Enhancing Productivity of CNC Machines by Total Productive Maintenance (TPM) implementation. A Case Study

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Abstract. Lean manufacturing is a business system that contributes to the growth of production efficiency and the company profit, by identifying and eliminating waste. TPM is one of the techniques used to eliminate production waste, being focused on the maintenance of production equipment, so as to increase their operation and efficiency, while ensuring the quality of production due to preventing the causes that lead to waste. In the present paper for the continuous improvement of the manufacturing process within the work cells equipped with CNC processing centers, TPM is implemented, which contributes to the optimization of predictive, preventive and corrective maintenance activities of production equipment, thus improving the efficiency of machine tools. TPM ensures maximum equipment efficiency due to the elimination of unforeseen equipment downtime, respectively increasing the speed and availability of the machine. The research is based on a case study from automotive industry. Monitoring the daily activities of the equipment is done through the TPM component, namely Overall Equipment Effectiveness (OEE) which presents the situation in the manufacturing process. The waste related to technological equipment were identified, such as: incorrect operation of the work equipment, unplanned shutdowns, respectively damages that occurred in the manufacturing process.

2. Introduction

The increase of productivity in the work cells equipped with CNC processing centers is directly influenced by the efficiency of the technological equipment and by the flow of raw materials and information.

Lean manufacturing is a concept that contributes both to increasing the efficiency of CNC processing centers and to reducing losses in the manufacturing process, thus optimizing the value flow. [1].

Lean manufacturing is a concept developed by Toyota and its main objective is to identify and eliminate losses. Any activity that does not create value is considered waste (muda in Japanese) and must be eliminated immediately from the operational flow [2].

To exemplify the value flow, a visual management tool is used, called Value Steam Mapping [3].

With the help of this tool the whole manufacturing process is drawn and analyzed, the first time it is drawn the current value stream mapping (which shows the initial state of the operational flow), and then following the proposals for continuous improvement in order to reduce losses it is drawn the future value steam mapping (showing improved operational flow) [4].

In terms of ensuring optimal operation (prevention of interruptions during the production process) of technological equipment, TPM is implemented, which is a world-class production strategy, respectively a Lean manufacturing component [5].

Any unplanned interruption of the production equipment represents a loss in the production process, which must be eliminated immediately, so that the manufacturing process to be a continuous one. [6].

Equipment maintenance is often reactive, intervening to fix it after a failure, but the adoption of specific TPM measures in the context of manufacturing on CNC procssing centers has a different perspective on equipment maintenance, because it applies a proactive approach, performing preventive maintenance activities of equipment [7].

Seiichi Nakajima, the founder of TPM, defines this production strategy as a concept through which a maximum overall efficiency is obtained for machines and installations throughout their lifetime, involving competence in maintenance of all departments within a company, but also of workers in order to ensure the good functionality of the equipment under their management [8].

The first implementation of the TPM concept took place in 1961 [9], by Nippondenso, which is one of the largest companies in Japan, producing components for the automotive industry, but the concept began with the introduction of preventive maintenance in Japan in 1951 [10].

TPM works on the basis of three prevention principles, according to the figure below.

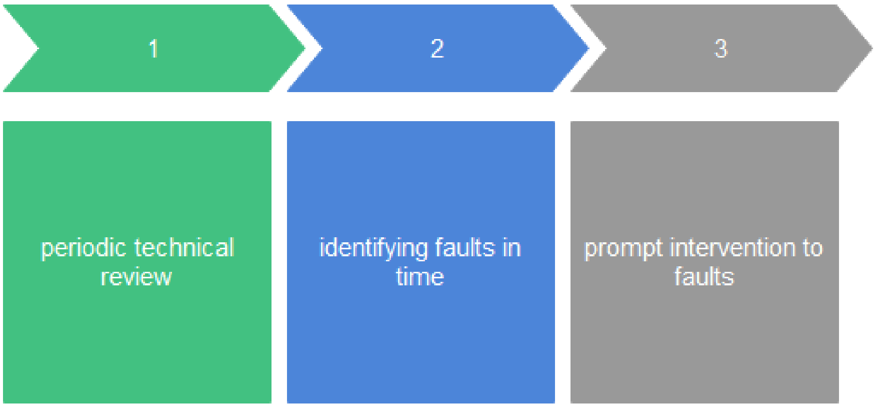

Figure 1. The TPM prevention principles

TPM ensure a stability of equipment including all type of maintenance politics like: preventive maintenance, corrective maintenance and predictive maintenance. All of these drive the equipment to its maximum productive efficiency. [11].

