Article citation info:
ANTOSZ K, STADNICKA D. Evaluation measures of machine operation effectiveness in large enterprises: study results. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2015; 17 (1): 107–117.

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EVALUATION MEASURES OF MACHINE OPERATION EFFECTIVENESS IN LARGE ENTERPRISES: STUDY RESULTS

MIERNIKI OCENY EFEKTYWNOŚCI FUNKCJONOWANIA MASZYN W DUŻYCH PRZEDSIĘBIORSTWACH: WYNIKI BADAŃ*

Maintaining a proper productivity and efficiency level of a technical infrastructure of an enterprise requires, above all, the use of appropriate managing methods and tools as well as an appropriate organization of services responsible for their management. Using a variety of measures is indispensable to evaluate the effectiveness of these practices as well as of the machine performance in any enterprise. The data obtained from measuring particular indicators are a primary source of information on the necessity of taking particular actions. Large companies are particularly willing to implement appropriate indicators of effectiveness evaluation because of a large number of machines and a vast range of their technical maintenance. Different indicators presented in the references are said to be efficient and willingly used by enterprises. The aim of the study, of which the results are presented in this article, was to identify the real actions taken by the surveyed enterprises concerning the use of the machine effectiveness evaluation metrics. Apart from that, the study also intended to obtain the information on which indicators are actually applied by enterprises. The study was carried out in large production enterprises of different industries on a specified area.

Keywords*: technical infrastructure, machine effectiveness, evaluation indicators, maintenance.*

Utrzymanie infrastruktury technicznej przedsiębiorstwa na odpowiednim poziomie produktywności i wydajności wymaga przede wszystkim stosowania właściwych metod i narzędzi zarządzania oraz właściwej organizacji służb odpowiedzialnych za jego realizację. Nieodłącznym elementem oceny efektywności tych działań oraz funkcjonowania maszyn w przedsiębiorstwie jest stosowanie różnorodnych mierników. Dane uzyskiwane z pomiarów określonych wskaźników są podstawowym źródłem informacji o konieczności podejmowania działań określonego rodzaju. Szczególnie duże firmy są chętne, aby wdrożyć odpowiednie wskaźniki oceny efektywności maszyn ze względu na dużą liczbę maszyn i duży zakres prac związanych z ich obsługą techniczną. W literaturze przedmiotu prezentowane są różne wskaźniki wskazywane, jako skuteczne i chętnie stosowane przez przedsiębiorstwa. Celem badań, których wyniki przedstawiono w niniejszej pracy, było zidentyfikowanie rzeczywistych działań realizowanych przez badane przedsiębiorstwa w zakresie stosowania mierników oceny skuteczności maszyn oraz pozyskanie informacji o tym, jakie wskaźniki są przez firmy stosowane w praktyce. Badania przeprowadzono w dużych przedsiębiorstwach produkcyjnych funkcjonujących w różnych branżach przemysłu na określonym obszarze.

Słowa kluczowe*: infrastruktura techniczna, efektywność maszyn, wskaźniki oceny, utrzy-manie maszyn.*

Introduction

One of the main components of the properly organized process of the machine and equipment supervision in any enterprise is the choice and the use of a proper management strategy. The literature widely describes kinds of management strategies and the actions within them [5, 9, 10, 14, 17, 40]. The implementation of the particular methods of machine and equipment supervision in an enterprise requires, however, periodic evaluation of the action effectiveness as well as of the state of the owned technical infrastructure. The degree of reliability of the information obtained is a basic condition for receiving positive final reports, and it facilitates taking proper decisions concerning preventive actions. There are many ways of obtaining information on the operation of particular machines and technological equipment. However, establishing what will be measured is the most important.

Thus, the choice of the appropriate evaluation measures is crucial. These measuring metrics help to evaluate the key actions realized within machines maintenance and they indicate the efficiency of the actions taken in relation to the goals of an organization [6, 10].

The references define different measures of the machine supervision evaluation [22], among them e.g. OEE [8, 18] or MTTR [7, 11, 21]. The references have also been reviewed for the measures used for the machine effectiveness evaluation in an industrial sector [24, 33]. The correlation of the selected indicators with other evaluation methods was assessed as well [2, 24].

Moreover, the analysis of the references showed that there were also studies conducted concerning maintenance activities based on the MTTF values obtained [22]. The study, that was carried out, also regarded the evaluation of the OEE measure values obtained [2, 18], the possibilities of its improvement [31, 39] as well as its computer based (automated) calculation [30]. Different models of optimization of the machine maintenance were also presented [32].

According to the authors, the analysed references lack a comprehensive comparative analysis of the machine evaluation measures practically applied that would take into account e.g. enterprise's size, industry, capital type, or production type. Additionally, in the articles analyzed, it is difficult to find any information on the problems of the enterprises regarding the application of the machine evaluation measures.

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

This article indicates the basic measures of machine operation, and the ways of their calculating. Next, it was checked if these measures were being actually applied.

1. Measures of the machine operation effectiveness evaluation

Effectiveness is one of the characteristics determining the properties in a set of items or systems. It is commonly understood as a property of an item (or system) which conditions the achievement level of the goals of an item or a system in the specified conditions of use and in the specified time period [14].Exploitation effectiveness can be defined as the quotient of the results obtained in a given period of the duration of a certain state concerning the operation object to the expenditures incurred to achieve these effects. System effectiveness is conditioned by both pre-exploitation factors such as the required activities and initial inputs related to the required system features and the features of the system environment, as well as by exploitation factors identified in the exploitation process (external factors e.g. cooperating systems or exploitation properties of a system such as reliability, durability, reparability) [40]. However, in case of an item exploitation (a machine, an appliance) we can talk about technical effectiveness of an item defined as a relation between its unreliability and its potential task capability in a system. In its classical approach, in order to describe machine operation, the literature e.g. [12, 20, 26] distinguishes two reliability states, which are fault and up states. Nevertheless, in some other articles e.g. [13, 35], the authors introduce multi-state classifications what results from the complexity and multitasking of some machines.

