quality indicator was determined for the entire set of machines. This approach is connected with the specific nature of mining exploitation, particularly for the analysis of machines included in the longwall system. The final product is the amount of excavated material transported away from the zone of the longwall face. The article also discusses the concepts of TPM and the base of OEE.

2. The Total Production Effectiveness conception

Total Productive Maintenance (TPM) is a concept of complex management of machine and device maintenance in a manufacturing company. According to the concept, the most important task is to take actions in order to prevent equipment failures in the whole exploitation process. TPM assumes the development of conservation service, attention to the technical condition of machines and equipment, and competent use of the machine park. These activities contribute to the longevity and efficiency of equipment [10].

The TPM concept is based on the assumption that the machine and device operators must be involved in maintenance because this could help to prevent downtime which is mostly caused by bad technical condition of the equipment. An important element is to carry out pre-planned services and machine inspections to check the technical condition and to apply appropriate preventive actions [12].

Moreover, TPM assumes that efforts should be made regarding the activation and involvement in the work of all employees at all levels of the company in order to make the best use of production resources. By reducing errors and accidents the processes improve and the availability of resources increases [15].

Total Productive Maintenance includes five basic aspects [8]:

1) maximizing equipment effectiveness and improving overall efficiency
2) introducing and developing the maintenance system which includes maintenance service and prevention that extend the life of equipment
3) the active involvement of employees in all departments of a company in order to increase the efficiency of the equipment
4) stimulating the level of involvement of every employee in the TPM actions
5) promotion and execution of preventive measures by autonomous small groups, activities which are usually formed by the operators involved in the operation of machinery during production works.

TPM helps to detect and eliminate losses associated with the operation of machines and devices. The strategy should be implemented consistently and include the entire process of maintenance. The consequences of the improvements, corrective actions and preventive actions are [9]:

- reduction of costs associated with different kind of failures
- reduction of costs associated with maintaining preventive measures which include periodic inspections and maintenance
- reduction of losses associated with producing the test parts used in determining and setting the work parameters
- reduction of losses caused by low efficiency of production equipment
- reduction of cycle times, as well as the time it takes to turn the equipment on and off.
- reducing the volume of stocks that are stored in case of occurrence of failure.

With regard to the name of Total Productive Maintenance, the word "total" should be considered in many aspects. S. Nakajima singled out three basic meanings which include [8]:

- *total effectiveness* relating to the action which implementation helps to improve particular technical and economic indicators
- *total maintenance system* relating to the whole maintenance system in which all tasks connected with the prevention must be made
- *total participation* meaning full involvement and engagement of employees who are responsible for machines and devices in the maintenance.

Maximizing the efficiency of the equipment is associated with the effective elimination of all types of failures, errors, defects and other negative events which cause losses of time, resources and increase costs. The concept has much in common with the philosophy called „zero defects" (ZD) invented by Philip Crosby. ZD is mostly used in quality management. TPM strategy also relates to the improvement of quality because the quality of the products depends on the quality of equipment. It can be claimed that when the use of machines and devices is more effective and efficient, the higher the productivity will be. Also as a consequence, the costs will be lower and the quality of the products will improve [8].

TPM assumes minimizing unintended negative events in order to achieve the ideal state which is based on the „three zeros". The concept of the „three zeros", which is presented in Figure 1, includes the following elements [5]:

- zero accidents
- zero failures
- zero downtime.

These zero values are more theoretical because in practice it is very difficult to achieve the ideal state. Nevertheless, they should be important points of reference in the process of progression and improvement. The planned exploitation activities as part of TPM should be mainly aimed at preventing the occurrence of unintended events [5].

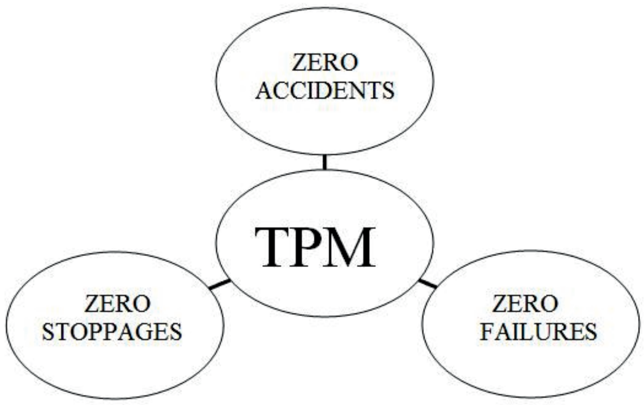

Fig. 1. The Total Productive Maintenance “three zeros” conception
Rys. 1. Koncepcja „trzech zer” w strategii Total Productive Maintenance
Source: Loska A.: Wybrane aspekty komputerowego wspomagania zarządzania eksploatacją i utrzymaniem ruchu systemów technicznych. Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją, Opole 2012.

