CONTRIBUTION TO MAINTENANCE ISSUES IN COMPANY PRACTICE

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Currently, companies are more and more interested in the issues of maintenance. The present article provides basic information about maintenance, describes its development stages; it also refers to the classification of maintenance and analyses the maintenance systems used in practice. Moreover, some modern approaches to maintenance are presented and supported by selected specific cases from engineering practice.

KEYWORDS

Maintenance, Classification of maintenance, Systems of maintenance, Preventive maintenance, After-failure maintenance, Total Production Maintenance, Reliability Centered Maintenance.

1 INTRODUCTION TO MAINTENANCE

The standard CSN EN 13306 defines the maintenance as a combination of technical, administrative and managerial actions during the life cycle of the object aimed at maintaining it in the current state or returning it to the state in which it can perform the required function.

A mission and position of maintenance in the company managed in a modern way should be seen as an important factor that significantly affects the manufacturing productivity. Such a company and its production require a controlled section that effectively takes care of tangible assets, is capable of preventing failures and production breakdowns. These are the main elements of the integrated maintenance management. This includes all managerial activities that determine goals, strategies and responsibilities for maintenance and where the management uses the means such as planning, control and maintenance inspections, improvement of maintenance control methods, including economic, safety and environmental aspects. The objective of maintenance can be seen as the objective attributed and adopted for the maintenance activities. A maintenance strategy is a method of management used to achieve the objectives of maintenance. In engineering practice, approaches to maintenance are numerous, but the most substantial one is to meet the objectives, i.e. the outcome.

Maintenance went through various stages of development associated with different classifications of maintenance and maintenance systems. For development of companies, a modern approach to maintenance is of considerable importance; there are several of them. Implementation of these approaches in specific companies is not at the same level and the results that could be generalized have not yet been known. However it is important that modern approaches are successfully being introduced into industrial practice and the experience acquired so far is positive.

2 DEVELOPMENT STAGES OF MAINTENANCE

Maintenance has been encountered ever since people began to satisfy their particular needs via manufacture of a variety of tools and utilities. This was probably also associated with the need for repair of these tools and utilities. [Legat 2013]

John Moubray in his book described the development of maintenance over three generations shown in Fig. 1.

The first generation of the maintenance ended about the World War II. Since at that time the devices were simple, guaranteeing a reliable operation and ease of repair, they were repaired only after the occurrence of a failure. Therefore even the managers paid attention only to the maintenance occurring after the failure. [Moubray 1997]

After World War II there was a change. While a demand for goods increased, workforce declined sharply. This resulted in a rapid rise of mechanization. A growing number of machines, and their increasingly complex construction caused more downtimes in production. These factors contributed to the implementation of preventive maintenance, which consisted of a thorough inspection and repair of equipment at specified intervals. Therefore, in the second generation, preventive maintenance prevails. Even this change was not without complications. In comparison with other operating costs, maintenance costs began to soar. To bring these costs under control, planning systems and maintenance management were introduced. Since the mid-seventies, changes in industry scooped dynamics. Production downtimes started to be a growing problem, because they resulted in a reduction of manufacturing output and a further increase in operating costs. With the increase of mechanization and automation, it was also increasingly difficult to maintain the quality of services and products while respecting safety and environmental regulations. Therefore, with the advent of the third generation, devices and information systems are already commonly used to monitor a machine condition, and new methods are developed to evaluate the monitored condition. Maintenance is seen as an integral part of the production, which affects not only the quality and reliability but also the price of products. [Moubray 1997] Maintenance of the third generation is called a predictive maintenance, and later it develops into a proactive maintenance. From these types of maintenance, there is currently a gradual pass to complex systems of maintenance. [Legat 2013]

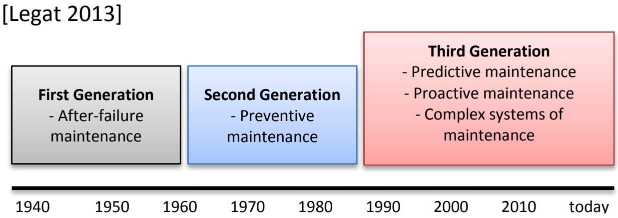

Figure 1. Generations of maintenance [Legat 2013]