TPM is a technique, which manage the maintenance of all equipment, implemented within Lean Manufacturing, in order to continuous improve (kaizen) degree of usage and equipment lifetime [12].

According to Ahmad M.D. et al, TPM helps maximize equipment performance and prevent outages (due to technical failures) [13].

The purpose of TPM production strategy is to increase OEE by integrating a maintenance management system of the equipment involved in manufacturing process [14], [15].

The implementation of TPM ensures a maximum efficiency of the equipment due to the elimination of unforeseen stops of the equipment in the production process, respectively the increase of the speed and availability of the machine, eliminating the 6 wastes and at the same time obtaining quality products [16].

Some companies have implemented a software to monitor equipment performance (called Total Factory Monitoring), through which they can track in real time the performance of technological equipment and online monitoring. The data provided through this software, contributes to the measurement and evaluation of the operational activities within the manufacturing process, providing an overview of the entire production. Once this information is collected and centralized, from production, wastes are easier to identify, which will implicitly accelerate the process of continuous improvement in production [17].

Also, the implementation of a software that helps to monitor the performance of technological equipment, motivate continuously workers from different departments to ensure that they take the required actions and act accordingly to planned production and set objectives because they can see the impact that its actions has on OEE.

Preparation for the implementation of the TPM consists of the following objectives [16], [18]:

- Direct reporting of the situation to the company's management team;
- Adequate training for workers implied in manufacturing process;
- Implementing the TPM methodology on selected machine.

In conclusion, TPM aims for the following objectives [19]:

- More efficient usage of the equipment;
- Collaboration and Involvement of employees from all departments which own equipment;
- Increasing working hours of the equipment;
- Support from management team;
- Using equipment for continuous improvement;
- Reducing leading time, respectively maintain and increase the quality of the products.

TPM is basing on the following pillars [5], [17], [9]:

- Autonomously equipment maintenance;
- Kaizen (Continuous improvement);
- Planned maintenance;
- Quality of equipment maintenance;
- Training for involved staff in manufacture;
- TPM office
- EHS (Environment, Health, Safety);
- 5S (the basis of TPM).

5S is the base pillar in implementing 5S, which help to create safe and standardized working environment, it ensure obtaining of a perfect quality of the products by eliminating specific maintenance waste (the 6 wastes specific to used equipment).

In conclusion, the implementation of TPM would not be possible without the implementation of the 5S (Sort, Set in Order, Shine, Standardize, Sustain) [20]

2. Equipment monitoring using OEE

The general/global effectiveness of the equipment is a TPM component, through which are monitored daily activities of the equipment, the frequency of stop production caused by technical defections, in order to improve availability and technological equipment performance and implicitly it has the role to ensure the quality of the final product [21], [16].

Also, the most frequent Key Performance Indicator (KPI) in manufacturing cell which influence the implementation of lean practices is OEE. This KPI represent the initial state of the manufacturing process but it is also an instrument for management through which they can monitor and improve the manufacturing process thanks to its capability to measure and evaluate the productivity of the equipment/machine tool [22], [17].

2.1. Types of waste

Because of TPM component, manufacturing companies which own different technological equipment, managed to double(rarely even more) the productivity and performance of their machineries/machine-tool/CNC machining center, reducing, in some cases eliminating completely the OEE specific waste.

In the maintenance process for the equipment are identified 6 wastes, which are integrated in OEE, as following [23]:

- Breakdown losses;
- Setup and adjustment time;
- Speed waste;
- Minor stoppages;
- Defect;

- Rework and quality defects.

2.2. Benefits of OEE in manufacturing process

The OEE value represents the production equipment productivity, respectively, the ratio of maximum productivity capacity of the equipment (planned production) and the real production capacity from the manufacturing process, including any unplanned intervention in production (settings, adjustments, stops, defections, operator's error, changes).

Usually, the optimal OEE value is 85%, but in the most cases, OEE value is between 40% - 60%, which create significant possibilities for improvement and equipment performance increase.