3. Methods for assessing the effectiveness of TPM – an indicator of Overall Equipment Effectiveness

In addition to taking action as a part of TPM, a very important issue is the choice of the appropriate method that will be used to assess the effects of the implemented strategy. In the literature and in practice there is a variety of methods of measuring effectiveness. The Total Productive Maintenance mostly uses three indicators: Mean Time to Repair, Mean Time Between Failures and Overall Equipment Effectiveness. Mean Time to Repair (MTTR) is the average repair time which is calculated as the arithmetic mean of all durations of repairs - for example of some device or some machine. Mean Time Between Failures (MTBF) shows how long the machine works on average without failures. Overall Equipment Effectiveness (OEE) determines what percentage of realizable effectiveness is characterized by a machine, a device, group of machines or devices or production line. This paper presents and discusses the OEE indicator [6].

The Overall Equipment Effectiveness model analyzes three areas which include availability and performance of the machines or devices and product quality. The value of coefficient for each of the areas has been determined. OEE is the product of the three calculated components [1].

Availability is described as the ratio of the actual operating time (t_r) to the theoretical time at which the machine is able to work (t_t):

$$A = \frac{t_r}{t_t} \tag{1}$$

Usually, planned downtime is taken into account to determine the theoretical time. The value of availability is reduced by unplanned breaks and stoppages which include breakdowns, rearming, set up, adjusting and regulations [11]. Breakdowns can occur sporadically as well as cyclically. Most of the causes of breakdowns need to be identified and eliminated. Then the corrective actions and preventive measures must be made. Otherwise, there will be delays, unplanned interruption, and loss of time which will lead to additional costs [6].

Performance demonstrates the production rate. Is calculated by multiplying the number of produced units of a product (p) and the planned cycle time (t_c) and then dividing the result by the actual (operating) work time (t_r) of the machine [11]:

$$P = \frac{p * t_c}{t_r} \tag{2}$$

The value of performance is undermined by minor stoppages, which refer to situations not caused by breakdowns and in which the machine or device does not fulfill its function. These include lack of raw materials or blockades. Another factor contributing to the decrease in the value of performance is a decline in the rate of production, caused, for example, by blunting machines, employee fatigue or other factors [6].

Quality refers to the state of the products. It shows the ratio of acceptable products (p_a), which meet the quality requirements, to the total production units (p) in the analyzed period of time [11]:

$$Q = \frac{p_a}{p} \tag{3}$$

Quality losses result in time wasted on the production of defective products, their repair and material losses. In order to prevent them, it is necessary to carry out systematic quality control, and identify and eliminate the causes of defects [6]. Figure 2 shows the relations between total time, planned time, operating time, net operating time, fully productive time and main losses in the process of maintaining the machines.

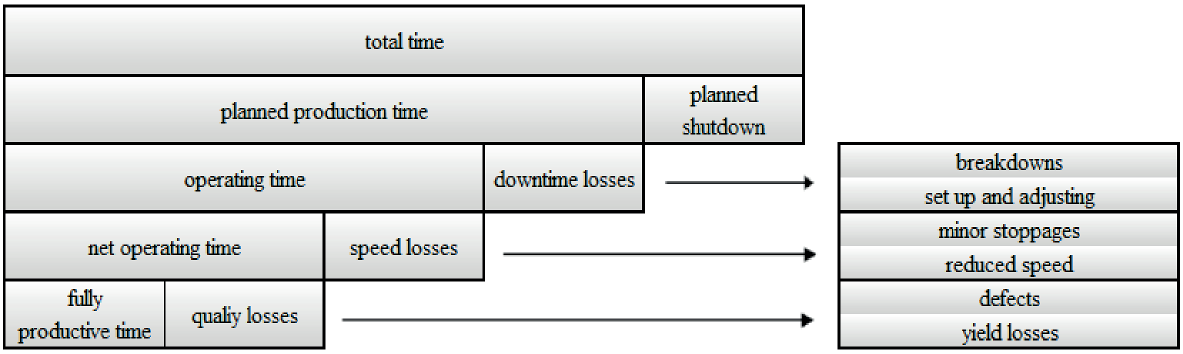

Fig. 2. The relations between time and the main losses in the process of maintaining the machines
Rys. 2. Stosunek między czasem a głównymi stratami w procesie konserwacji urządzeń
Source: Elevli S., Elevli B.: Performance measurement of mining equipments by utilizing OEE. Acta Montanistica Slovaca, Slovak Republic 2010.

