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TPM in Large Enterprises: Study Results

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***Abstract*—**Having regard to the necessity of maintaining the technical infrastructure in a proper condition that ensures production continuity, companies decide to implement modern methods of technological machines park management. These methods include TPM, RCM and outsourcing. Large companies, in particular, are ready to invest in the implementation of these methods because of a great number of machines and a wide range of tasks of their technical service. Methodology of implementing these methods is well known. The aim of the studies, of which the results are presented in this publication, was the identification of real actions that are conducted in enterprises within the application of the TPM method. The studies were carried out in large manufacturing companies of different industries located on a certain area. The study's results point to the actions actually performed within TPM as well as to the effects of those actions achieved by the studied enterprises.

***Keywords*—**Infrastructure management, modern methods, technical infrastructure, TPM.

I. Introduction

ALLthe enterprises which decide on implementing one of the modern methods of the technological infrastructure management are well aware of the necessity of maintaining the machines in good condition. This good condition will enable the sustenance of the production continuity and also reduce the costs concerning machine failures and their effects. Large enterprises in particular realize that applying methods such as TPM, RCM or outsourcing is justified [1], [2]. Machine failures in large companies, where often one production line is the other's supplier and one department is the other's supplier, may lead to serious consequences and cause significant delays in production as well as resulting problems and costs for the company. Therefore, in large companies great emphasis is put on the implementation of modern methods of the technical infrastructure management [1], [3], [4]. Many companies see the connection between the particular modern methods of technical infrastructure management [5], [6] and the quality management [7]–[9].

The studies carried out until now have been limited to indicating the actions and stages in the implementation of the modern methods of technical infrastructure management, in both RCM [3], [10], [11] and TPM [12], [13]. The implementation costs were also analyzed [14]–[16]. In the literature, the ways of machine operation assessment such as e.g. calculating OEE indicator, that is recommended to use [17], [18], as well as many other indicators e.g. MTTR [19], [20] are indicated.

The literature offers several examples of the TPM implementation in different enterprises [7], [19], [21], [22] and in different industries such as e.g.: pharmaceutics, food [8], [23], [24], or in different countries e.g.: Nigeria, China, the Caribbean, Finland, Japan [25]–[29].

However, according to the authors, there is a lack of a comprehensive, comparative analysis concerning the real actions performed within the TPM implementation and operation in companies.

It is difficult to find in the available publications the information regarding problems of the companies with the implementation of the modern methods of the technological machines park management, or regarding the benefits brought to companies by these methods.

This article presents the review of the modern methods of the technical infrastructure management such as TPM, RCM and outsourcing, as well as it indicates the actions which should be performed whereas applying specific methods with the particular emphasis on TPM, which was the subject of the study. Next, it was checked whether the actions related to TPM are performed in practice.

In the study, of which the results were presented in this article, large enterprises located in the limited geographical area (podkarpackievoivodeship – the Aviation Valley) and which implemented TPM took part. The studies were limited to the area of one voivodeship because of its specificity i.e. a high concentration of the companies of aviation industry and the companies cooperating with aviation companies. The studies concerned the identification of actions realized within TPM as well as the benefits obtained.

II. The Review of the Modern Methods of Machine Supervision and Actions Performed within Them

A. Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a tool related to Lean Manufacturing philosophy. This philosophy is believed to the most effective way to increase radically the productivity of enterprises through the elimination of futility, understood as any activities, processes or investments that don't add value to a product [4],[13], [30], [31].

The basic objectives of TPM are:

1) Reduction of costs related to unexpected downtimes caused by defects.
2) Reduction of overall investment costs.
3) Reduction of unitary costs of a product due to better machine use.

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4) Improvement of the production process stability – a controlled process guarantees a product quality and its lower costs.
5) Introduction of an autonomous machine service system by operators as well as the system of machine scheduled service and repairs.
6) Providing work in groups consisting of people of different professional skills, what enhances all the workers' engagement [32], [33].

