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ANALYSIS OF THE CORRECTNESS OF DETERMINATION OF THE EFFECTIVENESS OF MAINTENANCE SERVICE ACTIONS

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Abstract
This paper reports the results of an analysis of indicators describing the effectiveness of actions taken and repairs made by the maintenance services in a food industry company which had implemented a new manufacturing execution system (MES) 10 months prior to the study. The application of the above effectiveness indicators plays a significant role in the rationalization of functioning of maintenance services. Therefore, it is vital that they are calculated correctly and interpreted in a way that has a positive effect on the organization of maintenance works. The paper investigates four effectiveness indicators employed by the maintenance services of the company in question, i.e., mean time to failure (MTTF), mean time between failures (MTBF), mean time to repair (MTTR) and overall equipment effectiveness (OEE). The objective of the analysis was to verify the correctness of determination of the above indicators in the analysed company. In addition, the study was to determine whether the use of correctly determined indicators and results interpretation could lead to a higher effectiveness of the actions taken by the maintenance services department. Moreover, the paper presents a diagnosis of problems connected with incorrect determination and visualization of the above-mentioned indicators in the analysed company.

Keywords
MTTF, MTBF, MTTR, OEE, maintenance services effectiveness.

Introduction

The maintenance of machinery and technical objects in production companies entails considerable expenses on the part of these companies [1]. With a growing competition on the market and growing demands from customers companies have to take more sophisticates actions to reduce costs wherever it is possible [2]. The costs of ensuring production continuity on technological lines primarily depends on [3, 4]:

- selection of suitable organizational structure of maintenance services,
- formulation of an optimal operating strategy.

Naturally, the operation of the maintenance department organized in accordance with optimal organizational structure that executes an operating strategy relevant to given conditions (defined by the type and volume of production, type of machines and tools used, etc.) is more effective, which directly affects maintenance costs of the company.

By taking suitable decisions concerning the above organizational issues it is possible to improve the work of maintenance services and thus to improve the effectiveness of their operations and to reduce the costs resulting from wastes. This is connected with the solving of current problems and execution of scheduled actions (e.g., in accordance with the technical documentation of machines) [5]. Therefore, improvements oriented at increasing the effectiveness of maintenance services practically boil down to analysing the results of operation to date (e.g., mean repair time) and the causes of these results as well as, importantly, drawing relevant inferences

on their basis. Hence, it is necessary to continually analyse produced effects to verify the correctness of assumptions, work methods etc. Nonetheless, the need of savings cannot be too great a burden leading to considerable impediments to the operation of maintenance services. To this end, it is worth establishing clear criteria that enable the monitoring of the effects of actions taken by maintenance services as well as implementing new solutions aimed at improving maintenance services effectiveness.

In practice, the most widely used criteria for measuring the effectiveness of actions taken by maintenance services are: MTTR, MTTF, MTBF and OEE [6]. For this reason the paper investigates four effectiveness indicators employed by the maintenance services of the company in question. The analysis concerned the maintenance services in a food industry company which had implemented a new manufacturing execution system (MES) 10 months prior to the study.

The first part of the article describes the strategy performance indicators of the maintenance service activities. Next, it presents key indicators of the effectiveness of these activities. The third part of the article focuses on an analysis of the activities. The fourth part gives a diagnosis of the problems. The last part presents a summary of findings.

Strategies and indicators for assessing the effectiveness of maintenance service actions

To understand the usefulness of establishing maintenance departments in production companies, understand the necessity of their efficient operation and account for the investment aimed at maintenance services modernization, it is necessary to consider three basic tasks that make the essence of maintenance [4]:

- correct technical servicing of means of production enables the manufacturing of a large quantity of high quality products,
- incorrect technical servicing of means of production enables the manufacturing of only a small quantity of low quality products,
- lack of technical servicing of means of production does not enable the manufacturing of any products at all.

To ensure the manufacture of a large quantity of high quality products, the maintenance department must be responsible for the execution of a given maintenance strategy describing the way of handling the machines and devices in the company [7].

The functioning of maintenance services is strictly linked with the development of industrial plants due to technological progress providing access to more and more complex and technologically advanced production machines.