Knowing the value of the three factors, it is possible to calculate the value of OEE indicator. It is determined by multiplying the value of the availability, performance and quality:

$$OEE = A * P * Q \tag{4}$$

The OEE value equal to 100% means no breakdown, downtime, interruptions, unplanned rearming and regulation machine work at a specified constant speed that produces one hundred percent compliance with the quality requirements. Companies should strive for the ideal state, but in practice this is not easy.

4. Example of using the OEE model for a set of mining machinery

Mining machinery used in underground coal mining work faces very difficult conditions. In particular, the shearer and scraper conveyors are directly involved in the mining and transporting of excavated material from the longwall. These machines with roof support and crushers are mechanized longwall systems (Fig. 3). The purpose of these complexes is to ensure the safe and efficient exploitation of coal. Due to the high cost of these machines and vital meaning in the technological line of exploitation of carbon, the companies seek to maximize the use of these machines. This applies to both the availability and performance as well as the quality of excavated coal.

In order to determine the effectiveness of a longwall system consisting of a longwall shearer, scraper conveyor and belt conveyor, analyses were conducted using the OEE indicator. Analyzed machines work in the longwall with a length of 160 meters in the deck 510 and on the depth of 665 meters. Parameters of the operated longwall are summarized in Table 1.

Fig. 3. View of the longwall system during the work
Rys. 3. System ścianowy w trakcie pracy
Source: www.mining-technology.com.

Table 1

Parameters of the operated longwall

No.	Deck 510, level 665 m	
1	Thickness of deck in area of the wall	Layer at ceiling 3,5 m
2	Height of the wall	To 3,0 m
3	The slope of the deck	Around 6º
4	Length of the wall	160 m
5	Run of the wall	On the ramp – 586,5 m On the ramp – 549,5 m
6	The longitudinal walls slope The transverse walls slope	Av. 1º Av. 6º
7	Type of the system	Transverse
8	Roof managing	Roof collapse

Source: Own study.

Compressive strength of excavated coal is in the range of 7.2 MPa to 14.4 MPa, tensile strength of 0.46 MPa to 0.92 MPa and the rate of brevity rocks ranges from 0.72 to 1.44. A way of obtaining data on the machine operation is essential for the credibility of the analysis. In this paper the industrial automation systems were used. This guaranteed the independence of the recorded data from the subjective feelings of employees (dispatcher). As the OEE methodology refers to the behavior of machines while they are working, hence narrowing the mining time, it included the time of the sum of shifts (also including any overtime). Time deducted in terms of the OEE was from classified breaks which are technologically (e.g. change of maintenance) or organizationally (e.g. assumed the lack of occupancy) justified, which was a planned unavailability of the system.

In the next step there was the identification of a break which generated compartments within the time devoted to the production. In rare cases, these are downtimes of a technical or organizational character, but mostly these are failures resulting in breakdown of the exclusion shearer or other machines of the system. For the analysis it was assumed that all cases of this type are treated as failures. Target verification of this state was carried out by comparing the states on different devices (0-1 indications). In the calculations, it was assumed that in the case where two identified breaks are adjacent to each other, they are treated as one.

In order to determine the availability of the studied machines, as basic data was used the registered values of current by their engines. As supplementary data, the velocity of the shearer movement and its position in the longwall were registered. Figures 4 and 5 show examples of the velocity of the shearer movement, its position in the longwall and the values of the currents consumed by molding heads.