B. Reliability Centered Maintenance (RCM)

RCM is a process that allows determining the service requirements of the technical equipment with regard to its usage characteristics. RCM is often seen as a basis connecting several scientific fields such as: reliability, information technology, statistics and economics. It allows to achieve the effect of a synergy resulting from using many different methods to attain one clearly defined objective which is the optimization of overall service actions. The use of the formal procedure of RCM allows not only to choose a relevant strategy of servicing the particular parts and components, but also to determine specific techniques of a more effective implementation of the proposed strategy. All these tasks are based on the environmental, exploitation and economic factors. The main task of RCM is the maintenance oriented to reliability and equipment efficiency. RCM is one of the methods which were supposed to help to choose the best models of the reliability management of the objects and technical systems exploited [11], [34]. The term RCM was first used in a report published in 1978 and entitled *"Reliability Centered Maintenance"* authored by the engineers working for United Airlines: Tom Matteson, Stanley Nowlan and Howard Heap [10]. This report was created at the request of the US Department of Defense which expressed an interest in the effects of the work on the civil aircraft efficiency maintenance and the practices in this field. The report published by the engineers from United Airlines is one of the most important documents in the history of fixed assets management [3], [10].

Within a short period of time, the RCM method was adopted and introduced into different industries i.e. power industry, land and water transport, mining, gas and oil, heavy industry, chemical and pharmaceuticals.

C. Outsourcing

Outsourcing means using external resources. It is one of the concepts of improving enterprise activity by using the services or semi-finished products offered by an external supplier. The idea of outsourcing is to transfer the performance of tasks or processes to external companies which specialize in a given field. More and more commonly, outsourcing is used also to perform the enterprise's technical infrastructure management process [33], [35]–[37].

D. Actions Taken within Modern Methods of the Machine Supervision

Table I shows the actions that should be taken within particular methods of the technological machines park supervision.

TABLE I
ACTIONS RELATED TO THE USE OF PARTICULAR METHODS OF THE TECHNOLOGICAL MACHINE PARK SUPERVISION

Supervision method	Actions performed by maintenance services	Actions performed by an operator	Actions performed automatically	Use of additional tools
Total Productive Maintenance (TPM)	Machine maintenance, inspections and repairs according to the schedule	Autonomous service, regular assessment of the technical condition and discrepancy identification	Recording the machine working time	Machine work schedule
Reliability Centered Maintenance (RCM)	Analysis of the machines technical condition and continuous monitoring of their condition	Regular analysis of the technical condition, reporting the machine incorrect operation	Collection and analysis of the data considering technical parameters of the machine (e.g. vibrations, noise, processing accuracy)	Designing the maintenance process for the newly installed machines with account of technical, organizational and economic conditions
Outsourcing (O)	None – tasks performed by external services	Regular analysis of the technical condition	-	-

The actions indicated should be realized within a certain modern method of the technical infrastructure management. However, based on the authors' experience, it is not always the case.

That is why, the decision to carry out the studies presented in this paper.

III. STUDY SUBJECT AND METHODOLOGY

This paper focuses on the one of the modern methods of the technical infrastructure management, namely on TPM. The actions regarding TPM, identified and presented in Table I, were verified through the studies carried out in enterprises. The studies concerned manufacturing companies of different industries on the area of podkarpackievoivodeship (Poland).

As a detailed subject of the study, the areas concerning the TPM implementation and functioning in enterprises and described in the Table II were analyzed.

In the area studied (Poland – podkarpackievoivodeship), in 2010 when the studies began, there were 152 618 enterprises registered, including 202 large ones (data from the Marshal's Office of podkarpackievoivodeship, Department of Strategy and Planning). During the studies of the enterprises, the following categories for population identification were adopted: industry and production types. 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.

TABLE II
AREAS OF THE INFRASTRUCTURE MANAGEMENT COVERED BY THE STUDIES

Area	Description
Area of infrastructure management	Element of infrastructure management being studied
Reasons for TPM implementation	Reasons for TPM implementation by a company
TPM implementation	Criteria of choosing machines for TPM Actions performed in the TPM implementation process People engaged in the TPM implementation
Machine and spare parts categorisation	Criteria of machine categorisation Applied machine categories Criteria of spare parts categorisation Applied spare parts categories

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 studywas 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.

