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ANALYSIS OF THE IMPLEMENTATION OF THE SELECTED LEAN PRODUCTION METHOD IN THE PRODUCTION COMPANY

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Abstract: The article reviews the literature on the concept of Total Productive Maintenance (TPM) in manufacturing activities as one of the elements of lean production. On the example of an automotive manufacturing company, the TPM implementation process and the analysis of the effectiveness of the implementation of the method using the OEE indicator were presented. The analysis not only confirmed the effectiveness of the TPM concept in reducing the level and duration of machine failures, but also provided recommendations for further development of the concept in the company, and a basis for formulating objectives for the future.

Keywords: Lean Production, Total Productive Maintenance, Overall Equipment Effectiveness.

1. Introduction

Today's increasing globalisation, demanding customers and fierce competition are the main factors that motivate companies to undertake innovative ventures deciding whether or not an organization striving to continuously satisfy customer needs, the aggressive competitiveness of its products (Drucker, 2005). For this reason, organizations are looking for appropriate methods and business models to distinguish themselves from the competition and offer the customer a completely different product within the extended version of the product (Walczak, 02.05.2017). On the other hand, such challenges lead to changes in organisational structures, increasing modernization of production methods, management and maintenance of technical suitability of machines used in the company. In a competitive market, there is a need to reduce costs, e. g. by means of more efficient maintenance of the operated equipment (Burchart-Korol, 2007; Woźnicka, 02.05.2017).

The aim of rational operation is: to achieve the expected quality of products as well as to maximize the economic life of machines and production equipment while maintaining safe conditions of use. All these factors influence the need to minimize production costs and ensure the appropriate level of performance of machines, i. e. occasional interruptions in the production process. Achievement of these goals is possible through implementation of the TPM method, as confirmed by numerous literature reports (Borys, 1983; Nagashima, 1996; Szczepańska, 1998).

2. TPM – one of the basic methods of lean production

Total Productive Maintenance is an extension of TPM which means productive maintenance. A key feature of the TPM method is implementation of autonomous maintenance of machines and machines by operators, thus integrating many fundamental control activities into the production process. The main goal of TPM is to reach the level of three zeros: zero shortages, zero breakdowns and zero accidents at work (Legutko, 2009; Świątoniowski, 2011).

Although the TPM method comes from Japan, the initial systemic actions to improve the operation of the machine park date back to the beginning of the 20th century, and were taken in the United States. At the beginning of this period machines became more and more complex. As a result, the Americans separated a department in a production company, which was responsible for elimination of failures, maintenance and preventive maintenance (Aleksandrowicz, 2016; Wielgoszewski, 2007).

After the Second World War, the presented methodology was sent to Japan in order to rebuild the destroyed industry. The concept of functioning of a separate maintenance department has been improved – all employees have been included in the productive maintenance. The term TPM was first used and formulated by the Japan Institute of Plant Engineers in 1971. The TPM concept also encompasses the idea of Corrective Maitenance, which means constant improvement in the design of the machines, resulting from their imperfect design. In the 80's, constant development of methods monitoring the condition of devices influenced the emergence of the idea of Predictive-Maitenance – detection and removal of problems before they cause unplanned posting of the devices.

TPM is a method of organization that relies on proper fleet management – minimizing the costs caused by stopping a production line due to its failures. Introduction of TPM assumes inclusion of employees from the maintenance unit in production processes, and thus extension of the responsibility of machine operators for the maintenance of the machinery in orderly condition. Participation of the operators in the improvement, fault anticipation and prevention activities is an important element. Cooperation of the operators and the employees from the continuous maintenance department during maintenance or repairs, creates an opportunity for them to get to know one another and determines an increase in the operators' skills, which contributes to a better understanding of the machine. The TPM method is based on preventive prediction and prevention of failures during machine operation which makes it possible to reduce the number of malfunctions, repair time, extend repair cycles, as well as more efficient management of spare parts (Michlowicz, 2010).