The machine up state requires defining two basic notions: task operability and functional operability [5].

Task operability is the ability to accomplish the task t in a chosen period of time Δt or any other figure.

Functional operability is the ability to accomplish a task in a chosen moment of time t for each task out of the set of tasks which are possible to accomplish by a machine.

Modelling the two states of operability may take place at every stage of a machine operation in a production system or at every stage of the running technological machines system (of the technological machines park). These stages are: organizing the system, its use and liquidation or reorganisation with a particular maintenance strategy. To evaluate the system effectiveness different evaluation criteria may be used. In the articles [15, 16, 19, 23, 27, 29, 34, 36, 37, 42, 43] the authors propose the criteria of a system evaluation. Different indicators are used for each of the particular criterion. Table 1 presents the examples of indicators of the system according to the four criteria. The table shows their characteristics and sample types.

Most of these indicators can also be used at different levels in order to measure the quality of the production area, the selected line or used equipment or technological machines. PN-EN 15341: 2007 also classifies KPIs service by three main criteria: economic, organizational and technical. In addition, this standard defines the indicators according to the specified criteria on three levels. What is more, this standard [28] specifies the proper selection of indicators for assessing effectiveness. The selection of indicators for the assessment should take into account some relevant criteria such as: the efficiency of maintenance of machines and equipment reliability. When searching for the appropriate indicators, the standard recommends two approaches: – First, the selection of indicators from these available that meet the requirements of the analysis; Second, begin with a method that starts evaluating different machine maintenance processes chosen through the functional analysis. In practice, two approaches may be used. Among the indicators recommended by the standard there are MTBF (Mean Time Between Failure) and MTTR (Mean Time To Repair) indicators. MTBF (Mean Time Between Failure) shows from a static point of view how often the technical object is damaged. In enterprises this indicator is used to determine the preventive maintenance schedule. MTTR (Mean Time To Repair) defines the average time required to repair at the moment of failure. It is used to evaluate the effectiveness of staff maintenance services, as well as for the assessment the repair tasks they carried out [11]. The ways of calculating these indicators are as follows:

- MTBF (Mean Time Between Failures) – denotes the average time between failures or the failure rate. The indicator is understood as the average time of operation between failures in the specified time. It is calculated according to the formula (1).

Table 1. Criteria of the system evaluation. Source: own study based on [15, 16, 19, 23, 27, 29, 34, 36, 37, 42, 43]

No.	Criterion	Characteristics	Exemplary indicators
1.	Informational and operational	Related to the organisation and course of maintenance processes, as well as those concerning the achievement of goals or certain needs, and the impact of the control system on its operation.	Indicator of technological advancement Indicator of machine average age Indicator of repair service rate Indicator of repair requirements accomplishment Indicator of maintenance staff employment Indicator of timeliness of executing major, medium, current repairs and overhauls, Indicator of maintainability
2.	Economic	Related to plus (benefits) and minus (inputs) value effects as well as to profitableness of investment and finance activities in a system.	Indicator of profitability Fixed and variable costs of machines maintenance Indicator of the costs of major and medium repairs, and current maintenance Spare parts maintenance costs
3.	Technical and maintenance	Related to the system elements operability, particularly to technical means, and expressing the impact of technology on their operation; related to the operation of the elements and means for the system continuity, they also express the influence on the system capability to remain in an up state in the specified time.	Indicator of performance Indicator of machine idle time Indicator of machines damage and failures Indicator of technical availability Indicator of machine use Indicator of a shift system
4.	Safety	Related to the risk of losses (human – loss of life or damage to health, ecological, material), which commonly relate fault states of the system elements to the probability of loss caused by them; the extent of the potential losses.	A number of accidents at machine operation and use A number of hazards arisen during machine operation and use

$$MTBF = operating\ time / number\ of\ failures\ in\ this\ time \quad (1)$$

- MTTR (Mean Time To Repair) – the average time to complete of repair. It is understood as the average time of the actual repair from the point of its being reported until the point it is finished. It is calculated according to the formula (2).

$$MTTR = repair\ time / number\ of\ failures \quad (2)$$

Another indicator, which importance in the production process improvement has been emphasized in articles [1, 30, 31, 38], is OEE indicator. OEE describes the three basic areas of business activity: the availability, efficiency and quality of products. Calculating OEE enables to define the improvement actions implemented in the field of production processes, it allows to measure their effect on the implementation and the elimination of existing problems. It allows to identify bottlenecks and main problems of a company.

- OEE – Overall Equipment Effectiveness. It is calculated as a multiplier of other measuring metrics: availability, performance and quality, which are its constituent elements. The OEE indicator is calculated according to the formula (3). Its individual parameters are calculated according to the formulae (4–7).

$$OEE = Availability \times Performance \times Quality\ x\ 100\% \quad (3)$$

Availability is calculated according to the formula:

$$A = production\ time - downtime / production\ time \quad (4)$$

where:

$$downtime = maintenance + setups + failures + other \quad (5)$$

Performance is calculated according to the formula:

$$P = parts\ produced\ (good\ and\ bad\ quality) / production\ time \times rated\ performance \quad (6)$$

Quality is calculated according to the formula:

$$Q = parts\ produced - losses / parts\ produced \quad (7)$$

OEE considers a process. That means that it takes into account not only the availability time but also performance (actual performance / nominal performance) and a quality factor (good parts/ parts produced). In fact, it compares the machine use to its ideal use, which takes place when the production and its preparation follow the plan [25, 39, 41].

2. The scope and methodology of the study

This paper shows the results of the study conducted in the selected large enterprises located on a limited geographical area (Poland, podkarpackie voivodeship). The study regards the identification of real activities performed by the surveyed enterprises within the application of the machine effectiveness evaluation, as well as the indication of which indicators are actually used by the companies.

The study was carried out in two stages. The first stage was carried out in the following areas:

1. Analysis of the current state of knowledge.
2. Defining the scope and the area of research.
3. Developing a research sheet.
4. Selection of the study.
5. Conducting the research and the analysis of results.