In terms of time, one can distinguish three evolving periods characterized by a different approach to maintenance. Three basic operating strategies were developed for these three periods, and they are currently used by production companies [3, 8–10]:

– *reactive maintenance* – it consists in performing repairs after the appearance of damage. A characteristic of this strategy is the use of equipment and machinery until the intensity of their damage is increased, and repairs are only made after a failure causing the loss of their further operational use.

– *preventive maintenance* consists in carrying out planned preventive repairs. This strategy is based on the operational potential of machines. The repair is determined by the so-called service life, a measure of the ability of machines and equipment to perform their assigned tasks. Maintenance operations are carried out at scheduled service intervals. Detailed information about their maintenance is specified in the technical documentation of a machine provided by the manufacturer.

– *predictive maintenance* – this strategy consists in the monitoring of technical condition of a machine stock and the use of state-of-the-art expert systems for specifying actions to be taken to ensure operational efficiency of a machine, considering aspects such as operating conditions, operating history, technical condition.

The operating strategy adopted in the company should affect not only organizational issues such as the design of a specific organizational structure and the determination of technical staff number, at the same time it should also determine the nature of tasks performed by the maintenance services and consequently their qualifications and tools supporting the implementation of their actions [11]. For example, the implementation of a predictive maintenance strategy will require the use of advanced tools (e.g., computer programs supporting data analysis, diagnostic tools based on residual processes), and therefore the qualifications of the staff members themselves will have to be higher than is the case with reactive maintenance.

The same pertains to the effectiveness indicators – they should be measured for a specific purpose related to the nature of actions taken by maintenance services under a specified operational strategy. It should be noted here, however, that in order to determine values of even the simplest indicators,

it is necessary to have information (data) obtained from the production machinery monitoring systems. Therefore, the decision related to the implementation of each indicator should be justified by a specific objective and verified in terms of the capacity of a production company in question. A capital mistake is to tailor the effectiveness indicators to parameters that are currently measured in the company. On the contrary, if the indicators are to evaluate the way the company operates with a view to taking actions to streamline some production processes, the measurement of the production process should be tailored to the indicators that will be calculated and used by the maintenance services [12].

Key indicators for assessing the effectiveness of actions taken by maintenance services – calculation methodology

As it has already been mentioned, the effectiveness of actions taken by maintenance services can be measured by means of some basic indicators interpreted as follows [8, 13–18]:

1. Overall Equipment Effectiveness (OEE):

$$\text{OEE} = A * P * Q * 100\%, \tag{1}$$

where A (availability) – expressed as the ratio of product manufacturing time to net operational time including the working shift time decreased by scheduled down-time. This parameter decreases due to failures, non-standard SMED Times, logistic events, e.g., material shortage; P (performance) – ratio between a number of produced products and target production, or the number of products which can be produced at the maximum operating speed of a machine. This parameter is decreased when the machine's actual operating speed is lower than the rated speed specified by the manufacturer; Q (quality) is the ratio between a number of products that meet quality requirements to overall production output. The manufacturing of spoilage has a negative effect on this term.

The OEE is schematically illustrated in Fig. 1. In connection to this, it is worth stressing that scheduled down-time does not decrease the OEE value.

2. Mean Time Between Failures (MTBF) :

$$\text{MTBF} = \frac{T_p}{L_a}, \tag{2}$$

where T_p is the up-time of a repairable system, e.g. a production line, L_a is the number of failures that have occurred.

3. Mean Time To Repair (MTTR):

$$\text{MTTR} = \frac{T_n}{L_a}, \tag{3}$$

where T_n is the time of a repair, L_a is the number of failures.

4. Mean Time to Failure (MTTF) is the predicted mean time of a machine's operation since the beginning of its operation or last repair to failure:

$$\text{MTTF} = \text{MTBF} - \text{MTTR}, \tag{4}$$

where MTBF, MTTR – denoted as above.

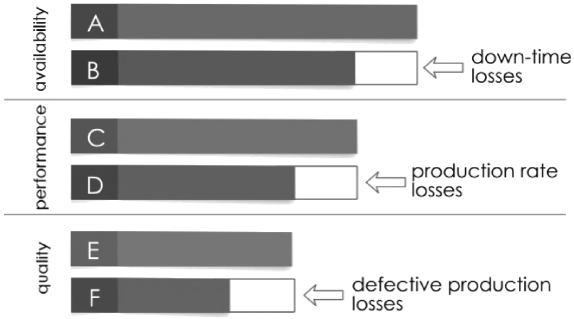

Fig. 1. Schematic interpretations of OEE components (developed by the authors based on [5]).