The approach to machine inspection and maintenance also constitutes a difference between TPM and classic maintenance. In this respect, TPM assumes the primary role of widely understood preventive measures, in the understanding of inspections or maintenance, over the production plan. According to the TPM method, time spent on modification and maintenance is beneficial in the later period when the machine is kept ready for production. Implementation of this assumption is possible thanks to the use of such tools as: improvement service (modification of equipment to prevent defects and facilitate operation), preventive maintenance (preventing failures), prevention of operation (design and subsequent installation of reliable equipment requiring reduced maintenance), as well as maintenance of failures (repairs) (Furman, 2016).

In order to achieve the assumed objectives, it is necessary to take actions in eight key areas (Kubik, 17.02.2019):

- autonomous maintenance,
- targeted improvement,
- technical training for operators in the field of operation and maintenance of machinery,
- execution of planned inspections by operators and maintenance workers,
- an early equipment management programme,
- safety and environmental management,
- maintenance of an appropriate level of quality,
- TPM in offices.

3. TPM in the context of other concepts of improvement

In many cases, implementation of TPM takes place in companies where other improvement concepts, such as TQM (total quality management), lean manufacturing or six sigma, already exist. In the area of methods and tools, TPM aims at elimination of waste by continuous, small and, at the same time, fast and often cost-free improvements – kaizen, as a result of which this idea is the closest to the approach of lean manufacturing (Thota 02.05.2017). Therefore, TPM could be called a specific approach to fleet maintenance.

In terms of the so-called "soft"; aspects of management, activity of the employees in the process of TPM implementation, from the members of the highest management to the operators, is rooted in TQM (Kedar, 2016), is reflected in autonomous maintenance (Kocher, 2012). Another similarity between TPM and TQM is the use of mistake tools – proofinfing, the way processes are documented, as well as benchmarking (Gupta, 2005).

In relation to the six sigma methodology, which was born on the basis of TQM, responding to the difficulties of the previous concept (e.g. poorly defined objectives, too broadly understood role of training), the positive impact on TPM implementation is specified due to the systematized data collection that accompanies the implementation of the six sigma. At the same time, such activities are the foundation of the "analyse"; and "streamline"; phases in the DMAIC process (define, measure, analyse, improve, control), as well as the DMAIC process itself which allows to specify only the source causes which, after the statistical analysis, were considered statistically significant which allows for improvement of the process, focusing on the activities that will bring the best results (Thomas, 2016).

4. Evaluation of equipment efficiency – OEE indicator

The OEE (Overall Equipment Effectiveness) model is the most important element of quantitative evaluation of the TPM strategy. Due to its high flexibility, the model is also used at manufacturing companies in which this strategy has not been implemented. The OEE index is characterised by three main areas of company's activity: availability, efficiency of use and quality of manufactured products. Calculation of this indicator makes it possible to define improvement measures in the area of production processes, enables measurement of their effects and provides elimination of existing problems. The OEE indicator also identifies the company's bottlenecks and main problems (Rathenshwar, 2013).

Measurement of the TPM strategy is a result of the need to strive for one of its key objectives, which is to maximize the operational efficiency of technical facilities/systems. It is possible to achieve this goal by achieving: (Loska, 2013):

- maximum availability of machinery for use,
- maximum machine performance,
- maximum level of quality resulting from the purpose function of the machinery in operation.

The OEE efficiency model expresses the overall operating efficiency using three main factors (Table 1).

Table 1.
Performance indicators for OEE

Accessibility	Effectiveness of activities	Quality
$D = \frac{t_d - t_p}{t_d}$ (1) t_d – Available time t_p – Standstill	$E = \frac{t_c \cdot n}{t_o}$ ……………………………(2) t_c – theoretical cycle time n – the quantity processed t_o – operational time of operation	$J = \frac{n-d}{n}$ ………………………(3) n – the quantity processed d – number of defects
$OEE = D \cdot E \cdot J$ ……………………………………………………………………………………(4)		

Source: Nakajima, 1988.