The second stage of the research was carried out as follows: testing, analysis of the results, the proposal of changes in the use of machines assessment indicators. A detailed analysis of the results is presented in this work afterward.

3. Study results

3.1. The first stage of the study

3.1.1. Area and carrying out of research

The first stage of the study concerned identification of the measures for the evaluation of technological machines operation effectiveness. The study involved production enterprises of different industries on the area of podkarpackie voivodeship (Poland). As a detailed subject of the study the following areas were analyzed:

- the information gathered on the machine supervision,
- kinds of downtimes recorded in enterprises,
- the way of recording the information on machine failures,
- the average failure time,
- measuring parameters of quality, performance and availability,
- OEE indicator.

150 enterprises were invited to take part in the studies. Any enterprise, plant or its department that had its own strategy and accounted of its accomplishments could be the object of the study. 46 questionnaires were obtained as a feedback.

The study took the form of interviews. The subjects of the study were the representatives of a medium and top management as well as the employees directly responsible for the process of the technological machines and appliances supervision in a company, as well as the chosen machine operators. The study was conducted in a conjunctive multiple choice format, and included a list of prepared, provided in advance options presented to a respondent with a multiple response item in which more than one answer might be chosen. Additionally, a respondent could give other answers if they were not among the provided options.

3.1.2. The structure of the studied enterprises

During the study, the enterprises were classified according to the following criteria: industry type, production type, ownership (type of capital) and technical infrastructure organization. Table 2 shows the structure of the studied enterprises.

Most companies, because as many as 42%, were aviation companies and 34% were automotive companies. The remaining industries included, among others, metal processing, chemical, wood and paper, and food industry. Among the studied enterprises most were the organizations with a big-batch production as a dominant type of production – 27%. In the 6% of the studied companies, there are a few types of production combined at the same time.

Most of the studied companies (91%) are privately owned, the rest (9%) are state-owned. 68% of them possess foreign majority capital, 15% domestic majority capital, whereas 17% possess entirely Polish capital. In most of the companies, CNC machines are mainly used. In the majority of the studied enterprises, numerically controlled machines prevailed (74%). Among other technical machines, i.a. automatic machines, were mentioned. Most of the studied enterprises, because 72%, describe their situation as developing, and 28% as stable. None of the companies described their situation as difficult.

3.1.3. Study results

The effectiveness of the technical infrastructure management depends largely on the kind and amount of information on machines.

Table 2. The structure of the studied enterprises

Criterion	The structure of the studied enterprises					
Industry	Aviation	Automotive	Metal processing	Wood and paper	Food	Chemical
	42%	34%	13%	5%	3%	3%
Production type	Piece	Small-batch	Medium-batch	Big-batch	Mass	A few types
	20%	22%	18%	27%	12%	6%
Ownership type	Private			State		
	91%			9%		
Capital type	Entirely Polish capital	Polish majority capital		Foreign majority capital		
	17%	15%		68%		
Type of possessed machines	Mainly manually-controlled machines		Mainly numerically-controlled machines		Other	
	24%		74%		12%	

If we are not aware of the problems and of where they occur, we can neither eliminate nor prevent them.

Collecting the needed information, taking the right decisions in the right time as well as providing intended actions and accurate reactions are a continuous challenge for the information system of an organization.

One of the groups of information which should be recorded in companies concerns the information on downtimes. The study shows that the most commonly recorded types of downtimes are machine failures, what was indicated by 93% of the surveyed enterprises (Fig. 1). 71% of the companies record downtimes caused by setups.

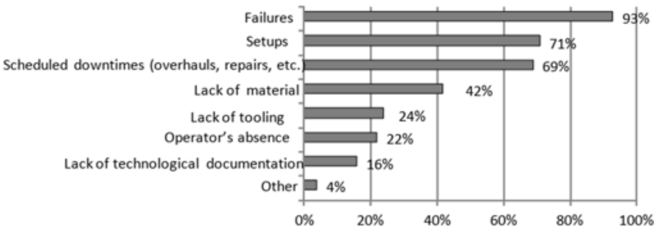

Fig. 1. Types of downtimes recorded in enterprises

Different types of information concerning machines are gathered in the enterprises. They consider both single workstations as well as production lines or departments. They concern machine uptimes, the waiting time for service or machine spare parts, as well as machine performance and load. The conducted study shows that the information, which is the most commonly gathered in the companies in order to facilitate machine-related actions, concerns a number of failures of particular machines (72%). Figure 2 also shows other information gathered as well as the percentage of enterprises which record such information.

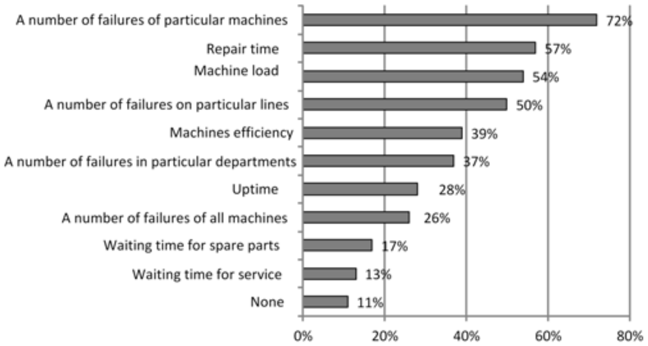

Fig. 2. Types of machine-related information gathered in enterprises

An important element of the completeness and credibility of the obtained data is to determine an appropriate and effective way of the data collecting and recording. In most of the companies (81%) a maintenance worker is responsible for collecting information on machines. At the same time, it is worth mentioning that in 52% of the companies, a few people collect and record information. A question may arise if the same kinds of information are recorded by different people and if the data overlap in such a case. However, it wasn't verified in the conducted study. Among other people engaged in collecting information, a continuous improvement specialist and a technologist were also mentioned.

