A CASE STUDY OF USING TPM TO IMPROVE OVERALL EQUIPMENT EFFECTIVENESS IN THE AUTOMOBILE INDUSTRY

Basant Kumar Das[1], Malay Niraj[2], Nishant Singh[3]

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Abstract:

This paper evaluates methods to increase plant value by utilizing overall equipment effectiveness (OEE) through total productive maintenance (TPM). TPM is a quantitative measurement method that evaluates the efficiency of a machine or integrated production system. The study focuses on improving equipment performance and system reliability in an automotive production plant, aiming to reduce operational failures. Three cases from the automobile industry were investigated, demonstrating the most effective way to enhance OEE with the support of TPM's pillars. The results show that implementing all TPM pillars in a systematic manner leads to continuous industry improvement. The actual OEE levels for the analyzed machine were 70.62%, 64.34%, and 67.63%, with OEE improvements of 7.29%, 9.17%, and 6.8%. These results emphasize the importance of sustainability in achieving high-performance objectives and establishing a robust foundation for implementing the TPM model in the automobile industry.

Keywords: Overall Equipment Effectiveness, Productivity, Total Productive Maintenance, Quality.

[1]Department of Mechanical Engineering, National Institute of Technology, Jamshedpur, 831014, Jharkhand, India.
[2]Faculty of Mechanical Engineering, National Institute of Technology, Jamshedpur, 831014, Jharkhand, India.
[3]Department of Mechanical Engineering, National Institute of Technology, Jamshedpur, 831014, Jharkhand, India.

Corresponding Author's Email: [1] basant122.nitjsr@gmail.com, [3]kaalkhanday@gmail.com

NOMENCLATURE

TPM	:	Total Productive Maintenance
OEE	:	Overall Equipment Effectiveness
VSM	:	Value Stream Mapping
CSVSM	:	Current State Value Stream Mapping
A	:	Availability
P	:	Performance Efficiency
Q	:	Rate of Quality
KPI	:	Key Performance Indicator

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1. INTRODUCTION

The principle of Total Productive Maintenance (TPM) was introduced by the Japan Institute of Plant Maintenance (JIPM) in 1971. Its primary objective was to enhance equipment performance and improve the overall effectiveness of the automotive industry. The concept of Total Productive Maintenance (TPM) plays a crucial role in improving operational efficiency and maximizing productivity within this particular industry. Since the late 1980s, there has been an increasing adoption of TPM in western countries, driven by the intense competitive environment where the automobile industry must meet customer demands for quality, cost, flexibility, and delivery times. As a result, it is imperative for organizations to develop strategies aimed at enhancing the adaptability and efficiency of their processes [1].

This study focuses on utilizing one of the lean manufacturing tools, namely overall equipment effectiveness (OEE), which establishes a standard and aids in identifying waste removal opportunities within the manufacturing process. Setting a target of 85% OEE is a reasonable initial objective, with subsequent attention given to additional techniques for further improvement. Across all industries, efforts are being made to enhance production and quality to strengthen their competitive position. The adoption and integration of "total productive maintenance" (TPM) not only enhances the operational efficiency and effectiveness of the production system, but also equips the facility to effectively address the demands presented by global competition and attain the esteemed status of world-class manufacturing (WCM) [2], [3]. Additionally, the goal is to reduce total production costs, increase profitability, and enhance the quality and performance of manufacturing processes simultaneously [4], [5]. Therefore, it is important to monitor and assess all current operations and tasks using specific evaluation methods in order to establish a consistent and reliable workflow that supports overall effectiveness [6]. The main aim is to utilize these approaches in order to eradicate process waste by means of implementing total productive maintenance [7].