The OEE indicator consists of three components which can play an independent role of indicator at a company, but each component is divided into individual elements which influence its over- or under-value (Oechsner, 2003). The components of OEE are:

- Accessibility – it is the percentage value within which the object is available to carry out the tasks entrusted to it. Availability is expressed as the ratio of working time (time spent on the production of products) to net operating time, including working shift time, less planned downtime.
- Effectiveness of activities - the ability of machines to maintain standard work rate. The use is expressed as the ratio of the actual production (number of manufactured products) to the target production (number of products that could be manufactured assuming maximum working speed of machines).
- Quality - defines the ratio of the number of good pieces to all pieces that have been produced. Quality is expressed as the ratio of good production (products meeting the quality assumptions) to actual production. This is the simplest component of OEE.

The essence of the OEE index is to compare the use of a used machine for ideal use, which occurs when production and its preparation are carried out as planned (Wilczarska, 2012).

An index value of more than 60% is considered desirable. World-class companies achieve an OEE ratio of more than 85%. A company that achieves a low OEE coefficient should not inflate it artificially as it is only an indication of the company's high potential (Palonek, 2009).

5. The process of implementing the TPM system in an automotive company

The implementation of the TPM concept in the analysed company started with management training. The information obtained in cascade was directed at the other employees of the plant. After a series of training courses aimed at making employees aware of the planned objectives and the scope of assigned tasks, a TPM implementation plan was drawn up. The plan covered several selected machines on the machining line and the assembler, creation of sheets and determination of the persons responsible – the owners of the machine. An important element in the implementation of the TPM concept was the selection of appropriate pilot machines whose technical condition could be defined as average. An average machine in a company with an average number of failures was a suitable source for developing appropriate TPM procedures.

The AUERBACH AX5 B2200 milling station with its surroundings has been selected. AUERBACH AX B2200 is a five-axis numerical machine on which mainly covers are produced. A preliminary TPM audit was carried out in the company, thanks to which inconsistencies were located. The following factors were taken into account: machine cleanliness, hydraulic system, lubrication, electrical and environmental documentation. The environment of the machine was taken into account, i. e. auxiliary stations, tool tables, cleaning products, health and safety etc. The state and location of tools used in the work were assessed. The workstation was evaluated using the two-stage method: 0 – no non-conformity, 1 – non-conformity. An excerpt from the results is shown in Table 2.

Table 2.
Part of the results of the TPM pre-audit

A PRE-AUDIT CARD TPM		
Name and type of machinery: Milling station AUERBACH AX5 B2200		
Category	**Areas to be checked**	**Points**
Cleanliness of the machine	1. Whether the dirt, dust occur on:	
	a. Machine body	1
	b. Machine guards	1
	c. Moving/rotating parts	1
	d. Switches, switches, limiters	0
	e. Indicators, meters	0
	f. Electrical cables	1
	g. Engines	1
	2. Are there unscrewed/released parts?	0
	3. Are there any bolts/nuts missing	0
	4. Are there redundant fasteners?	0
	5. Are there unnecessary objects?	1
	6. Is the machine fixed to the floor properly?	1
	7. Are the markings clear and legible?	0
Electrical system	1. Are the electrical connections damaged?	0
	2. Are the electrical wires damaged?	0
	3. Are the electrical wires properly protected?	1
	4. Is the lighting of the stand adequate?	1
	5. Are the controls working?	1
	6. Are the switches/switches/switches working?	1
	7. Are there any electrical safety signs?	0

Source: own elaboration.

The results of the audit carried out at the workstation were very poor. While analyzing the cleanliness of the machine within the scope of the seven specified areas, five of them did not meet the required standards. Irregularities in the area of machine cleanliness are shown in the figure 1.