IV. 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 III shows the structure of the studied enterprises.

The most companies, taking a part in the survey, represent aviation (42%) and automotive industry (34%). The remaining industries included, among others, metal processing, chemical, wood and paper, and food industry. Among the studied enterprises most were the organizations with 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.

TABLE III
THE STRUCTURE OF THE STUDIED ENTERPRISES

Criterion	The structure of the studied enterprises					
Industry	Automotive	Aviation	Food	Chemical	Wood and paper	Metal processing
	34%	42%	3%	3%	5%	13%
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 possessedmachines	Mainly manually-controlled machines		Mainly numerically-controlled machines		Other	
	24%		74%		12%	
Condition of the company	Difficult		Stable		Developing	
	0%		28%		72%	

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, mainly CNC machines are used. In the majority of the studied enterprises, numerically controlled machines prevailed (74%).Among other technical machines, i.e. automatic machines were mentioned. The studied enterprises described their situation as developing (72%) or stable (28%). None of the companies described their situation as difficult.

V. STUDY RESULTS

A. Reasons for the TPM Implementation in an Enterprise

As stated in references [2], [19], one of the main reasons for implementing TPM in enterprisesis the failure decrease and, therefore, the increase of machine capacity. 71% of the studied enterprises decided on the TPM implementation. The studies confirmed (Fig. 1) that most of them decided on TPM implementation because of low machine capacity (41%) as well as a high failure rate (34%).

Among other reasons for the TPM implementation the companies mentioned:

1) the desire to improve machine reliability and capacity,
2) the necessity of providing the production continuity,
3) work safety reasons,
4) as preventive actions,
5) the awareness that TPM supports the fulfillment of client's demands,
6) the necessity of the reduction of the failure causes,
7) the need for better machine control,
8) the need for the processes improvement.

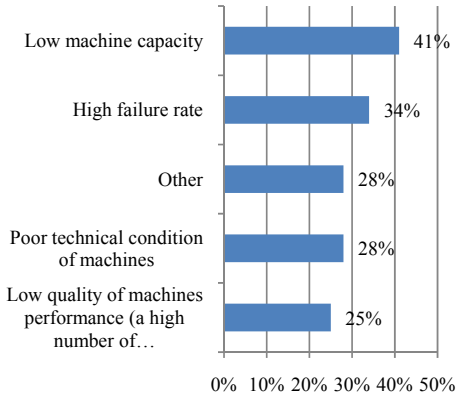

Fig. 1 Reasons for TPM implementation in enterprises

B. Actions Performed within the TPM Implementation Process

The sort of actions taken both during the TPM implementation and in the later period of the company's operation undoubtedly influences the effectiveness of the TPM implementation [4], [38]. The studies showed that 75% of the companies prepared the inspections schedule within the TPM implementation.Moreover, the companies took the following actions (Fig. 2):

1) The assessment of a machine technical condition (72%),
2) TPM workshops in a chosen pilot area (position, line, etc.) (66%),
3) The establishment of the autonomous maintenancescope (for an operator) (63%),
4) The assessment of machines with regard to meeting the health and safety requirements (63%) and other.

In 84% of the companies, mainly maintenance services workers took part. However, the companies stated that the direct supervision workers (81%) and production workers (81%) were also engaged.

C. Classification of Machines and Spare Parts

The implementation of the TPM system takes place gradually on particular machines in an enterprise. Determining the typing order of machines included in TPM is useful whereas implementing this system. For that purpose, categorization is conducted. It is also useful in determining preventive and predictive maintenance that is realized, what generates additional costs. It may be justified to increase costs related to that for important machines and to resign from such maintenance in case of machines of lower categories.

Among the enterprises studied, only 59% of them conduct classification.

A number of criteria for assessment of machines and the models of their classification are known. 70% of the companies indicated, among classification criteria, the technical condition of a machine. Other significant criteria of assessment proved to be a machine failure rate (67%) or its load (63%) (Fig. 3).Among other criteria of machine classification, machine changeability, criticality of maintaining production and the degree of the complexity of a machine construction were indicated.