3 CLASSIFICATION OF MAINTENANCE

After - failure (breakdown) maintenance, as mentioned above, ranks among the first generation. During operation, the full utility life of object is employed, thus maintenance occurs after the failure. This oldest type of maintenance can therefore be applied to a simple and cheap machine where a rapid repair or replacement is possible and where the maintenance also does not bring disadvantages in the form of extended unplanned downtime and high repair costs. This maintenance is therefore used for the cases where there is no way how to repair an object or when the repair is not worthwhile; furthermore, if it is not possible or economically advantageous to use a different type of repair. [Famfulik 2007]

As for the planned maintenance, we distinguish two basic types. The former is preventive maintenance which predominates in the second generation; the latter is predictive and proactive maintenance which represent the third generation. For both types, a system of maintenance is implemented under which the maintenance is then realised. The essence of the principle of preventive maintenance is to prevent a failure. Intervention into an object is deliberately carried out before the risk of failure exceeds tolerable limits. Preventive intervention can occur only if the object subjected to maintenance has acquired the characteristics which predispose it for predictable service life. Preventive maintenance is further divided into maintenance with constant interval and maintenance with variable interval. When the maintenance with constant interval is applied, only certain parts of the machine have a planned lifetime; other parts of the machine are expected to last throughout the entire operation. This maintenance is therefore used for machines which are expected to have a short-term operation. When the maintenance with variable interval is applied, this interval varies depending on the age of the machine. The reason is that while using the machine the life of its components changes, which affects the machine as a whole. [Famfulik 2007]

As for predictive maintenance, this maintenance is carried out only at the moment when the technical life of component has already been run down up to its maximum but at the same time before this component can cause an unexpected accident. Predictive maintenance can be further divided as follows: maintenance on the basis of a single assessment and maintenance based on a periodic assessment. Maintenance based on single assessment is applied in the cases where the occurrence of failure is expected with an extremely low probability, and a single intervention can prevent further repetition of the same failure. For this maintenance it is essential to have such information and methods for their processing, which would allow for the selection of the right decision based on a single retrieval. Maintenance based on a periodic assessment is selected in the cases where the machine is supposed to have a longer operating time than is the lifetime of certain components. Due to maintenance, the information obtained from the machine and consequently processed is therefore the information describing a change in technical condition of monitored components. Monitoring the development of failures is the concern of technical diagnostics. Proactive maintenance arose from predictive maintenance and both of them use technical diagnostics as a source of information. The purpose of proactive maintenance is not only to monitor and evaluate the technical condition of the object, but also to carry out such interventions that prevent or reveal a failure. It is based on the observation that certain failures are repeated regularly and have clear causes, which are therefore emphasized. [Famfulik 2007]

Schematic representation of maintenance classification is shown in Fig. 2.

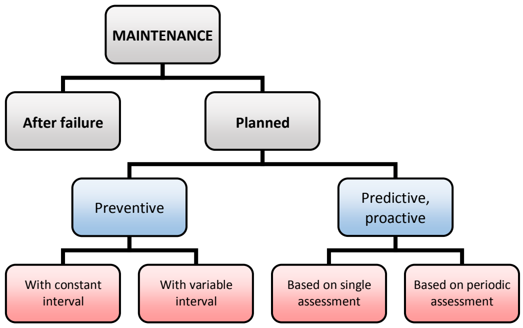

Figure 2. Classification of maintenance

4 SYSTEMS OF MAINTENANCE

Historically the development of maintenance systems is linked with the industrial revolution. Their development can be observed for example in connection with the development of railway transport. After putting the first steam locomotive into operation, a problem with its maintenance occurred. The former maintenance system was simple, thus directly proportional to contemporary knowledge of science, technology and experience with daily operation. Therefore, there is no doubt about a close connection between the vehicle and service personnel who not only drove the locomotive, but also maintained it. From the perspective of today's maintenance classification, it was an after - failure maintenance system. Since the vehicles were rarely used, this system had many advantages. These included, for example, a good knowledge of immediate technical condition of the vehicle or the need for a low number of skilled workers to perform maintenance. Therefore the system was able to ensure the adequate safety, but not a reliability of operation. With increasing use of rail vehicles it was necessary to put some standards into operation and maintenance of vehicles; therefore the first maintenance plans were created. Due to the production of increasingly complex vehicle designs, it was necessary to create specialized shops-floors to deal with larger maintenance tasks. The initially introduced after-failure system of repairs was gradually changed and a system of preventive elements began to be introduced. There were regular inspections of vehicles and in the case of insufficient technical state, repairs were performed. Further development gradually continued and after World War II a study field of reliability was established with research focuses on the origin and mechanism of failure processes; also a new diagnostics study field emerged. This changed the view of maintenance, a system of productive maintenance is introduced, and last but not least there occurs the development of reliability centered maintenance. [Nemecek]