The primary objective of this study is to analyze and evaluate methods of maintenance in order to enhance the operational efficiency of equipment within a semi-automated cell. The objective of implementing the Total Productive Maintenance (TPM) strategy is to decrease maintenance expenses and operational costs. This study aims to improve the overall performance and cost-effectiveness of the equipment within the specified cell using the proposed approach [8]. The OEE metric functions as a quantitative measure aimed at improving the overall efficiency of a plant and is commonly employed as a fundamental performance indicator. The pursuit of achieving an ideal manufacturing environment, characterized by the absence of breakdowns, defects, irregularities, and incidents, is a fundamental aspect of implementing Total Productive Maintenance (TPM) [9]. The achievement of an optimal state necessitates ongoing enhancement and the active engagement of all organizational tiers, ranging from frontline employees to top-level executives. When a substantial disparity exists between the present condition and the desired condition, it is imperative to concentrate on bridging this gap and formulating strategies to rectify it. The focus of Total Productive Maintenance (TPM) lies in addressing the six primary losses or gaps in machinery with the aim of enhancing operational efficiency. By quantifying these losses, individuals can determine the order of importance for necessary enhancements and eliminate inefficiencies [10], [11]. The process of adopting Total Productive Maintenance (TPM) involves several key stages. The procedure encompasses multiple phases, including the identification of the experimental region, the restoration of equipment to its optimal operating condition, the measurement of Overall Equipment Effectiveness (OEE), the addressing of significant losses, the implementation of proactive maintenance measures, and the cultivation of a culture centered around continuous improvement. The successful implementation of TPM necessitates active participation and engagement from all organizational levels, encompassing both top-level leadership and frontline operators.

The assessment of Overall Equipment Effectiveness (OEE) is predicated upon three fundamental elements, namely availability, performance, and quality rate [7]. In order to ensure accurate assessment of Overall Equipment Effectiveness (OEE), it is imperative to refrain from making assumptions and instead focus on gathering real-time data. The main aim of this study is to employ Total Productive Maintenance (TPM) as a strategy for improving the Overall Equipment Efficiency (OEE) of the specific machines being analyzed. The attainment of an 85% Overall Equipment Efficiency (OEE) serves as a crucial indicator of the importance of this agreement [12] [13].

2. LITERATURE REVIEW

2.1 Overall Equipment Effectiveness

The assessment of manufacturing system efficiency is facilitated through a commonly utilized approach in the field of lean management and Total Productive Maintenance (TPM). Total Productive Maintenance (TPM) is a methodology that incorporates the utilization of a quantitative metric known as Overall Equipment Effectiveness (OEE) to evaluate the efficiency of a productive system [14]. The evaluation of Overall Equipment Effectiveness (OEE) is of paramount importance in the identification of areas that necessitate enhancement, thereby facilitating the optimization of machine performance [15]. This underscores the importance of assessing Overall Equipment Effectiveness (OEE) as a strategy to improve the efficiency of manufacturing systems. The metric described in this statement pertains to the evaluation and improvement of machine performance, product quality, and changeover efficiency. The term "production efficiency" refers to the quantifiable measure of the ratio between the realized production output and the maximum production capacity of the equipment in question [16], [17], [18]. Through the integration of these metrics, all criteria related to equipment manufacturing undergo a transformation into a comprehensive measurement system. This system serves to assist manufacturing and supply chain teams in the optimization of equipment performance and the reduction of maintenance costs, employing the OEE method.