Increasing OEE value has a positive impact on productivity, bringing with it multiple benefits in manufacturing process as following:

- Quick ROI (Return Of Investment) for technological equipment;
- Identification of problems from production process and avoiding wastes caused by those;
- Contribute to reducing production costs, which lead to increasing competitiveness in the market;
- Improvement of the manufacturing process has an impact even on the quality of the manufactured products;
- Increase the company reputation thanks to effectiveness and quality of delivered products;
- Reduce costs for equipment/tool-machine maintenance thanks to preventive maintenance.

2.3. OEE factors

In order to measure the EEO, the following key factors are identified and measured [11]:

a. Availability rate

Availability = (execution time)/(planned production time) (1)

Where:

Execution time is planned production time from which are deducted the times when the equipment was stopped (planned stops – changes in production process or unplanned stops changes, machine/equipment settings).

Planned production time is total time the equipment waits to produce.

Execution time = planned production time-down time (2)

Where:

down time represents the time allocated to the manufacturing process in which the machine / equipment is not in working order.

b. Performance Rate

Performance = (ideal time cycle * total amount of manufactured parts)/(Running time) (3)

c. Quality Rate

Quality = (total amount of quality parts)/(total amount of manufactured parts) (4)

After obtaining the 3 values above, OEE can be obtain using the next formula:

OEE=Availability *Performance * Quality (5)

2.4. OEE implementation

In order to calculate the performance of work equipment, the recording and analysis of production carried out over a well-defined period of time and established together with the production manager / engineer who is responsible for increasing production capacity and also quantifying operational activities, movements, storage, expectations and control.

In some companies, the OEE is measured daily to propose new solutions to improve the manufacturing process, respectively solutions that improve the factors that have an impact on the OEE. Once the values of these activities have been obtained, the main wastes are identified and specific solutions and techniques are proposed to eliminate them.

Given the high cost of investment in production equipment, the aim is to increase the overall effectiveness of the equipment in order to recover the investment in the shortest possible time and also to increase productivity and reduce leading time.

3. Case study

At the basis of this research is a study case, in which are analyzed all the wastes accumulated over 12 months, respectively, the 1st of January 2020- 31th of December 2020, at one of the CNC machining center.

The wastes are closely related to operational activity of the CNC machining center.

In order to implement and evaluate the OEE, the following steps will be performed:

- Establishing the machine - in this case it is a CNC machining center - DMG 55 H;
- The cause of the appearances of the different defects presented in the previous graphs will be identified;
- Relevant data about the production process will be collected;
- The data will be analyzed, respectively graphs will be built in order to have an overview of the current situation;
- Specific TPM actions will be implemented in order to remove and prevent defects registered on the CNC machining center.;

For realizing this case study, all wastes, thanks to lack of preventive maintenance of the CNC machining center DMG 55 H has been centralized, on which are realized different mechanical parts.

On this machining center has been realized machining operation, which involves technological itinerary with all operations specific to manufactured product.

DMG DMC 55 H is an horizontal CNC machining center duoBLOCK with 3 axes (longitudinal travel - x-axis: 560 mm, transversal travel - y- axis: 600 mm, vertical travel - z - axis: 600 mm), the maximum loading dimension is 500kg.

It has been identified and recorded a number of 355 defects because of lack of proper preventive maintenance for CNC machining center DMG DMC 55 H, over the 12 months, structured accordingly to the diagram below.