In 65% of the cases, the place of recording the information regarding machines is the maintenance department. In 42% of the companies the information is directly entered into IT system e.g. via an information kiosk located in a production hall.

The main aim of the study was to gather the information concerning the types of measures used for the machine effectiveness evaluation. The survey involved the questions on determining if the machine quality, performance and availability were measured. The quality metric was defined as a number of conformity products out of the total products produced on the machine. The machine performance was defined as a number of total parts produced on the machine to the production rate of a machine. The machine availability was defined as the actual amount of production time the machine is operating to the production time the machine is available. The detailed results of these studies are shown in the work [3].

The results are presented in Fig. 3. The study shows that 53% of the enterprises do not analyze the quality metric of their machines. This fact impedes the analysis and the possibilities of identifying the

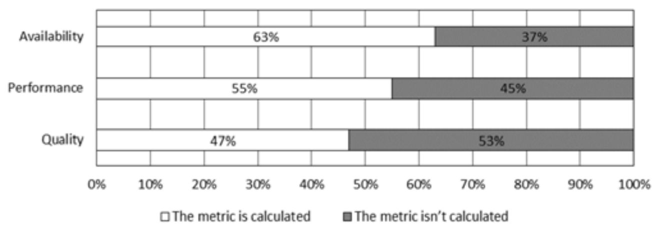

Fig. 3. Percentage of the enterprises which calculate quality, performance and availability parameters

potential causes of nonconformities occurrence in the production.

In case of the performance metric, as many as 55% of the enterprises calculate and analyze it. Collecting such information considerably facilitates the process of production planning which allows on-time processing of customers' orders. It helps to identify machines

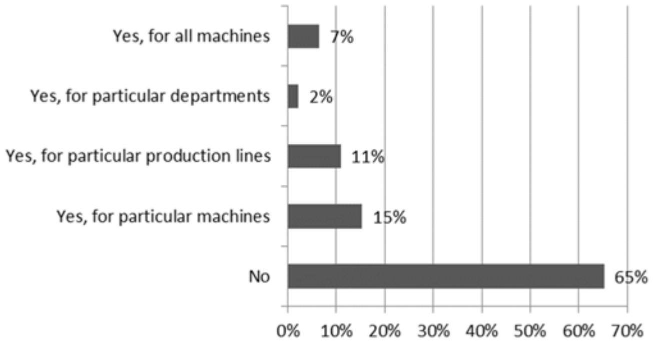

Fig. 4. Percentage of the companies calculating OEE indicator

of bigger or smaller production capacity and thus, indirectly, evaluate the technical condition of the machines owned.

The availability metric is recorded and analyzed in 63% of the enterprises. The value of this metric indicates the actual operating time of the production process. It helps to identify the production stations at which machines often fail or their setup time is too long. Due to this information the enterprise may take actions which result in minimizing the risk of unplanned downtimes and failures. These actions include TPM (Total Productive Maintenance) implementation or the implementation of the methods which allow to reduce the setup times such as SMED (Single Minute Exchange of Die).

One of the measures recommended in the references is OEE indicator. While evaluating the effectiveness of the owned machines and of TPM implementation this parameter is very important. The study shows that it is not always used [4]. This indicator was also analyzed in the conducted study. The obtained information proved that as many as 65% of the enterprises did not use it, and only 15% of the companies calculate OEE for the chosen machines (Fig. 4). Merely 7% of the analyzed companies calculate it for all the machines owned.

Analyzing closely the companies on the production type (Fig. 5)

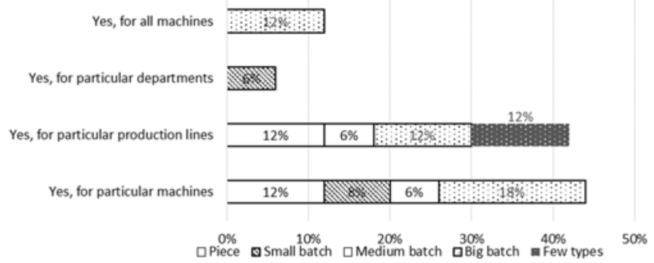

Fig. 5. Percentage of the companies calculating the OEE indicator on the basis of the production type

and industry (Fig. 6), it occurs that OEE is calculated in case of a big-batch production. It mainly concerns the electric, metal processing and automotive industries. For the particular departments, the indicator is calculated only in case of a small batch production, in aviation and automotive sectors. The analyzed enterprises predominantly cal-

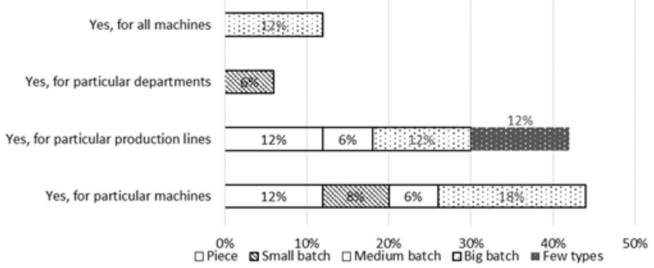

Fig. 6. Percentage of the companies calculating the OEE indicator on the basis of the industry