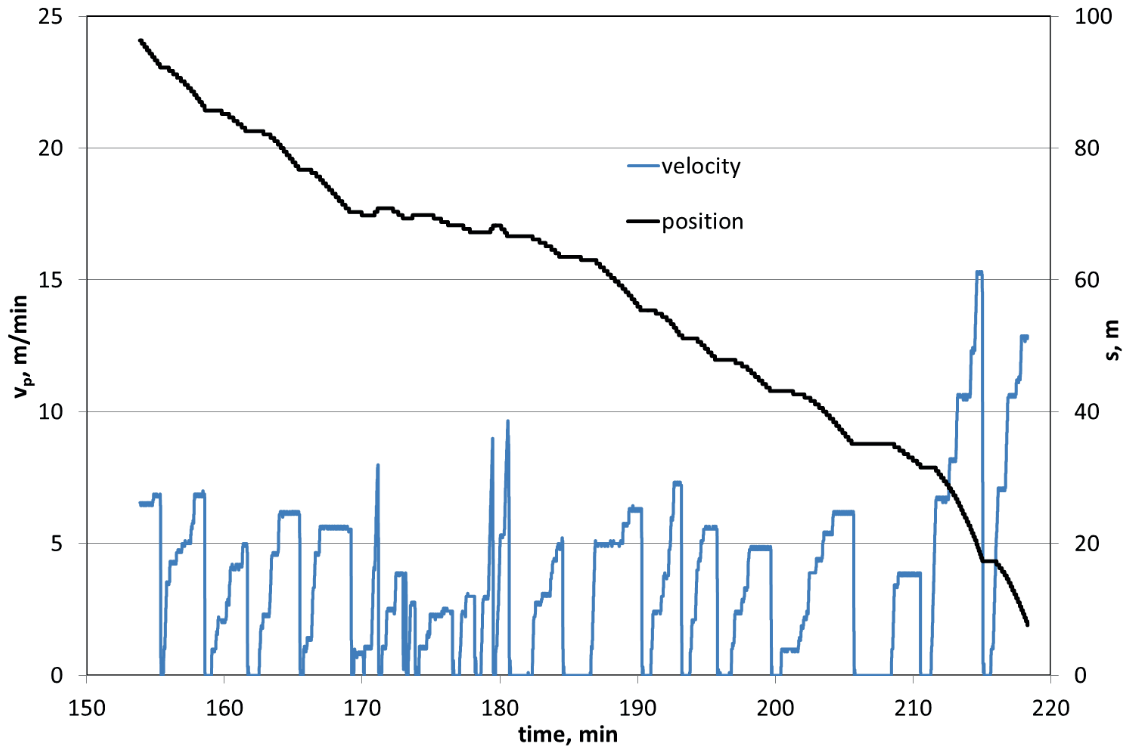

Fig. 4. Temporal waveforms of the velocity of the shearer movement and its position in the longwall
Rys. 4. Przebiegi czasowe prędkości ruchu kombajna i jego pozycja w ścianie
Source: Own study.