Analysis of maintenance services effectiveness indicators

Production companies implement systems for determining the effectiveness of actions taken by maintenance services in order to obtain knowledge that could improve their functioning. The objective can be achieved is the following conditions are satisfied:

- indictors should be calculated in a correct way (in some cases the systems being implemented have incorrectly pre-defined calculation algorithms),
- analysis and interpretation of the obtained indicator values should be done correctly (taking into account factors that affect variations in their values or lead to undesired values),
- conclusions should be adequately used to organize the maintenance services (companies often limit themselves to archiving entries and their interpretation, but the inferences made do not lead to taking decisions about the implementation of organizational changes).

It seems justified to inspect production companies applying such indicators for their observance of the above criteria.

The analysis of effectiveness indicators was performed based on information obtained from a middle-size bottling company. There are four arbitral indicators in the article and there is assessed their usefulness in the considered case. The company

calculates the following indicators: MTTR, MTTF, MTBF and OEE. These indicators were examined with respect to their suitability for increasing the maintenance service effectiveness was preceded by verification of their correctness of their calculation. According to the MES-generated report (Fig. 2), the mean value of MTTR describing the machine comprising the analysed technological line is 1 minute, which is unreal to obtain between failure occurrence and repair. In connection to this it must be stressed that the down-time of up to 5 minutes is defined as a micro-downtime.

MACHINE	MTTR [min]	MTTF [min]	MTBF [min]
FILLER	1	18	20
LABELLING MACHINE	3	45	48
WASHER	0	6	7
INSPECTOR	0	14	15
UNLOADER	4	29	33
LOADER	1	6	8
PALLETIZER	1	30	32
GLASS DEPALLETIZER	1	2	4
DEPALLETIZER	0	6	7
PACKING MACHINE	2	6	8
WRAPPING MACHINE	2	37	39
	1	18	20

Fig. 2. Comparison of the MTTR, MTTF, MTBF of the machines comprising the bottling line between 1 August 2015 and 2 November 2015.

It was observed that the source of the calculation error lies in the incorrect classification of events occurring on the machines. Based on the condition report generated by the MES, it was observed that all cases of self-interference are classified as failures. Such an approach is incorrect, as most of such interference are short down-times mainly caused by non-technical factors and handled without noting maintenance services. Table 1 offers a self-interference report of one of the machines in the analysed production line.

As it can be seen in Table 1, the system identified 6 events as failure within less than 10 minutes. The MTTR (along with MTTR and MTBF) determined based on the above data cannot serve as a basis for assessing maintenance service effectiveness because the time required for a maintenance service employee to go from the workshop to the production is approximately 2 minutes. Therefore, it is impossible for the employee to spend between 12 and 79 seconds to remove the failure within 12 to 79 seconds after its occurrence. It is therefore necessary to take steps to ensure correct calculation of the indicators, for instance by a more precise classification of events occurring on the machines.

Table 1
Report on self-interference of the washer dated 1 August 2015.

Place	Condition	Subcondition	Duration [hh:mm:ss]
washer	self-interference	failure	00:00:36
washer	self-interference	failure	00:01:19
washer	self-interference	failure	00:00:31
washer	self-interference	failure	00:00:42
washer	self-interference	failure	00:00:12
washer	self-interference	failure	00:00:18

The correct calculation of OEE may also prove to be problematic. In the analysed company the focus was put on the OEE of the machines making part of the production line investigated between 1 October 2015 and 1 November 2015, and the OEE report reveals that on 2 October 2015, during one of the shifts, the above indicator for the loader was 108%. This value is incorrect because according to the applied calculation methodology it should be in a range from 0 to 100%. A fragment of the above report is given in Fig. 3.

LABELLING MACHINE	LOADER	PACKING MACHINE
0	0	0
9.3	0.0	11.8
42.7	0.0	43.5
45.9	0.0	41.8
52.6	108.0	0.0
56.7	56.6	0.0

Fig. 3. Fragment of the OEE report from October and November 2015.