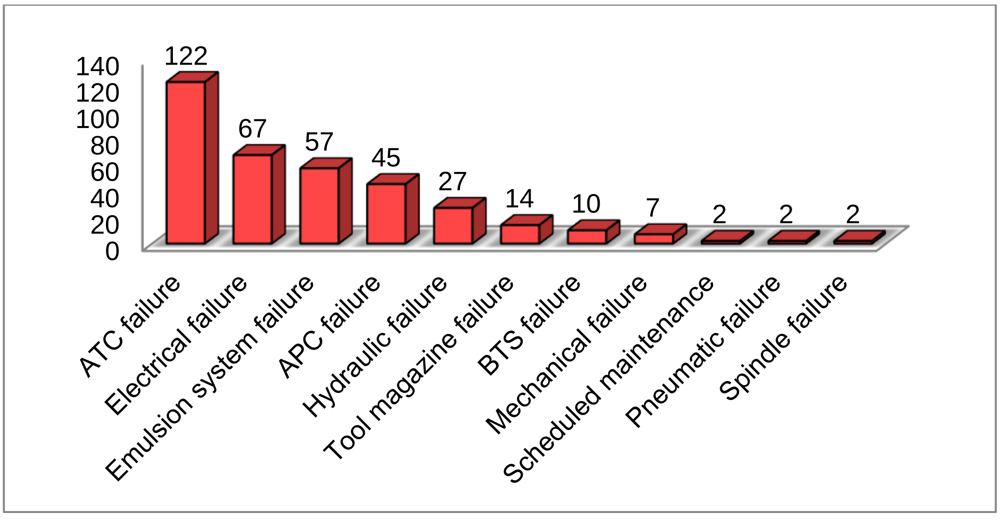

Figure 2. Distribution of the number of failures at the CNC machining center - DMG DMC 55H over a period of 12 months

In the company, the CNC machining center is working over 3 shifts (8hours/shift).

The diagram below, represents the total amount of recorded defects from CNC machining center over 12 month, distributed over the 3 shifts.

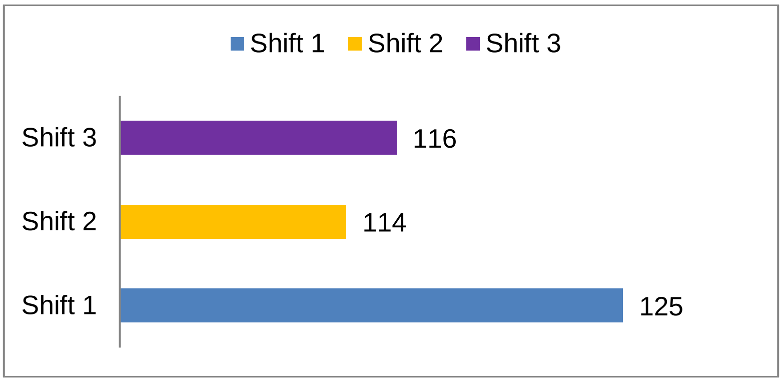

Figure 3. Number of defects distributed over the 3 shifts

First 3 defects (ATC defect, electrical defect and emulsion system defect) which were the most frequently repeated, represents 69.3% from the total amount of registered defects from this CNC machining center.

Once the main causes have been identified, preventive actions for these defects will be taken.

According to the graph in figure 4, the 355 defects occurred due to the lack of a corresponding preventive maintenance at the CNC machining center on the 8 types of products that were processed.

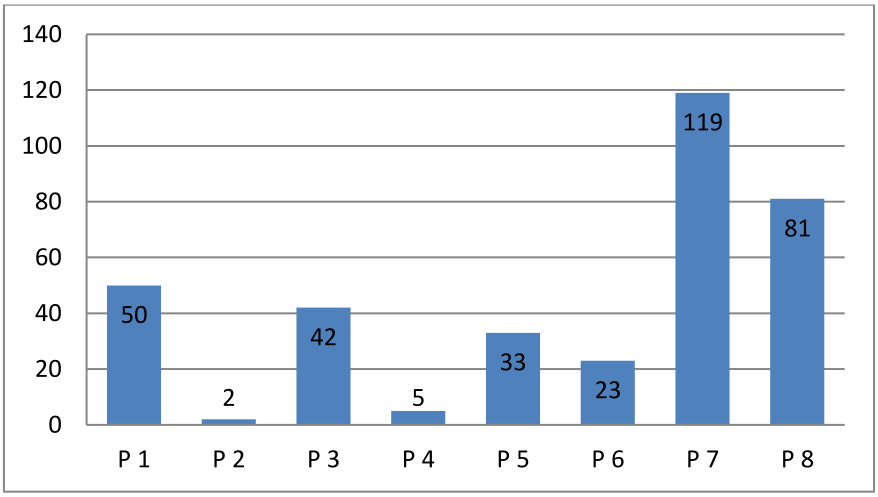

Figure 4. Distribution of defects by product types

According to graph from figure 4, the most defects have been registered at the production of product 7 (P7) and in graph from figure 5, are structured the 119 defects.