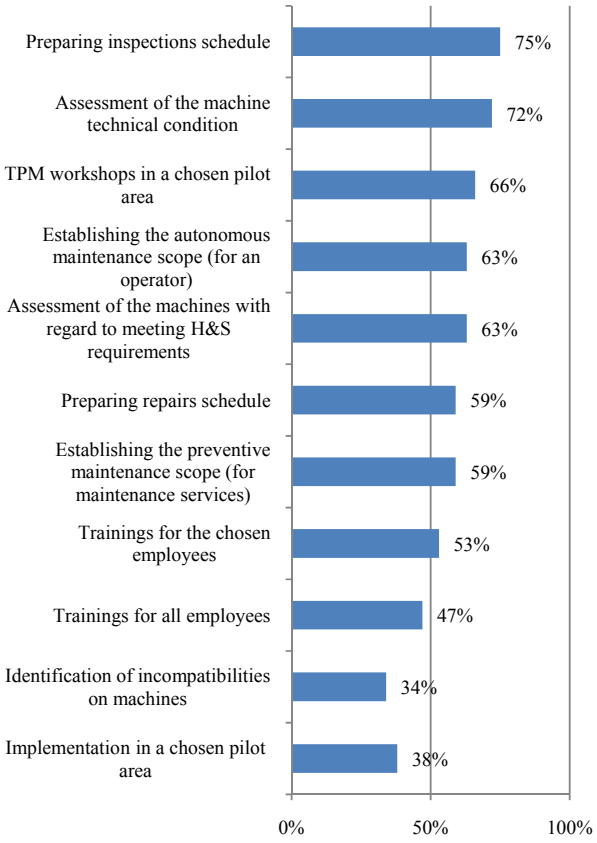

Fig. 2 Actions taken within TPM implementation

The enterprises used different models of machine classification. However, most commonly (67%) they classified machines according to the following four categories:

1) Very important machines, needing special supervision.
2) Important machines.
3) Less important machines.
4) Machines not in use (inactive).

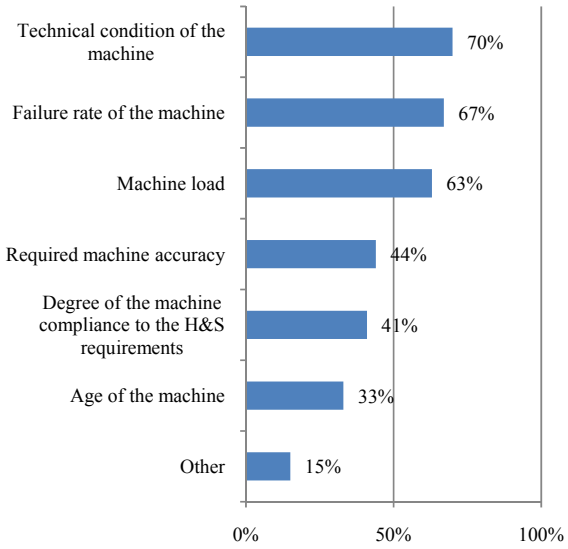

Fig. 3 Criteria of machine classification

The next important element influencing TPM implementation is spare parts classification (Fig. 4).

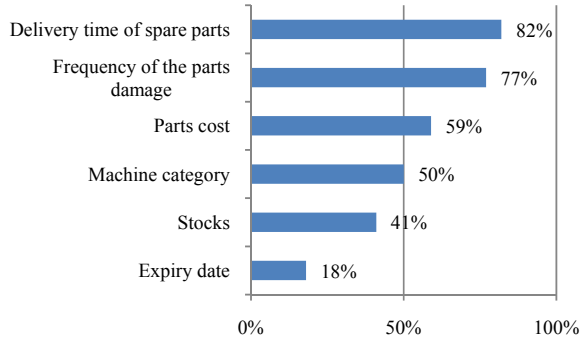

Fig. 4 Criteria of spare parts classification

The most often indicated criteria of spare parts classification were spare parts delivery time (82%) and the frequency of the parts damage.