Basic systems of maintenance to be used include:

4.1 *After-failure system of maintenance*

After-failure maintenance can be generally characterized as a basic or initial development stage of maintenance. This requires, in essence, a very small cost during the actual operation. It is based on the fact that a failure in this mode of operation necessarily occurs, and then the maintenance tackles the consequences. After-failure maintenance can be characterized as maintenance performed after the detection of a failure and is aimed at putting the object into the state in which it can perform its function.

This type of maintenance is mainly used for noncritical equipment that in the case of failure does not impair the manufacturing process or for the equipment that is planned to let live. [Helebrant 2013], [Legat 2013] A disadvantage of this system is thus a loss in the form of production breakdown, mainly because of the prolonged breakdown when the machine is not in use or its operation is very limited. These costs usually far exceed the costs of repair, so this kind of system is being phased out. [Nemecek]

4.2 System of planned preventive repairs

The second stage of development, which eliminates the shortcomings of the after-failure maintenance system, is a system of planned preventive maintenance. This system is often referred to as a system of maintenance carried out on the basis of the schedules, or cycles. After a specified time cycle, which is usually indicated by the equipment manufacturer, a preventive inspection and preventive repair are performed. The cycle of these inspections is given as the time interval between the acquisition of equipment and its overhaul. It begins with the so-called weekly repair, through a quarterly, half-yearly and yearly repair, ending with the overhaul.

Considering its content, this system is based on the machine reliability, and thus includes the requirements for ensuring the system care, which is an integral part of the optimal conditions for machine operation.

The main advantage and also the objective of preventive maintenance is therefore an effort to prevent the occurrence of failure. Since the maintenance is performed at appropriate intervals, maintenance costs are evenly distributed throughout the entire operation. Another advantage is that machine shutdowns are scheduled according to the production cycle, thus there are no unnecessary downtimes in production. From a financial perspective, the system is still quite expensive. The reason is a fixed time interval, based on intuition, regardless of the actual technical condition of the machine. [Helebrant 2013]

4.3 System of differentiated proportional care

Since each machine and equipment have different applications, complexity, characteristics, preset lifetime, operational loads, time usage, etc., maintenance is carried out according to a differentiated approach. This system divides or associates machines and equipment based on certain significance within the production process, the intensity of repair, technological complexity, the required level of safety and environmental impact, etc.

Therefore, this maintenance system determines a degree of complexity of machines, degree of technical level, technical condition on the basis of obvious signs of wear, and level of repairability.

In foreign literature, this system is also known as the productive maintenance. Its aim is to ensure the operability of machines and equipment with respect to fulfilment of essential requirements in production, elimination of losses in production in order to increase productivity. [Helebrant 2013]

4.4 System of diagnostic maintenance

This maintenance system respects, as the first, an actual technical state of the machine using objective methods of technical diagnostics. Machinery and equipment are being shut down only when they have reached the limit stage of wear or exceeded the limits of permitted tolerance.

Methods of technical diagnostics will detect a failure, locate the site of possible failures and specify the type of failure. Diagnostic measurements are performed through control-inspection activities in time cycles, on order, or by monitoring.

This maintenance system is therefore a qualitatively new maintenance system, built on the maintenance of machinery and equipment according to their actual technical condition objectively surveyed by methods of technical diagnostics. Quite often you can encounter a denomination, which is derived from the ultimate state of the measured diagnostic parameter, the so-called boundary maintenance. [Helebrant 2013]

The emergence and subsequent implementation of this system is mainly based on technological developments of machinery and equipment, when – in order to ensure the operation and maintenance - we can no longer rely solely on the inherent characteristics. [Pejsa 1995]

4.5 System of predictive maintenance

The system of predictive maintenance is seamlessly connected with the system of diagnostic maintenance, or can be viewed as its continuation. It is also known as the system based on the actual state, or it is denoted using a general term of elimination maintenance. Measured diagnostic parameters are used not only to evaluate the current technical state, but - based on trends - the prognosis of determining is performed, the so-called residual lifetime of diagnosed object, or if necessary, the time to the next necessary repair. The respective residual life is determined by the trend analysis, analytical measurement system or with the help of expert systems. Therefore this maintenance system requires a perfect diagnostic technology.