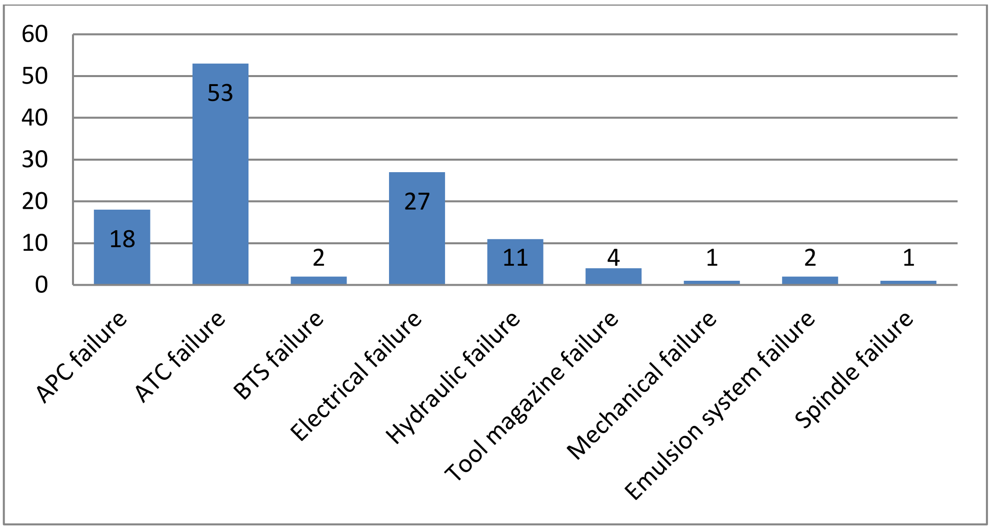

Figure 5. Distribution of defects for P7

3.1 OEE Calculation

It is important to mention the fact that other types of defects took place at the CNC machining center, but those were because of other causes than lack of preventive maintenance.

For determining OEE, obtained data about P7 product have been centralized, from 1st of Jan.2020 to 31th of Dec.2020

Product name P7;
Planned quantity 24940;
Produced quantity 13630;
Unprocessed quantity 11310;
Defective quantity reprocessed 95;
= Down time/year(min) 53640;
Cycle time 17 min/part;
Working days/year 301 (251 working days + 50 Saturdays);
Available minutes over year 301 day*24h/day *60min/h= 433440 min;
Break 0.

In the present study, OEE determination will be performed on product P7. In many cases, for OEE determination it is taken into account a well-defined period of time like: the number of shifts, over working hours or days.

For OEE determination, the 3 factors that determine OEE value will be calculated.

a) Availability

Total amount of time available represent the 301 days (including Saturdays when company was working).

The company works in 3 shifts, representing 24 working hours/day, respectively 433440 minutes available for work (planned production time).

Availability = (execution time)/(planned production time)
Execution time = planned production time-down time=433400-53640=379800 min
Planned production time=433440 min
Availability = (379800/433400)*100= **87.62%**

b) Performance

For determining the second factor, respectively performance, ideal cycle time (how long it takes to produce a part) will be determined, number of manufactured parts and planned running time.

Performance = (ideal time cycle * total amount of manufactured parts)/(Running time)

Performance = (17*13630)/433440= **53.45%**

c) Quality

For determining the last OEE factor, respectively the quality, the total amount of good parts manufactured will be determined, in ratio to the total amount of manufactured parts.

Quality = (total amount of quality parts)/(total amount of manufactured parts)

= (total amount of manufactured parts-scrap)/total amount of manufactured parts

Total amount of quality parts = manufactured quantity- scrap= 13630-95= 13535

Quality=13535/13630 parts=0.9930*100= **99.30%**

OEE = A*P*Q

OEE = 0.8762*0.5345*0.9930= 0.4650*100=**46.50%**

3.2 TPM implementation

After analyzing defects from production process for part P7, for improving the productive efficiency, actions to reduce and eliminate certain defect (accordingly to figure 6) related to machining center will be taken. These defects represent activities that are not add value for the manufacturing process, representing time waste.

By eliminating some of the defects via specific TPM actions, it will significantly influence OEE increase and improvement.