Figure 1. Dirt on the unit and the machine's dirty and unstructured environment.

The audit of the electrical system revealed several anomalies that could pose risk to the operators and the employees. Anomalies in the electrical system in Figure 2.

Figure 2. Dirt on the cabinet, electric cable filters and 220V sockets.

When considering the hydraulic and lubrication systems, six out of fourteen requirements did not meet the standards, or it was not possible to check this issue due to the dirt on the machine. The category of documentation showed no list of failures and repairs, critical parts for machinery or personal protective equipment.

The audit of TPM at the workstation revealed a number of inconsistencies that hinder the work of the operators and the employees of the production line. All incompatibilities and failures hinder not only work, but also the possibility of early detection of defects or failures, which translates into potential downtime or shutdown of the machine from production. Table 3 shows the anomalies, taking into account the machines and their surroundings.

Table 3.
Summary of irregularities in the workstation area

Machine: Milling station AUERBACH AX5 B2200		
Summary of irregularities		**TPM – preliminary audit**
Number	Irregularity	Suggested action
THE SURROUNDING AREA OF THE MACHINE		
1.	Floor defects around the tool stand	Complete, smooth out
2.	Coolant pipes are “sweaty”	Install the installation
3.	Absence of a designated and permanently marked space for fire-fighting measures	Mark
4.	No marking of the place of the safety phone	Determine, mark
5.	Leakage of oil at the oil tank	Clean up, secure
MACHINE		
1.	Impermeability in the refrigeration system power supply lines	Seal
2.	Contaminated safety switches	Replace
3.	Contaminated 220V socket at the workstation	Replace
4.	Poor fixing of the electrical installation - covers, inputs to switches, sockets	Improve the fastening
5.	Dirty metal covers for electrical installation	Replace
6.	Polluted filters	Replace
7.	Descriptions of control buttons in a foreign language	Execute in a foreign language
8.	Dirty table with auxiliary tools	Replace

Source: own elaboration.

One of the stages of implementing the TPM plan for a specific position was to draw up a list of autonomous and preventive maintenance. The stand-alone service list and its scope apply to parts, machine elements and devices which are not interfered with by checking them during the work of the operator. Drawing up an autonomous list imposes an obligation and responsibility on the employee to carry out regular inspections and maintain cleanliness. Separation and continuous monitoring of control points places the responsibility for the position at which he works on the operator. Control of these points makes it easy to quickly detect possible incompatibilities or faults. The defined scope of autonomous operation for the AUERBACH AX5 B2200 milling station in the company is presented in Table 4.

Table 4.
Stand-alone service list

STAND-ALONE SERVICE LIST		
Name and type of machinery: Milling station AUERBACH AX5 B2200		
Marking on the machine	Activities	Frequency
1	Check the operation of the safety switches	Before any change
2	Check the function of the limit sensors	Before any change
3	Check the function of the safety switches	Once a day
4	Check the pump pressure gauges	Once a day
5	Check the completeness of the tool cabinet	Before any change
6	Check the cleanliness of the mats on the floor	Before any change
7	Remove the collected chips from underneath the table and workplace	Before any change

Source: own elaboration.

The next stage was to develop a list of tasks for employees from the maintenance cell. The scope of preventive maintenance concerns comprehensive maintenance of equipment and machines. A list of preventive maintenance activities is given in Table 5.

Table 5.
Preventive maintenance list

PREVENTIVE MAINTENANCE LIST				
Name and type of machinery: Milling station AUERBACH AX5 B2200				
Lp.	Activities	Performer	Machine parts	Frequency
1.	Replace hydraulic oils and oil filter	Mechanic	Hydraulic system	Once a year
2.	Perform inspection of electrical systems	Electrician	Power supply	Once a quarter
3.	Check the control elements	Mechanic	Switches	Once a year
4.	Check the hydraulic system	Mechanic	Hydraulic system	Once a quarter
5.	Check the mechanical clearances	Mechanic	Mechanical system	Once a quarter
6.	Check the cooling system	Mechanic	Hydraulic system	Once a quarter
7.	Check bearings	Mechanic	Mechanical system	Once a quarter
8.	Check the actuators	Mechanic	Hydraulic system	Once a quarter

Source: own elaboration.