The main objective is, by means of diagnostic methods, to apply, identify their locations, extent and sources and to characterize the economic, environmental and safety consequences of possible further operation without repair. Then, in the subsequent prognosis of technical state, to characterize the probable development of failures, depending on the time of operation, which will enable the right tactical decision on the accumulation of necessary maintenance and repair tasks and also enable strategic decisions on the effective termination of the machine operation or its reasonable selling price. [Helebrant 2013], [Pejsa 1995]

This maintenance system allows for significant improvement of the maintenance management in accordance with the requirements of production, or to coordinate technological and maintenance shutdowns, and at the same time to prevent accidents with all their consequences.

4.6 System of automated maintenance

This system of maintenance management enables the maintenance management in real time; more often than about the system of automated maintenance, we are talking about information systems for maintenance management. Therefore the prerequisite for this maintenance is a support of computer technology.

Deployment of information systems constituted a revolution in the management of the entire maintenance system within the organizations. Computerized maintenance management is known under the abbreviation CMMS (Computerized Maintenance Management System) or the abbreviation CMMIS (Computerized Maintenance Management Information System). The main objective of these systems is to provide the users or organizations that are licensed with a full support for maintenance management, based on which a higher efficiency of supporting processes can be achieved. Currently, the market offers dozens of suppliers of software products that can provide their customers with the best solutions in information technology, based on actual requirements. [Helebrant 2013], [Legat 2013]

4.7 System of total productive maintenance (TPM)

TPM (Total Productive Maintenance) stands for the productive operation of the machines and equipment, and is currently considered an integral part of modern concept of production.

The origin of TPM is inseparably connected with Japan. Its core is based on the long-term development of maintenance systems, using mainly the theory of preventive maintenance, which was widespread particularly in the United States. However, TPM obtained its final shape only after its application in Japan. TPM is therefore an interconnection between the US preventive maintenance and the Japanese concept of total quality control. [Ben-Daya 2009]

5 MODERN APPROACHES TO MAINTENANCE

5.1 Total productive maintenance (TPM)

Total Productive Maintenance is a modern mode of managing the organization and production equipment with the entire organization being involved in, including all employees in all working positions. TPM does not accept the attitude of the worker - "I'm here mainly to make products, maintenance is the responsibility of the maintenance department"; it begins with changing the environment and care of machines and equipment, and ends with a change of corporate culture.

In order to work really well, TPM must become an integral part of corporate culture. That is why we talk about all the employees of the company being involved in. If there is an insufficient support for TPM ideas or insufficient pressure of the managerial staff, there is no functioning teamwork or TPM is not an integral part of daily work, then TPM cannot perform well. [Legat 2013]

The core concept of TPM is based on several principles:

- focus on maximizing the overall efficiency and performance by reducing equipment failures, scrap, idling, adjustment, the start-up losses, etc.,
- improvement of the current maintenance concept in the organization,
- development of autonomous maintenance,
- enhancement of knowledge and skills of all employees through teamwork, motivation,
- continuous improvement of equipment. [Helebrant 2013]

Therefore the aim of TPM in relation to production facilities is to maximize their efficiency throughout their entire technical life, minimize downtimes of these machines and avoid failures and non-conforming products.

TPM is based on the assumption that the best chance to detect unusual behaviour of the machine and thus influence the occurrence of potential failure has only the particular employee who operates the respective machine. Not for nothing because Václav Legát in his book refers to the TPM motto: "Protect your machine and take care of it with your own hands." [Legat 2013]

TPM concept was originally based on five pillars:

5.1.1 Evaluation of overall effectiveness of machinery and equipment

An evaluation of the overall effectiveness of machinery and equipment is carried out using the indicator of the overall equipment effectiveness (OEE).

The overall equipment effectiveness is a function of the losses caused by failures, errors in the processes, repairs, adjusting and readjusting times, fixing of operation, power losses due to reduced speed, idle machines or idle runs, but also by low quality of products. Maximizing the facility efficiency and minimizing the costs can be ensured by elimination of just these major losses. [Legat 2013]

5.1.2 Autonomous maintenance

Autonomous maintenance is performed by the machine operator; the operators independently carry out a part of the maintenance interventions. Other maintenance tasks, such as complex repairs or repairs requiring special qualifications, remain the responsibility of the maintenance department.