D.Problems with the TPM Implementation

Modern methods implementation entails a lot of problems. It is not only connected with the ignorance of rules, aims and techniques of the implemented solutions, but also with the workers' anxiety of the unknown, of the new. Introducing changes is often associated by many workers with the employment reduction. A lot of problems appeared in the studied enterprises during the TPM implementation (Fig. 5).

The most common problems that appeared in the TPM implementation identified by the enterprises studied were: a lack of possibility of the machine exclusion from the production process for the time of TPM workshops (41%), workers' resistance (31%), difficulties in the machine compliance to the health and safety requirements (31%) and a lack of spare parts (28%).

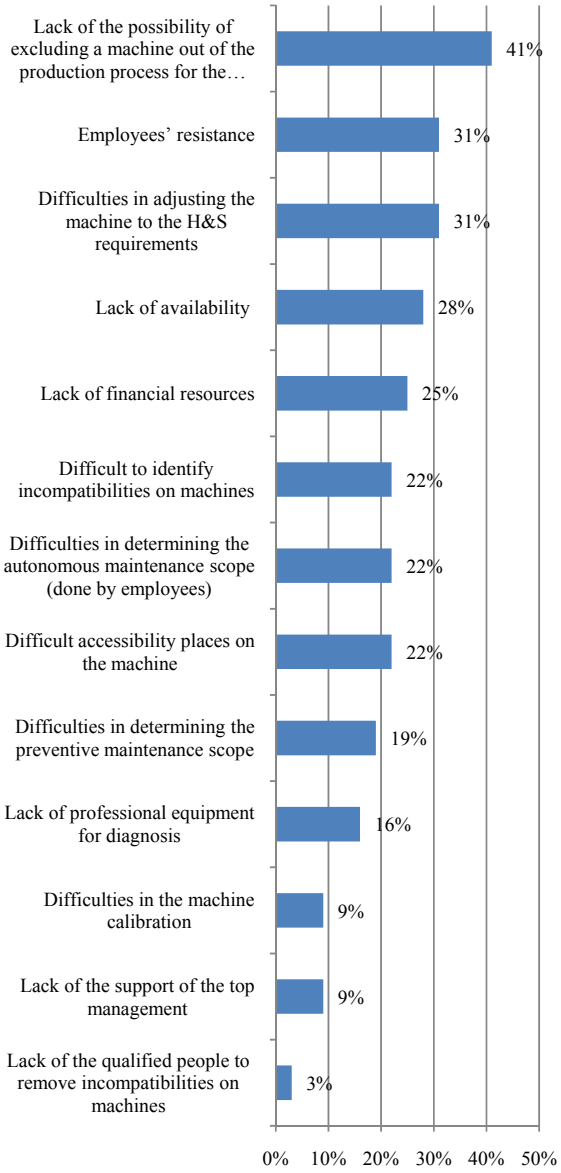

Fig. 5 Problems which appeared in TPM implementation

E. Effects of the TPM Implementation

TPM implementation in a manufacturing plant largely facilitates the process of the technological equipment supervision. The basic benefit resulting from the TPM implementation is the awareness emerging among workers which is the subject to constant improvements in conflicts and the problems accompanying them.

A crucial role in the assessment of the effectiveness of the TPM implementation in an enterprise is monitoring the TPM implementation effect on an ongoing basis. Many of the studied companies emphasize that the main effect is the decrease of the number of unplanned downtimes and failures. Table IV shows the effects of the TPM implementation

indicated by the companies studied.

The studies show that the enterprises notice the effects in the form of the reduction of a number of failures and unplanned downtimes. Additionally, in 9% of the companies a number of maintenance services workers decreased.

Only 25% of the studied companies calculate the OEE indicator. The values of the OEE indicator obtained by the companies are presented in Table IV. In these companies, the indicator is calculated with a different rate. It is most often calculated once a week or once a shift (36%).