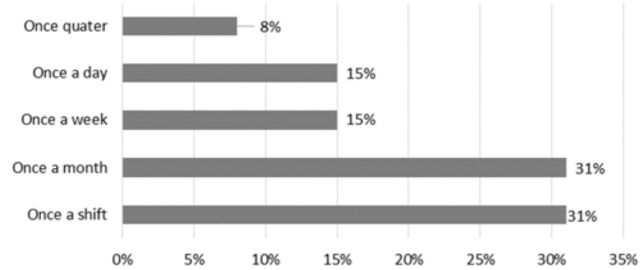

Fig. 7. The OEE calculation rate

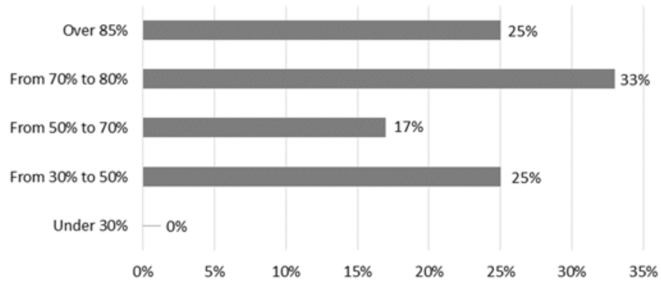

Fig. 8. The average value of the OEE indicator in the enterprises

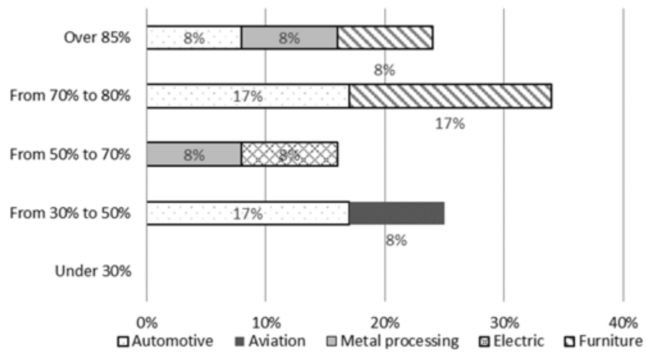

Fig. 9. The values of the OEE indicator for particular industries

culate OEE for the particular, chosen machines in most of the production types and industries.

Another significant issue was to obtain information which concerned the OEE calculation rate. The rate of obtaining such information is substantial because the values of OEE keep us informed about the productivity of the machines owned. If the information is gathered too sporadically we won't be able to react promptly when there is any decline in the machines use. The study showed that in 31%, the analyzed enterprises calculate shift and daily indicators (Fig.7). Only 8% of the companies calculate the OEE indicator quarterly (Fig.8).

It was significant during the study to gather the information concerning OEE values. Its value is important because it initially helps to make a general analysis of the effectiveness of the machines owned. World class standard for this indicator is over 85%. In the enterprises such a standard is reached only by 25% of the analyzed enterprises whereas 33% of the companies range between 70–80% of the OEE value (Fig. 8).

Figure 9 presents the OEE values obtained in the particular industries. The highest value of the indicator is obtained in the automotive industry for the metal processing machines, and in the furniture industry. The lowest value of the indicator was reported in the aviation and automotive industries.

3.1.4. Discussion and data analysis after the first stage of the study

The study conducted in the first stage shows that many companies collect many information concerning effectiveness of the technical infrastructure owned. The information on failures, unplanned downtimes as well as the data related to efficiency and quality of all and particular machines are also collected. The study proves that almost half of the surveyed companies do not evaluate the effectiveness of the machines owned and do not use metrics for their evaluation. The results show that this issue is worth studying and making the companies aware of the fact that monitoring the performance, quality and availability of the technological machines park owned is important for the timely production.

In the further analyses, the authors searched for the relations between:

- the capital type and the indicators of the machine effectiveness evaluation indicators used,
- the industry type of the company and the indicators used,
- the production volume and the indicators used.

For the data presented, *Chi²* analyses were conducted to evaluate if there is a statistically justified influence of the industry type, type of the possessed capital, or the production volume on the actions undertaken within the process of data collection as well asthe evaluation of the value of the analyzed indicators in an enterprise. The results of the analyses are presented in Table 3.

Table 3. Hypotheses made and P-values obtained

It.no.	Hypothesis	*P-value*
1.	There is no difference betweenthe kinds of indicators calculated by the enterprises with Polish capital or Polish majority capital and the enterprises with foreign capital	0,000
2.	There is no difference between the kinds of indicators calculated by the enterprises of different industries	0,995
3.	There is no difference between the kinds of indicators calculated by the enterprises with different production volumes	0,981

The analyses conducted show that both the collection and evaluation of the value of the analyzed indicators are not conditioned by the industry type, nor by the production volume of large enterprises. However, they are dependent on the type of capital, what is confirmed by P-value of 0,000 (<0,005).

Figure 10 shows the types of measuring metrics based on the capital type possessed by the enterprises.

As the figure 10 shows, the machine quality, performance as well as availability metrics are predominantly calculated in the companies with the foreign capital. The quality metric is calculated by 28%, performance metric by 37% and availability metric by 43% of the analyzed companies with the foreign capital.

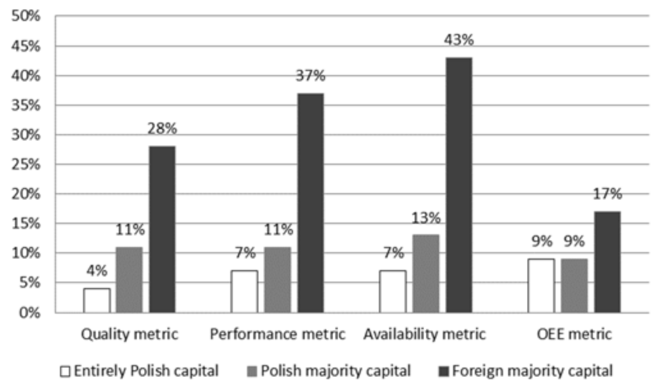

Fig. 10. Types of the metrics collected based on the capital possessed by a company

3.2. The second stage of the study

3.2.1. Study area and methodology

The second stage of the study concerned a detailed analysis of the indicators of the technological machines effectiveness evaluation on the basis of a randomly chosen enterprise. As a detailed subject the following areas were analyzed:

- kinds of machine maintenance actions,
- kinds of the metrics of effectiveness evaluation used in the enterprise,
- the values of the metrics used,
- the manner of recording the information on machines
- the use of OEE and the values obtained.

The results of the analyses conducted at the first stage of the study show that collecting and evaluating the values of the analyzed indicators depend on the capital type. That is why, that was a main criterion in choosing an enterprise. For the further study, out of the studied group, one enterprise with the foreign majority capital was chosen.