Operators better perform some of maintenance interventions because they know the machine and can use their experience from production. Gradually they are gaining a feel for detecting irregularities in the operation of the machine and can detect a possible failure already in advance. The result is a significant reduction of unplanned downtimes. [Legat 2013]

5.1.3 Planned maintenance

A planned maintenance program is aimed at creating an effective system of planned maintenance interventions, designed to guarantee a stable production process. Preventive maintenance is focused on the activities intended to ensure prevention of failures and includes inspections, controls, checks, planned renewal, replacement, diagnostics, etc.

A reward for preventive maintenance is an increased flow of production, reduction of the consequences of failures and their impact on quality and work safety, emergency of equipment, significant reduction of the cost for repair and maintenance of machinery and equipment. [Legat 2013]

5.1.4 System for designing the preventive maintenance and timely management of equipment

The system for designing the preventive maintenance and timely management of equipment consists of seven phases, which are as follows: development of product, concept of equipment, design of equipment, manufacture of equipment, installation of equipment, start-up of equipment and operation. Similarly, this system can be termed as preventive technical preparation of production, which can include designing of products with regard to easy manufacturability, organization and management of maintenance, repair plans, production plans, design and management of preventive maintenance. [Legat 2013]

5.1.5 Training to improve the skills of employees

Training of employees is carried out according to the individual needs of the organization; it mainly concerns the knowledge, principles and TPM tools, team communication, autonomous maintenance, planned maintenance, and knowledge of production.

Current requirements for production systems on efficiency, performance, quality and costs required an extension of these five pillars up to eight pillars of TPM. New pillars are 5S in administration, Quality, safety and environment, and Material flow.

The extension of the original five pillars helps the organization improve the overall quality of the working environment. It may be due to both the change of people's behaviour and the change of the facility because the change of facility initiates the change of the attitude of employees to their work. [Legat 2013]

In literature, this system can be ranked among the so-called proactive maintenance, which focuses on the causes of failures, based on the fact that the number one cause of failure is dirt and pollution. [Helebrant 2013]

In operational practice we can also find, for example, the maintenance systems and approaches to maintenance referred to as:

- RCM – Reliability Centered Maintenance,
- RBI – Risk Based Inspection,
- and more.

5.2 *Reliability – centered maintenance (RCM)*

Reliability - centered maintenance was developed in the late sixties of the twentieth century. Originally, it was intended for the aerospace industry, nowadays it is also common in other industries. The purpose of this methodology is to ensure the greatest possible reliability of used, usually complex, machinery and equipment.

The core of RCM is to find such maintenance through which the required availability, safety and economy of operation will be effectively achieved and it will also be economically beneficial for the respective company.

The RCM method has four basic features which differentiate it from other processes of preventive maintenance. These are the following:

1. To maintain the system functioning.
2. To identify failure modes for the components that may cause undesired malfunctions.
3. To categorize the failure modes using the tree of logical decisions.
4. To look for useful and effective prevention activities.

The instructions how to use this method are specified in the standard EN 60300-3-11 Reliability Management, Part 3-11: Instructions for use - Maintenance focused on reliability. [CSN EN 60300-3-11]

According to this standard, the overall process of RCM is divided into five steps:

- Initiation and planning,
- Analysis of function failures,
- Choice of tasks,
- Implementation,
- Continuous improvement.

The outcome is a plan of analysis and operational context. First, the necessity and scope of the proposed study is established. The target systems, where the current management policy of failures has failed or is suspicious, are detected. This is conducted through an extensive analysis of the data available in the system of organization maintenance management. Further it is necessary to identify the available knowledge and experience of specialized professionals, individual responsibilities, needs of external expert assessments, and training requirements. The specification of operational context must refer to how the object is operated, including the details on technical parameters of system performance.

Further, the analysis of failure is conducted, the operational data are collected and analysed along with the data obtained from tests, functionality segmentation is carried out, functions and malfunctions are determined and mainly the types, consequences and criticality of failures. The outcome is the FMEA/ FMECA analysis.

The third point of the RCM process is dedicated to the selection of maintenance tasks; the outputs are maintenance tasks. Here, e.g. the consequences of failures are evaluated; the most appropriate management policy of failures is selected and the tasks interval is determined.

The penultimate point deals with the implementation; the output is to create a maintenance program. Here, e.g. the details on maintenance tasks are found, priorities are determined and other interventions are implemented; the impact of aging will be examined.