By the measures taken, it is aimed to reduce non-operational times, caused by the different mentioned defects with 50%, which will mean a total of 26820 minutes earned. Therefore, it will remain a total amount of 26820 minutes, non-operational times.

Given this aspect, OEE value would be **55.59%.**

4. Conclusions

This study case presented in this research, presents a tool which helps to measure equipment performance and also identify main wastes which led to a decrease in the efficiency of CNC machining centers.

After defects identification from CNC machining center, it has been implemented specific measures to eliminate these wastes, measure which will contribute to reducing production costs, reducing leading time, increasing the quality of the executed parts,, increasing production capacity and increasing the running time of the technological equipment.

The results of the research, emphasis the impact over increasing productive efficiency of the technological equipment (CNC machining center) because of TPM implementation. The increase of productive efficiency is reflected in measuring OEE, before and after TPM implementation.

According to the study, the OEE has been measured before and after the TPM implementation. Before implementing TPM, the OEE value was 56.50%, and after analyzing and taking some specific lean manufacturing improvement actions, OEE value was 55.59%, which represents an improvement of OEE value by 9.09%.

In graph from figure 6, it can be noticed the differences between the OEE factors before and after TPM implementation.

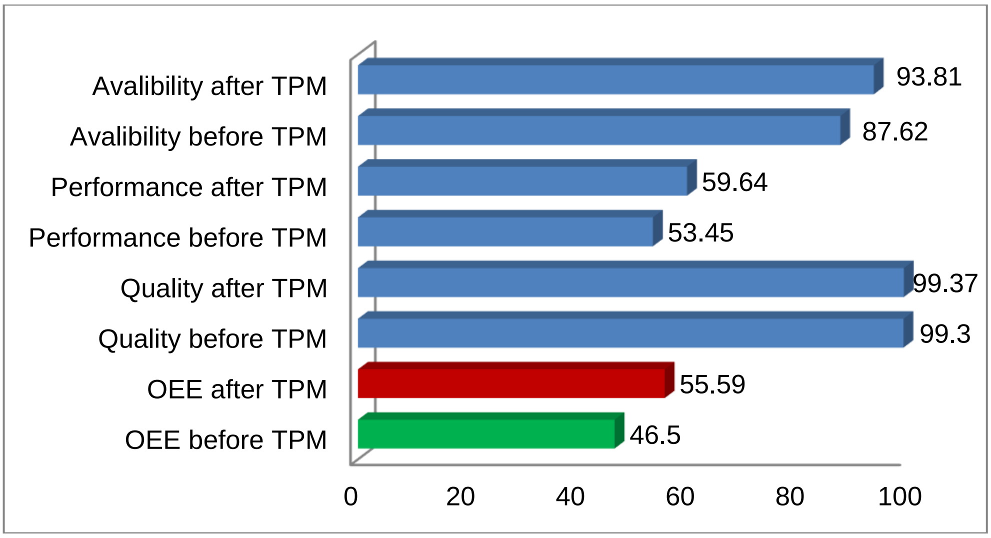

Figure 6. The difference between OEE factors between before and after TPM implementation

Considering the elimination of the non-operation times caused by some defect because of the lack of total preventive maintenance, the obtained improvement is significant.

The main measures taken for OEE grow, were measures for efficient solution to reduce defect like: 5S implementing, employees, respectively operators and CNC programmer trainings to maintain the equipment and also to identify easier the main causes which led to repetitive defects and maintaining the working place clean.

References

[1] Gherghea I C and Bungau C, 2018 Poka yoke application synthesis in manufacturing engineering *Proc. 6th Rev. Manag. Econ. Eng. Int. Manag.* Conf. **6**, pp. 564–571.

[2] Cirjaliu B and Draghici A 2016 Ergonomic Issues in Lean Manufacturing *Procedia - Soc. Behav. Sci.* vol. **221**, pp. 105–110.

[3] Gherghea I C, Bungau C and Negrau D C 2019 Lead time reduction and increasing productivity by implementing lean manufacturing methods in cnc processing center *IOP Conf. Ser. Mater. Sci. Eng.* vol. **568** no. 1.

[4] Gherghea I C, Bungau C and Negrau D C 2019 Best Practices to Increase Manufacturing Productivity - Comparative study *MATEC Web Conf.* vol. **290** pp. 1–9.