The implementation of the TPM method was related to implementation of works in which a group of employees was involved. Tasks were carried out while the machine was in operation, with production halted, or when the workload of the machine was sufficient to carry out the operations.

6. Analysis of the effectiveness of TPM implementation

The process of implementing the TPM method in the company started at the beginning of 2018. On the basis of the collected data, an indicator for machining lines and assembly lines was calculated (Figure 3). After the implementation of the method, the company achieved the objective which was to achieve the OEE ratio of 65-70% which is a positive signal of the effectiveness of the implemented TPM method.

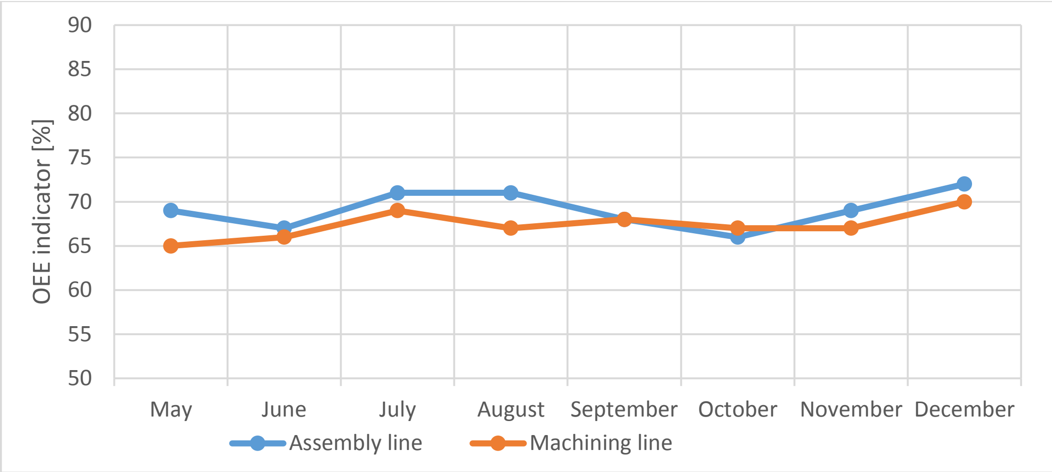

Figure 3. OEE indicator for assembly and machining lines.

The OEE values obtained on the assembly line and the machining line do not represent the actual status of the assessment of the effectiveness of the improvements introduced on individual machines, but provide an overall picture of the effective use of the production line in question. However, the OEE values form the basis for the formulation of targets for the future. Full use of the indicator consists in guiding it individually for each machine in operation. On the basis of the data obtained, equipment with the lowest OEE values should be selected, the causes of low usage should be analysed, and improvement measures should be implemented to minimise the occurrence of a given loss.

7. Summary

In the light of the presented results of the TPM method implementation, the effectiveness of comprehensive maintenance in reducing the duration and number of failures, and thus increasing the availability of operational equipment, has been confirmed.

An important factor that guarantees effective implementation of the TPM concept is a change in the approach to operators. The extension of their competence in the field of machine maintenance has contributed to an increase in the reliability of the equipment. The effects of the TPM implementation in the form of improving the technical condition of machines, their cleanliness and cleanliness of the production hall are clearly visible in the production plant. The benefit of the TPM implementation was also to relieve the employees from the maintenance cell by machine operators when removing simple failures. Qualifications of the maintenance staff were used to modify the equipment, major repairs and the implementation of new production equipment. The introduction of the TPM concept in the company has led to the emergence of positive changes contributing to production results.

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