The last step is devoted to monitoring of maintenance effectiveness, fulfilment of safety, operational and economic goals.

It must be noted that the RCM analysis can offer a maximum benefit provided that it is conducted at the design stage. The RCM method can be recommended for the creation of a maintenance program for more complex technical systems with a significant impact of their failures on operation disruptions and deterioration of their economy and also with a major impact on safety. [Legat 2013]

5.3 *Risk based inspections (RBI)*

This type of maintenance management is mainly used in the chemical and petrochemical industry and is focused on static equipment. Regular inspections of these facilities are governed by the legislature. Mostly the pressurised equipment, containers with hazardous chemicals, pipelines, etc. are concerned.

This method originated in the USA. Its principle is based on the identification of causes which could lead to cracks or tearing of devices. These causes and their possible consequences are subsequently evaluated with regard to the level of preventive and predictive inspections. This is ensured by qualitative and quantitative risk assessment methods. Based on the outcome of these methods, the assessed facility is assigned a risk level and, accordingly, the inspection interval is either extended or shortened. RBI therefore represents effective planning of inspections based on risk assessment. [Legat 2013]

For qualitative risk assessment, a matrix of 5x5 is used where the probability of failure is defined on the basis of summarizing six weight factors, namely the number of equipment elements, degradation mechanism, efficiency and usability of inspections, current state of equipment, nature of the process, safety of design and accessories. Consequences of failures are evaluated according to the risk of fire (explosion) and toxic dispersion.

Estimating the size of risk depends on a combination of failure probability and possible consequences of this failure where the sum of the individual risks represents the total risk value of the examined object.

For quantitative risk analysis, the estimate of probability of failure is related to the estimate of initiation of crack, hole or total rupture the container, i.e. to the event at which the hazardous content can be released into the environment. This quantity is time – dependent and it can be expressed as the product of three factors - frequency of the failures specific for the particular facility, the factor of care devoted to the facility and the factor to assess the mechanical condition of the facility. A quantitative analysis requires proper procedures, experienced team, and a sufficient amount of input information. This allows estimating a degree of risk for the facility with a higher degree of certainty. The analysis result is an effective and efficiently determined inspection program. [Legat 2013]

RBI is primarily used for reassessment of cycles of repetitive tests, and for rationalization of maintenance. An advantage of RBI is to optimize maintenance activities, as well as the effectiveness of financial means spent on maintenance with regard to the actual state of the object and possible consequences of failures. A disadvantage consists in increased time demands and the need for experts in the theory of risk. [Legat 2013]

6 SELECTED PARTICULAR CASES

The first example describes the implementation of TPM method. Since the company's founding in 1904 until 2000, maintenance was seen as a part of company. In 2000, outsourcing of maintenance was conducted; an external company was selected to carry out the maintenance in the company. In 2006, the company management decided, using an external consulting company, to streamline the process of machinery and equipment maintenance, and approved the introduction of TPM system. A team was established to implement all the necessary processes across the whole company. To start with, the company management decided to introduce the first three pillars of TPM - CEZ Improvement Program, Autonomous Maintenance Program and Planned Maintenance Program. [Team 2014]

First, a pilot program of tracking CEZ was introduced. Instead financially demanding automatic data collection, a flipchart was installed in each of the selected key machines, into which the machine operator, the employee of quality department and the supervisor of the respective shop-floor recorded every day the data needed to calculate CEZ.

Over the following six months, in pre-agreed intervals, CEZ was evaluated and the development of this indicator for each of the selected machines was monitored. Already after ca. 2-3 months, an increasing trend of CEZ was apparent. However, this system of CEZ evaluation was very time-consuming. Based on this and on a current lack of investment resources needed to create a digital infrastructure for automated data collection for CEZ evaluation, it was decided that only the availability of machines and equipment would be monitored and evaluated. The availability of machines is an actual time of machine operation where the time of failure is subtracted from the theoretical time of machine operation. Availability can be monitored by means of SAP R3, which controls the operation of the entire plant. To monitor availability, the machines were divided into three categories; availability was monitored for the category of the machines which, in case of failure, will stop the entire production line.