F. Data Analysis

TABLE IV
EFFECTS OF TPM IMPLEMENTATION

Measure	Effects obtained				
Average failure time	< 1 h 30%	1-8 hrs 54%	8 -16 hrs 16%	16-24 hrs 5%	>24 hrs 3%
Reduction of a number of failures	<10% 21%	10- 30 % 57%	30-50% 14%	>50% 7%	No change 0%
Reduction in a number of unplanned downtimes	<10% 7%	10- 30 % 75%	30-50% 11%	>50% 0%	No change 7%
Change in a number of maintenance services employees	A number of employees increased 9%		A number of employees decreased 9%		No change 82%
Value of the OEE indicator	<30% 31%	30-50 % 8%	50 -70% 23%	70-85% 15%	>85% 23%

In the following analyses the authors searched for the connection between:

1) the typeof capital and the form of the actions taken in the TPM implementation,
2) the industry type of a company and the form of actions taken in the TPM implementation,
3) the production volume and the form of actions taken in the TPM implementation.

For the data presented, *Chi²* analyses were conducted to evaluate if there is a statistically justified influence of a industry type, type of the possessed capital, or a production volume on the actions undertaken in the TPM implementation. The results of the analyses are presented in Table V.

The analyses conducted show that the sort of actions taken within the TPM implementation, are not conditioned by the type of capital, neither the industry type, nor the production volume in large enterprises. Minitab 16 program was used to conduct the analysis.

G.Evaluation of the Actions Performed within the TPM Implementation in Comparison to the Theoretical Assumptions

The aim of the studies, of which the results are presented in this paper, was the identification of the real actions that are performed in large enterprises within implementing one of the modern methods of the technological machines park management, namely the TPM method. Table VI shows the actions related to the TPM implementation and maintenance in an enterprise recommended by the theory and these which were identified in this study as used in practice.

The percentage of the enterprises which perform specified tasks has been given too.

Based on the analyses of the data from Table IV, it may be concluded that within the TPM implementation in enterprises great emphasis is put on establishing the scope of preventive and autonomous maintenance.

The companies recognize the need of continuous skills enhancement of employees, particularly operators, in the technological machines supervision process. As a result of this, most or all employees take part in different trainings. In many enterprises, in compliance with TPM principles, an operator due to the autonomous maintenance takes over the basic activities connected to sustaining the proper work of technological machines.

VI. SUMMARY AND CONCLUSIONS FOR FURTHER STUDIES

The studies done show that all the studied companies with a foreign capital implemented TPM. It can be assumed that great emphasis is put on the implementation of modern methods in the technological machines park supervision in companies. The interviews with management staff show that guidelines for the TPM implementation came along with the foreign capital. In companies with the Polish majority capital the situation is a little different. There is stronger resistance, also among management staff. Nevertheless, some positive changes may be noticed as well as greater awareness and the need for the TPM implementation.

This sort of study is worth expanding to the companies of other industry types and to small and medium businesses, which generally possess smaller financial resources to be spent on implementing modern methods such as e.g. TPM. The study results may indicate the objectives which should be pursued to encourage companies to improve the supervision of TPM methods as well as to make them aware of the benefits and influence on the competitiveness increase of the companies operating on the more and more challenging global market.

TABLE V
HYPOTHESES MADE AND *P-VALUES* OBTAINED

Hypothesis	*P-value*
There is no difference in actions taken in the TPM implementation by the enterprises with Polish capital or Polish majority capital and the enterprises with foreign capital	0,999
There is no difference in actions taken in the TPM implementation among enterprises of different industry types	0,992
There is no difference in actions taken in the TPM implementation among enterprises with different production volumes	1,000

TABLE VI
ACTIONS RELATED TO THE TPM IMPLEMENTATION RECOMMENDED BY THE THEORY AND USED IN PRACTICE

	Actions	Percentage of the companies where the actions are applied in practice
Actions performed by the maintenance services	Machines assessment in respect of safety requirements	47%
	Assessment of machines technical condition	51%
	Identification of nonconformities on machines	27%
	Machines inspections according to schedule	56%
	Machines repairs according to schedule	44%
Actions performed by an operator	Preventive maintenance by maintenance service	42%
	Autonomous maintenance by operators	47%
Other actions	Training of chosen employees	40%
	Training of all employees	33%
	Pilot implementation in chosen area (work stand, line etc.)	27%
	TPM pilot workshops in chosen area (work stand, line etc.)	49%

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