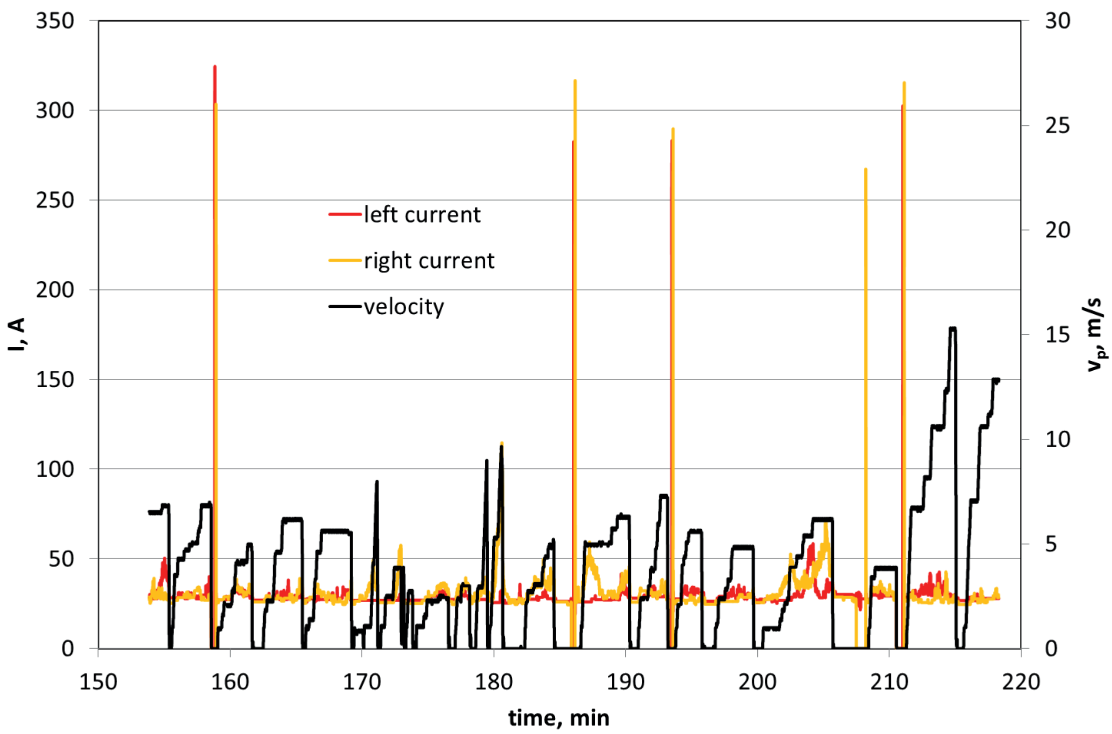

Fig. 5. Time courses of the velocity of the shearer movement and the currents of molding heads
Rys. 5. Przebiegi czasowe prędkości ruchu kombajna i pobór prądu głowic urabiających
Source: Own study.

Performance of individual machines was determined based on the estimated values of the amount of extraction in particular shifts, related to their nominal performance that was determined for the concrete longwall. Quality indicator was set on the basis of information obtained from the processing plant related to the assortment of excavated coal and gangue content in the ore. These data were determined as the mean values of the decade measuring period. Data designated this way became the basis for determining the average value of the partial OEE indicators and indicators of the set of machines for forty work shifts (Tab. 2).

Table 2

Average values of OEE and its components of studied machines for forty work shifts

	Availability	Performance	Quality	OEE
Longwall shearer	70,4 ±4,5%	89,8±6,0%	89,5±3,1%	56,5±5,1%
Armored face conveyor	68,3±3,7%	80,1±6,1%	89,5±3,1%	48,8±4,2%
Beam stage loader	72,9±3,8%	80,1±6,1%	89,5±3,1%	52,1±3,9%
The set of machines	70,5±6,7%	83,4±7,6%	89,5±3,1%	52,5±5,4%

Source: Own study.

5. Conclusions

The analysis of using the OEE model to evaluate the efficiency of use of mining equipment that is presented in the paper should be an important source of information for mine maintenance services to improve the use of these machines.

The determined values of the OEE indicator for each machine and for the entire set of machines clearly indicate that they are at a low level. Therefore, it seems necessary for the appropriate mine services to take actions in order to improve the value of these indicators. The designated values of these factors, especially in comparison with the values for machines working in other industries are unsatisfactory. Therefore, it can be assumed that in the mining industry, there are plenty of reserves to improve - mainly through the appropriate organization of work.

When interpreting the results, the specific nature of mining production should also be taken into account. It includes high variability and unpredictability, particularly in the emerging threats and the mining and geological disturbances. For this reason, as a practical measure, each of the studied longwalls should be considered individually, taking into account its specificity. It should also be noticed that using an industrial automation system for determining availability indicators of the machines allows very objective and accurate registration of all kinds of interruptions in their work. This information in subsequent stages should be analyzed to identify the causes of these breaks and necessary actions should be taken for their elimination and reduction.

The studies clearly show that tools and procedures, which allow an objective assessment of the level of the use of equipment, should be more widely used also in the mining industry. This should influence the overall improvement in the efficiency of the enterprises, which are forced to operate in an increasingly competitive domestic and global market.

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Omówienie

Artykuł dotyczy efektywności wykorzystania sprzętu, która stanowi bardzo ważne zagadnienie dla każdego przedsiębiorstwa produkcyjnego. W artykule przedstawiono podstawowe założenia strategii Total Productive Maintenance (TPM), której celem jest maksymalizacja dostępności oraz wykorzystania maszyn i urządzeń. Osiąga się ją przez zapobieganie powstawaniu i eliminowanie zdarzeń negatywnie wpływających na efektywność, do których należą: awarie, wypadki, przestoje, pomyłki oraz różnego rodzaju straty. Omówiony został także model ilościowej oceny strategii TPM, jakim jest wskaźnik Overall Equipment Effectiveness (OEE). Wskaźnik ten, będący iloczynem trzech wskaźników składowych: dostępności, wykorzystania i jakości, wyznacza się na podstawie danych uzyskanych w czasie procesu produkcyjnego. Praktyczne zastosowanie modelu OEE zostało przedstawione na przykładzie zespołu maszyn górniczych.