Fig. 3 shows the availability of machines in the respective production shop-floors over the entire fiscal year 2006/ 2007 and over 10 months (October/ July) of fiscal year 2007/ 2008. The graph shows the trend of increasing availability of machines in pre-production, foundry and assembly, and a declining trend in the availability of machines in a winding shop-floor. Despite the negative overall comparison of the machine availability against the previous fiscal year 2006/ 2007, the development in the individual months of the fiscal year 2007/ 2008 was positive and the availability target of 95.5% was met. [Team 2014]

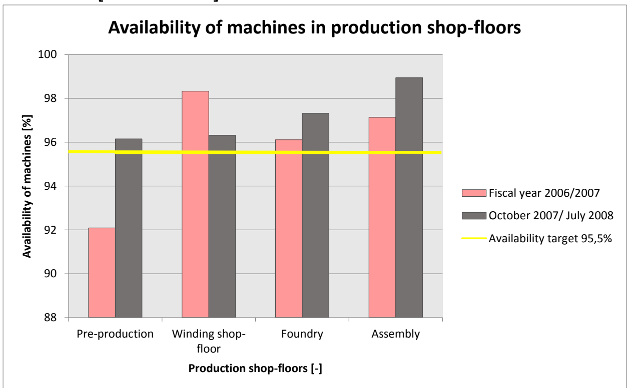

Figure 3. Availability of machines in the individual production shop-floors

Application of autonomous maintenance program initially required a selection of machines which allowed a simultaneous monitoring of availability. The first step was the introduction of standards for cleaning – shift-based, weekly, monthly and quarterly. For the standard of cleaning, the name of the machine is filled in, including its photograph, the area of the machine to be cleaned, who carries out the cleaning, method of cleaning, cleaning aids, the state of the machine to be cleaned, cleaning time and frequency of cleaning. Identical standards have been also introduced for lubrication.

To establish a program of planned maintenance, it was essential to obtain the necessary information on failures of machinery and equipment using the control system SAP R3, specifically the PM module, which is used for maintenance of machinery and equipment. For this reason, all production areas were equipped with an extended network of terminal connectors serving for check out of the production of electric motors, and also of terminal connectors for reporting the failures of machines. Subsequently, it was possible to create the necessary types of reports on failures or reports on planned maintenance in the PM module of the control system SAP R3. Types of reports and their division into planned maintenance and after-failure maintenance are indicated in Table 1. [Team 2014]

Unplanned maintenance	Planned maintenance
Report MP It is reporting of machine failures reported by the operator via terminal connectors in production. **Report MT** It is reporting of failures on buildings reported by shop-floor supervisors via computer (SAP R3). **Report Mx** It is reporting of minor repairs of the machines that do not cause a machine shutdown and are reported by shop-floor supervisors via computer (SAP R3).	**Report MF** This is a planned inspection of the machine. There is a call-off from the planning (from the SAP R3) and defined standards are carried out. **Report MO** It is a result of the planned machine inspection. In agreement with production, measures are planned in SAP R3.

Table 1. Planned maintenance and after-failure maintenance – types of reports

Having introduced the first three pillars of TPM, it can be clearly noted that the state of machinery was improved, which is at present expressed not only by the availability of the machines of monitored category (fiscal year 2014/ 2015) at an average value of 99.5%, but also by extending the life of machinery and equipment. This is achieved not only due to the improved care devoted to the machines by their operators under the autonomous maintenance, but also due to the pre-planned shutdown of equipment within the system of planned maintenance, carried out by specialized personnel of plant maintenance department. [Team 2014]

The second example describes the application of RCM method to the equipment for injection moulding, specifically on these parts - injection unit, closing unit, hydraulic system, electrical and electronic equipment. According to CSN EN 60812 Techniques for analyzing the system reliability - Procedure for Failure Modes and Effects Analysis (FMEA), the analysis was conducted of malfunctions of each component of equipment. Based on the FMEA analysis, it was impossible to determine which failures are the most relevant, most likely to occur and with the highest level of detectability. These values then served as a basis for calculation of the risk number for malfunction. Malfunctions, with the highest value of risk number, were subsequently paid the greatest attention to. [Team 2014]