This production enterprise operates in the aviation industry in podkarpackie voivodeship. The data obtained during the own study as well as the data from the article [44] were used for the analysis.

The analyzed enterprise operates in production, repair and maintenance, service as well as in design and research. The company business is particularly involved in the production of aircraft components and drive units.

3.2.2. Machine maintenance

The actions related to the machine maintenance in an enterprise are performed by the maintenance services (MS) which are present centrally as well as in particular departments. Preventive maintenance is mainly used in the enterprise. The enterprise uses a modern strategy of the technological machines management that is TPM. The size of the technological machine park owned is about 2500 machines. These machines are mainly numerically controlled machines.

Over 300 workers of different professions and at different posts are employed in MS. Figure 11 presents the workers of the central and departmental levels of maintenance.

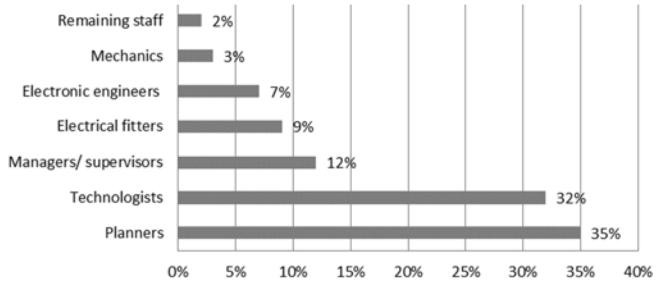

Fig. 11. Workers of the Maintenance Services

The largest number of workers are mechanics. The category of 'remaining staff' includes auxiliary service workers such as the workers of OSH, distribution and sharpening departments which function within MS. They constitute 35% of the MS employees, and their duties and the scope of their work are not related to this unit in any way.

The fundamental actions realized by MS of the analyzed enterprise include the actions realized in five basic areas. Table 4 presents the areas and their characteristics.

Based on the working time, the percentage of maintenance services in particular actions was identified (Fig.12).

The largest share of the MS tasks (74%) is constituted by the area related to the current maintenance of the machines and equipment. The remaining actions cover merely 26% of the available time.

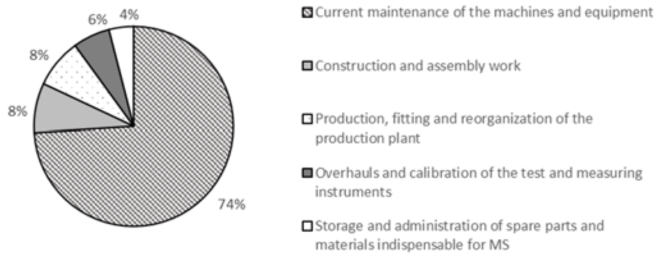

Fig. 12. Percentage of MS in particular areas

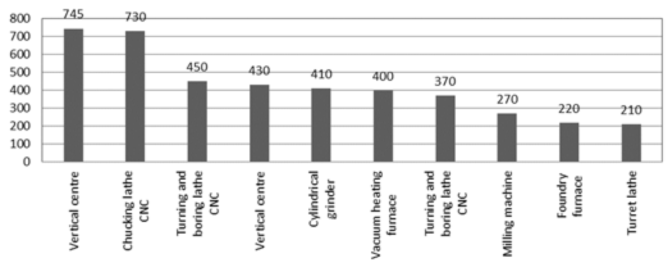

Fig. 13. The most damageable machines in a chosen period of time

Table 4. Areas of MS operating in the analyzed enterprise.

It. No.	Area	Characteristics
1.	Current machine and appliances maintenance	Failure removal, periodical overhauls of machines and equipment, actions related to TPM implementation, preventive maintenance, machine repairs and modernization.
2.	Construction and assembly work	Actions related to maintaining the technical condition of buildings and building structures, removing defects of the equipment in production halls, construction of steel structures and sanitary systems.
3.	Production, fitting and reorganization of the production hall	Repair and regeneration of tooling, service and supervision of pressure instruments, machine tool setups, production hall reorganization – relocation of machines and equipment.
4.	Overhauls and calibration of the test and measuring instruments	Actions related to calibration and overhauls of the equipment such as manometers, thermocouples, dispersed systems, electrical measures, etc.
5.	Storage and administration of spare parts and materials indispensable for MS	Identification of the spare parts needed, resupplying the stock, management of the materials indispensable for MS operation.

3.2.3. Measures of machine effectiveness evaluation

To evaluate the effectiveness of the machine system operation, the enterprise applies a few measures of machine effectiveness evaluation. Table 5 shows their characteristics.

Table 5. Measures of the machine system effectiveness evaluation in the studied enterprise.

It. no.	Measure name	Characteristics
1.	Machine downtime	Downtime is a total equipment stoppage time that is counted since reporting the failure till it is repaired and the machine is restarted, for different kinds of downtimes, e.g. a breakdown, modernization, overhaul, etc.
2.	Timeliness of the overhauls performed	The comparison between the actual time of an overhaul and a period of time determined for the service, i.e. the time is counted according to the scheduled date based on the service schedule ±14 days (Note: it is possible to consider a different period of time).
3.	Failure rate graph – Top 10	The graph of the 10 most prone to failure machines in a specified analyzed time.
4.	Percentage measure of preventive actions to failures ratio	Percentage of the time devoted to maintenance actions to the failure time (according to 80:20 rule)

Figures 13–16 present the way of the representation of some measures and their values in a chosen time. Figure 13 presents the graph of the most damageable machines – TOP 10 in a chosen period of time. Such a graph is developed for both particular production lines as well as for particular departments. It is prepared weekly and monthly. This measure allows to monitor on ongoing basis the most damageable machines in a given production area. It results in the increase of preventive actions on such machines. A trend graph in figure 14 shows the data concerning machine downtimes in a chosen period of time.