The computer system for calculating effectiveness indicators also had other errors due to ambiguous visualization of OEE or incorrect calculation formula for one of components of the above term [19].

Problem diagnosis

The identification of irregularities in the calculation and visualization of the above indicators poses a risk of incorrect interpretation of the company's effectiveness. This should be particularly important for the company management, and this body should take affective corrective measures. Problems can be effectively eliminated if they have been fully diagnosed. To eliminate the problems preventing the correct use of inferences drawn from calculations and results interpretation for some of the measured indicators, it is necessary to determine their source and the methodology of a repair programme.

In the analysed case, we can claim that the IT software used by the company in question has wrongly defined time after which the down-time is described as a failure and wrongly calculates and visualizes the OEE, as demonstrated by the analysis results. Therefore, it is necessary to establish a diagnosis enabling determination of the source of occurring errors. For this reason the 5 Why method [14, 20] was employed to determine the cause of abnormalities in the method of calculation and visualization of the above term. The results obtained with this method are given in Table 2.

Table 2
Problem diagnosis by 5 Why.

	Problem:	Calculation and visualisation irregularities
1.	Question:	Why do irregularities occur?
	Answer:	The systemvwas configured incorrectly by an external company.
2.	Question:	Why was the system configured incorrectly?
	Answer:	The production company did not set out implementaton details with the IT company.
3.	Question:	Why weren't the implementation details set out?
	Answer:	The indicators were not defined beforehand.
4.	Question:	Why weren't the indicators define beforehand?
	Answer:	No clear goal was set.

The results presented above (Table 2) suggest that the implementation of the advanced IT system supporting the calculation of effectiveness indicators was not dictated by a specific need (e.g., the desire to achieve a specific target). This decision was certainly dictated by the desire for self-improvement and the need for evaluation and verification of the results, both in the technical and production field. However, without a clearly defined objective behind the system purchase specifying in what areas it will provide production support, who will be using it, and how it will eliminate incorrect practices, such an investment does not seem justified. Ultimately, it is difficult to expect that an external IT company implementing generally universal IT systems for machine and device maintenance support will understand individual needs of all customers.

The main guideline in establishing effectiveness indicators is to link them with the company's goals and vision, while the definition of these indicators is essential prior to their implementation. A correctly executed process of defining these indicators should ensure that all interested staff members understand these indicators in a unanimous way. To this end, it is necessary to obtain the following data about individual indicators [12]:

- a short and unambiguous name of the indicator,
- description of the indicator, i.e., describing the information it provides,
- desired value and boundary values,
- formula for determining the indicator and a clear description of the components required for calculations,
- interested parties (users of information), parties responsible for measurement and value of the indicator value.

Therefore, it seems that the lack of objectives and the absence of clearly defined indicators by the company is the cause of the identified irregularities. It can be said that these are two priority actions which should be implemented in the first place. It should also be expected that any attempt to intervene with the system to rectify errors without taking into account their root causes will only be masking, as workers will still have no set goal and will be unable to understand individual indicators in an unambiguous way.

Summary

Goals set in companies – whether by the management or lower level executives – should comply with the SMART criteria (i.e., they must be simple, measurable, achievable, realistic and time-bound). In addition to being informative and providing feedback on the process, effectiveness indicators also ensure measurable objectives. The allocation of resources to expensive IT systems only for the sake of process information does not seem to be economically justified. On the other hand, treating such a purchase as a conscious investment with a clearly defined goal can actually be successful. Just because almost every process in a manufacturing company entails losses, the elimination of which can lead to significant savings.

The analysis of correctness of the calculation of the maintenance service effectiveness indicators in the company in question has revealed many irregularities. Unfortunately, the irregularities make it impossible for the effectiveness indicators to perform their control function and thus improve production processes, leading to cost reductions [21]. Due to operating errors, it was difficult to determine the potential of machines or the effectiveness of maintenance service activities. The diagnosis of the causes of the irregularities allows us to undertake actions aimed at solving problems with the system, which, in turn,

will contribute to the use of the machine stock in a more effective way.

During the analysis, the computer system responsible for the calculation of the indicators in the analysed production company was in the final test phase. It is therefore worth noting that the manufacturing companies that outsource the implementation of MES systems should continually monitor the implementation process so that the software and its functions are convergent with and tailored to actions taken by the maintenance services.

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