The analysis revealed that the highest value of RPN (Risk Priority Number) has a hydraulic system because the hydraulic system performs the most important function of the device. Hydraulic equipment can be damaged by incorrect conduct of hydraulic oil in the hydraulic system, improper air-venting of hydraulic equipment, improper or fluctuating oil pressure in the system or a faulty filtration and oil cooling. Malfunction due to faulty conduct can be caused by leaks in the hydraulic system or by damage to the hosepack. Faulty air-venting of the hydraulic system is caused by a faulty air-venting tank. Incorrect or fluctuating pressure is caused by failure of the pressurised tank, electric motor, or by incorrect setting of pressure in the system. Faulty filtration and oil cooling can be caused by failure of electric pump or by the use of improper oil. The highest RPN number was achieved by failures of pressurised tank caused by mechanical damage and leaks. These two failures have the most considerable impact on the operation of the equipment. Malfunctioning of nitrogen tank does not ensure the required hydraulic oil pressure in the system; nitrogen leakage, in turn, has an impact on the imbalance of hydraulic values. Moreover, nitrogen leakage can cause possible environmental contamination. Another failure with a high RPN number is a poor condition of hydraulic oil. Insufficient amount of oil can lead to equipment seizure; improper oil level can cause filter clogging. Subsequently, it can lead to damage of the entire hydraulic system. Detectability of this failure without conducting the required preventive maintenance is very low. A high RPN number is also ascribed to the failure of the electric pump that has an impact on the process parameters and the environment. However, the pump is secured against leakage of oil by a drain sump; therefore the severity of failure is significantly lower than that of pressurized tank. An overview of malfunctions of the hydraulic system including the RPN numbers are shown in Fig. 4. [Team 2014]

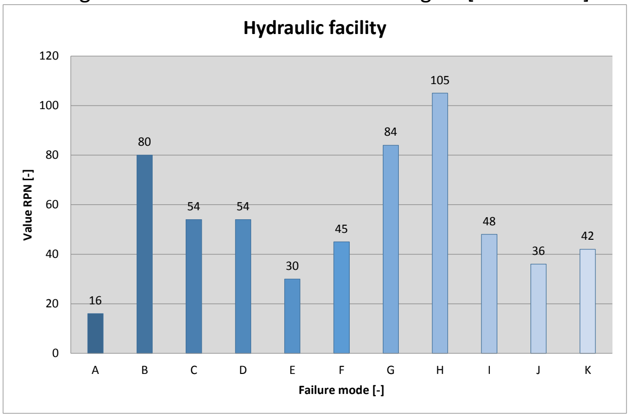

Figure 4. Graph of hydraulic facility malfunctions

A – failure of air-venting tank, B – improper state of hydraulic oil, C – mechanical failure of electric pump, D – leakage of electric pump, E – damage to tightness of hydraulic equipment, F – damage to hosepack, G – failure of pressurised tank, H - damage to tightness of pressurised tank, I - failure to observe overpressure in the pressurised tank, J – improper setting of hydraulic pressure, K – mechanical damage to electric motor.

According to the results of FMEA analysis, malfunctions of device were assessed in terms of environmental impact, safety and operation. At the same time the evaluation was carried out whether the failure is hidden or obvious. Based on RPN numbers, assessment of the consequences due to the failure and recommendations of equipment manufacturers, an appropriate maintenance plan was subsequently selected for each failure, including a preventive maintenance of equipment. This is essentially a regular cleaning and lubrication, control of functions, or replacement of components of equipment, so as to achieve a reduction of equipment failures, thus increasing the reliability of equipment. Further, a suitable interval of maintenance performance was chosen along with responsibility for this performance. The maintenance plan was selected so as to achieve the desired level of equipment reliability. [Team 2014]

7 CONCLUSION

The present article is a contribution to the issues of maintenance in the company practice. Maintenance becomes, especially in the last period, more and more important and becomes an integral part of the management of integrated care related to tangible assets. Maintenance represents an interdisciplinary process, which is a combination of technical, technological, managerial, economic and administrative activities aimed at maintaining or restoring the state in which tangible assets fulfill all the required functions. [Legat 2013]
Maintenance of tangible assets is one of several supporting processes of production that can contribute to the increase of manufacturing productivity and economic performance of the entire organization.
As is clear from the content of this article, maintenance has undergone a relatively complex development. Authors of the article also tried to briefly highlight this issue. Similarly, this also applies to the description of maintenance systems. Particular emphasis is placed on modern approaches to maintenance, which are being implemented in various companies; the experience is collected and the results are evaluated. Therefore, two specific examples from industrial practice were briefly discussed.
The authors of the present article tried to contribute to the understanding of maintenance, which is nowadays considered to be a separate scientific discipline having a significant impact on the quality of production, availability of production facilities, the company sales and also the company production costs.
In addition to the information above, the authors see also benefits of the article in fact, that the existing literature in this area did not sufficiently described all aspects of this problem.

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