The compiled data, as shown in figure 14, allow to monitor machine downtimes as well as their types in a given period of time. Downtimes are classified as follows: failure, certification, defect, overhaul, actions targeted at TPM implementation and other. Such compilation allows a detailed analysis of the most frequent downtime and its duration. Completing the further periods with e.g. the data concerning scheduled overhauls, TPM related actions or modernization, additionally enables a more effective production planning process. The measure allows to optimize the actions related to machine maintenance, both in particular production areas as well as in the entire enterprise.

Figure 15 presents the percentage of preventive actions and failures in a chosen period of time. The maintenance services of the enterprise use the 80:20 rule to analyze this measure, where 80% of the MS working time devoted to preventive maintenance is supposed to result in reducing the failure duration to the level of 20% of the total available working time. The presented data show that during twelve months the failure indicator decreased considerably from the highest value of 77,8% to 51,9%. The change of the value of this indicator was caused by the significant increase and improvement of preventive maintenance performed in the enterprise. The indicator's value increased from 22,2% to 58,1%. To improve the preventive maintenance in the enterprise, the company applied chosen methods and tools of Lean Manufacturing such as a process approach, Value Stream Mapping (VSM), TPM implementation for the most of machines. In addition, the company entirely changed the organization of maintenance services work.

The evaluation of the overhauls timeliness is significant in machine maintenance effectiveness evaluation (table 6). The record allows current monitoring of the scheduled overhauls progress. It allows to analyze the timeliness of overhauls in particular departments what makes it possible to send more workers to the areas where machine overhauls need speeding up. The available data are used for different analyses which help to identify machines awaiting for an overhaul, those after overhauls or the ones with delayed overhauls in a quick and easy manner. Table 6 shows on-time overhauls marked red and the delayed overhauls grey. Electronic reporting and ordering of overhauls help to eliminate laborious manual records, and they facilitate the data analysis.

Unfortunately, the studied company doesn't use the OEE indicator for the effectiveness analysis. The company has tried to apply this indicator, however with no effect. As the explanation of the failure, the company gives the following reasons:

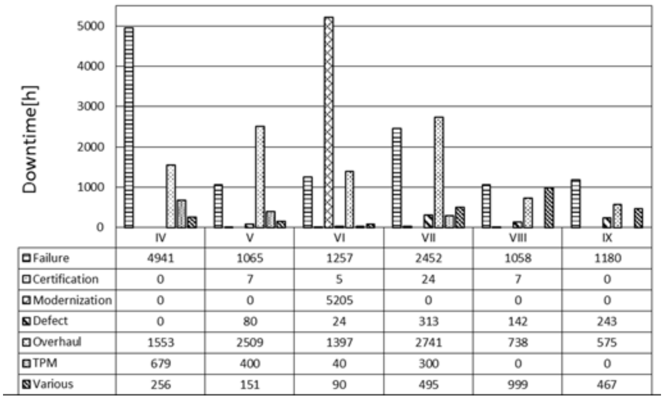

Fig. 14. Machine downtimes in a chosen period of time

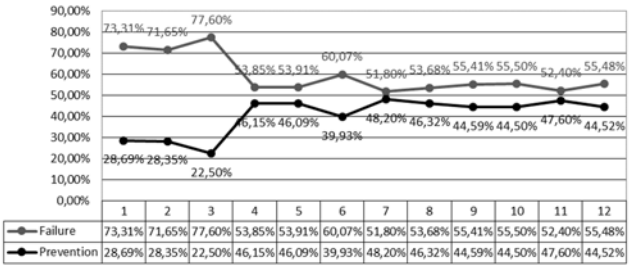

Fig. 15. Percentage of the prevention and failure rate in a chosen period of time

- too much information needed what requires engaging many people from several organizational units to collect it,
- too much effort at the manual system of its calculation, in particular because it is a large enterprise with lots of machines and equipment,
- automated data collection should be introduced as the data collected manually are often encumbered with a big measuring error,
- emerging problems with the regular collection of data in different areas,
- electronic and automatic system of data collection is also indispensable to analyze the data systematically because only that could help to implement the OEE indicator effectively, however it occurred to be too expensive to implement,
- the implementation of the OEE indicator requires the standardization of procedures and of the type of the information gathered in all departments of the enterprise, what unfortunately turned out to be too difficult and time-consuming.

The company has plans for another attempt to implement the OEE indicator. The first step to achieve this is the standardization of the machine supervision processes as well as of the collection of the information on their performance in a production process in particular departments.

3.2.4. Discussion after the second stage of the study

The study conducted in a chosen enterprise showed that not only the proper organization of the services responsible for the machine performance but, above all, the right choice of the measures applied are important for the machine effectiveness evaluation. The analyzed enterprise uses very simple measures of the machine effectiveness evaluation. However, they are, according to the enterprise, sufficient and they provide a lot of information helpful for the effective process of technological machine and equipment supervision. The study shows that some of the elements of the appropriate process of the machine effectiveness monitoring are completeness, availability and reliability of the obtained information. Unfortunately, obtaining the above requires electronic and automatic system of support.

4. Conclusions and suggestions on indicators to use in enterprises

An effective process of machine and equipment supervision in an enterprise requires not only the choice of the right strategy for the technical infrastructure management but, above all, reliable indicators of its performance evaluation. The conducted study determined that almost the half of the studied companies don't evaluate the effectiveness of the owned machines or they use only some indicators for its evaluation.

The study shows that only 35% of the enterprises apply the recommended OEE indicator. In the second stage of the study, the machine evaluation indicators used in a chosen enterprise were analyzed in detail. The analysis proved that the enterprise do not use most of the indicators recommended by the references such as OEE, MTTR or MTBF, despite the fact that it is a large enterprise with the foreign majority capital. The company has developed and used its own simple measures which don't require the workers to be involved in an excessive and additional task of collecting the needed data.