[5] Tondato R and Gonçalves M B 2013 Total Productive Maintenance: A casey study *22nd Int. Conf. Prod. Res. ICPR* vol. **12** no. 1.

[6] Arunagiri P Gnanavelbabu A. 2014 Identification of major lean production waste in automobile industries using weighted average method. *Procedia Eng.* **97**, 2167–2175.

[7] Patil J and Raut N 2019 Study Of Total Productive Maintenance And Improving The Production vol. **6**, no. 1, pp. 519–522.

[8] Gosavi A 2006 A risk-sensitive approach to total productive maintenance *Automatica*, vol. **42,** no. **8**, pp. 1321–1330.

[9] Aziz I, Karim S and Hossain 2013 M Effective Implementation of Total Productive Maintenance and Impacts on Breakdown Time and Repair & Maintenance – A Case Study Of A Printing Industry In Bangladesh *Int. J. Eng. Res. Dev.* vol. **8**, no. 1, pp. 1–9.

[10] Sharma K, Gera G, Kumar R, Chaudhary H K and Gupta S K 2012 An Empirical Study Approach on TPM Implementation in Manufacturing Industry *Int. J. Emerg. Technol.,* vol. **3**, no. 1, pp. 18–23.

[11] Dennis P 2015 Lean Production simplified - A plain - Language Guide to the World's Most Powerful Production System, **Third Edit**. CRC Press.

[12] Kulkarni A and Dabade M 2013 Investigation of Human Aspect in Total Productive

Maintenance (TPM): Literature Review *Int. J. Eng. Res. Dev.,* vol. **5**, no. 10, pp. 2278–67.
[13] Ahmad M F, Zakuan N, Jusoh A and Takala J 2012 Relationship of TQM and Business Performance with Mediators of SPC , Lean Production and TPM, *Procedia - Social and Behavioral Sciences* vol. **65**, pp. 186–191.
[14] Riezebos J, Klingenberg W and Hicks C 2009 Lean Production and information technology: Connection or contradiction? *Computers in Industry*, vol. **60**, pp. 237–247.
[15] Laugen B T, Acur N, Boer H, and Frick J 2005 Best manufacturing practices: What do the best-performing companies do? *Int. J. Oper. Prod. Manag.,* vol. **25**, no. 2, pp. 131–150.
[16] Méndez J D M and Rodriguez R S 2017 Total productive maintenance (TPM) as a tool for improving productivity: a case study of application in the bottleneck of an auto-parts machining line, *Int. J. Adv. Manuf. Technol*, vol. **92**, no. 1–4, pp. 1013–1026.
[17] Ng K C, Chong K E and Goh G G G 2014 Total productive maintenance strategy in a semiconductor manufacturer: A case study, *IEEE Int. Conf. Ind. Eng. Eng. Manag.,* pp. 1184–1188.
[18] Arslankaya S and Atay H 2015 Maintenance Management and Lean Manufacturing Practices in a Firm Which Produces Dairy Products *Procedia - Soc. Behav. Sci*., vol. **207**, pp. 214–224.
[19] Bakri A H, Rahim A R A, Yusof N M and Ahmad R 2012 Boosting Lean Production via TPM *Procedia - Soc. Behav. Sci.*, vol. **65**, no. ICIBSoS, pp. 485–491.
[20] Bungau C, Blaga F and Gherghea C 2011 Method of analysis and audit, used to implement 5s in operational management *2nd Review of Management and Economic Engineering Management, Proceeding: Management of Crisis or Crisis of Management?,* pp. 36–47, vol. **2**.
[21] Wyrwicka M K and Mrugalska B 2017 Mirages of Lean Manufacturing in Practice *Procedia Eng.,* vol. **182**, pp. 780–785.
[22] Kumar A and Rajenthirakumar D 2016 Reducing the Manufacturing Lead Time of Export Pump Components in an Indian Pump, *Industry National J. Technology*, vol. **12**, no. 2 July, pp. 23–31.
[23] Almeanazel O T R 2010 Total Productive Maintenance Review and Overall Equipment, *Jordan J. MMechanical Ind. Eng.*, vol. **4**, no. 4, pp. 517–522.