The enterprise, while evaluating the effectiveness of its machines, requires simple, concise and useful information on the machines and their effectiveness. Additionally, it also needs the information on support services responsible for the machines supervision. Based on the information obtained from the conducted study, the authors suggested a set of indicators which the enterprises may use for the evaluation of

Table 6. The database of the timeliness of machine and equipment overhauls in a chosen period of time

Position	Scheduled date	Date of completion	Location	Difference	Timeliness/ status
Universal lathe 1	2010-01-01	2010-01-08	Prod. Dep.	7	On-time
Universal lathe 2	2010-01-01	2010-01-19	Prod. Dep.	18	Overdue time
Universal lathe 3	2010-01-02	2010-02-08	Prod. Dep.	27	Overdue time
Universal lathe 4	2010-01-02	2010-01-02	Prod. Dep.	0	On-time
Universal lathe 5	2010-01-02	2010-01-19	Prod. Dep.	17	Overdue time
Universal lathe 6	2010-01-02	2009-12-28	Prod. Dep.	-5	On-time
Universal lathe 7	2010-01-02	2010-01-12	Prod. Dep.	10	On-time
Universal lathe 8	2010-01-02	2010-02-01	Prod. Dep.	31	Overdue time
Universal lathe 9	2010-01-03	2010-03-01	Prod. Dep.	58	Overdue time
Universal lathe 10	2010-01-03	2010-01-11	Prod. Dep.	8	On-time
Universal lathe 11	2010-01-03	2010-01-08	Prod. Dep.	5	On-time
Universal lathe 12	2010-01-03	2010-01-19	Prod. Dep.	16	Overdue time

Table 7. The indicators suggested for the evaluation of machines and support services.

<table>
<tr><th>It. no.</th><th>Criterion</th><th>The indicator suggested</th><th>Information necessary for the indicator's evaluation</th><th>Manner of its calculation</th></tr>
<tr><td rowspan="3"></td><td rowspan="3">Informational and operational</td><td>percentage of preventive maintenance</td><td>• type of tasks done by support services
• tasks duration</td><td>$DP = \frac{\sum_1^m T_{DPm}}{\sum_1^n T_{Dn}} * 100\%$
where:
DP – Preventive maintenance
T_{DPm} – actual time devoted to preventive maintenance (h)
T_{Dn} – available operating time (h)</td></tr>
<tr><td>indicator of timeliness of work completion – mainly of scheduled overhauls and repairs</td><td>• work due dates
• schedule of works</td><td>$T_P = T_{rz} \pm 7 day.$
where:
T_P– scheduled due date of overhaul
T_{rz}– actual due date of overhaul
(Note: Instead of $\pm 7 days$ other period is possible)</td></tr>
<tr><td>mean time to repair (MTTR)</td><td>• repair duration
• a number of failures</td><td>$MTTR = \frac{\sum_1^n T_{WP_n}}{K_A}$
where:
T_{WPn} – repair time (h)
K_A – number of failures</td></tr>
<tr><td rowspan="2">2.</td><td rowspan="2">Economic</td><td>indicator of task completion costsrelated to machine maintenance</td><td>• particular tasks costs
• type of particular tasks</td><td>$K_{RP} = \sum_1^n K_{Pn}$
where:
Krp – implementation costs
K_{Pn} – particular tasks completion costs</td></tr>
<tr><td>Total and unit cost of maintaining and exchanging spare parts</td><td>• costs related to the maintenance and exchange of spare parts</td><td>$K_{CZ} = \sum_1^n K_{Wn} + \sum_1^m K_{Um}$
where:
Kcz – costs of spare parts
K_{Wn}– Total cost of spare parts exchange
K_{Um} – totalcost of spare parts maintenance</td></tr>
<tr><td rowspan="2">3.</td><td rowspan="2">Technical and maintenance</td><td>indicator of machine performance</td><td rowspan="2">• types of machine downtimes
• information concerning the number and duration of both planned as well as unplanned downtimes
• machine operating time in a production process
Note: Information can be collected and analyzed for individual workstations or a group of machines</td><td>$W = \frac{\sum_1^n P_{Wn}}{T_P \times W_Z}$
where:
W – performance
P_{Wn} – parts produced (good +bad) (parts)
T_P – available run time (h)
W_Z – nominalperformance(u/h)</td></tr>
<tr><td>indicator of machine availability</td><td>$D = \frac{T_P - T_{PRZ}}{T_P}$
where:
D – availability; T_P – available run time (h)
$T_{PRZ} = T_K + T_A + T_S + \ldots + N$
T_{PRZ} – downtime duration (h)
T_K – maintenance duration (h)
T_A – failure duration (h)
T_S – setup duration (h); N - other</td></tr>
<tr><td rowspan="2">4.</td><td rowspan="2">Safety</td><td>number of accidents at machine operation and use</td><td rowspan="2">• information concerning the level of safety in the process of machine operation and use</td><td rowspan="2">K_W – number of accidents
K_Z – number of hazards
(Note: values of these indicators may be analyzed on a daily, quarterly or monthly basis)</td></tr>
<tr><td>number of hazards emerged at machine operation and use</td></tr>
</table>

the machine performance and support services, and which usage is not related to excessive workload (Table 7). Table 7 presents a set of indicators, the criteria of their choice, the sort of information needed for setting the value of each of the indicators and the manner of their determining. The authors propose to use both the indicators which were most frequently used by the studied enterprises as well as the indicators which according to the authors' assessment are useful and should be used.

The indicators which have been suggested will allow to obtain the information that will be the basis for taking actions aiming at the improvement of technological machine park operation in a company. What is more, it will result in the quality of machine performance improvement, costs reduction as well as in the work safety improvement.

5. The need for further studies

It is worth to extend such studies to small and medium enterprises which, as a rule, possess smaller financial means that could be spent on the technical infrastructure improvement as well as on the process of the machine effectiveness monitoring.

It would also be advisable to examine the relation of the technical infrastructure management strategy to the measures of the machine park effectiveness evaluation used in an enterprise, taking into consideration both the type of capital as well as the type of production.

The obtained results could indicate the course of action that should be taken in order to motivate companies to improve the methods of supervision and to make them aware of the benefits and the impact of the proper machine supervision on rising the competitiveness of enterprises on an increasingly harder global market.

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