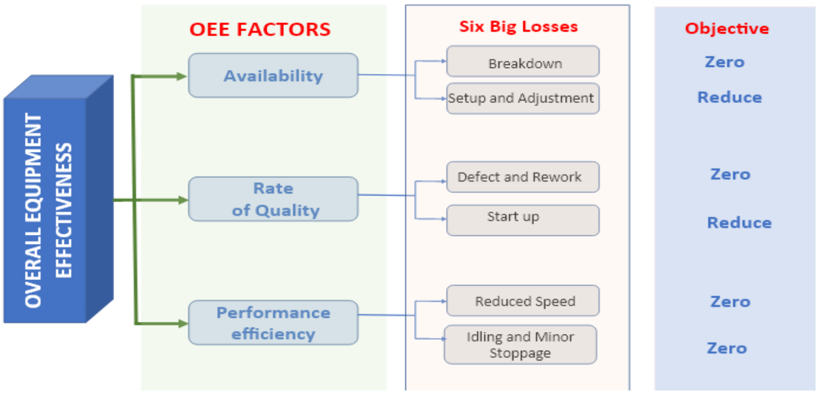


Figure 1. An overall equipment effectiveness model

Figure 1, presents a visual depiction of the six primary classifications of Total Productive Maintenance (TPM) losses [19]. The aforementioned categories encompass breakdown losses, setup and adjustment losses, defect and rework losses, start-up losses, speed losses, and idling and small stoppage losses. The utilization of the Overall Equipment Effectiveness (OEE) concept is frequently observed in conjunction with Total Productive Maintenance (TPM) and is widely acknowledged as a prominent approach in the manufacturing industry. The Operational Equipment Efficiency (OEE) metric functions as a quantitative indicator used to evaluate the operational efficiency of a manufacturing facility. The process involves the identification and establishment of a quantitative measure that directs and impacts diverse operations within the comprehensive framework of total productive maintenance. Figure 2 depicts the principal aims of Total Productive Maintenance (TPM).

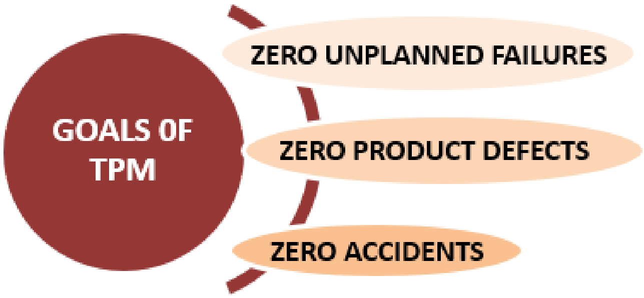


Figure 2. Goals of TPM

“OEE can be evaluated using plants performance efficiency, equipment availability, and rate of quality of the products based on the six major losses” [7].

$$\text{OEE} = \text{Availability} * \text{Rate of Quality} * \text{Performance efficiency} \tag{1}$$

$$\text{Where:} \quad \text{Availability (A)} = \frac{\text{Loading Time} - \text{Down Time}}{\text{Loading Time}} * 100 \tag{2}$$

$$\text{Performance Efficiency (P)} = \frac{\text{Total Pieces} * \text{Idle Run Time}}{\text{Operation Time}} * 100 \tag{3}$$

$$\text{Rate of Quality (Q)} = \frac{\text{Total Pieces} - \text{Defect Pieces}}{\text{Total Pieces}} * 100 \tag{4}$$

Downtime pertains to the temporal interval within the production process wherein the integrated system experiences a state of inoperability as a result of equipment malfunctions or the necessity for setup and adjustments. In contrast, the concept of loading time denotes the entirety of the production period that is available for utilization.

The processed quantity represents the number of pieces handled within a day or month, while the difference between loading time and downtime is referred to as operational time.

Defective pieces pertain to components that fail to meet established manufacturing standards, necessitating either rework or disposal. The Overall Equipment Efficiency (OEE) is widely regarded as a superior benchmark for evaluating maintenance performance within the manufacturing industry. Furthermore, it promotes the iterative improvement of policies and fosters the perpetual advancement of manufacturing systems. Table 1 presents the designated benchmarks for OEE, availability, performance rate, and quality rate, established at 85%, exceeding 90%, surpassing 95%, and surpassing 99%, correspondingly [16], [20].

When the calculated Overall Equipment Efficiency (OEE) is equivalent to the benchmarked OEE of top-performing manufacturing organizations, it indicates that the manufacturing organization is operating at an exceptional level. Nevertheless, in the event that the Overall Equipment Effectiveness (OEE) falls below the established elite benchmark, it indicates a pressing need for enhancements in maintenance policies and strategies. Failure to promptly address these issues could potentially compromise the operational continuity of the manufacturing organization. Table 1: Elite Objectives for OEE [20]

S. No.	OEE Factors	World Class Rate (%)
1.	Availability	>90
2.	Performance Efficiency	>95
3.	Rate of Quality	>99
OEE		**85**

2.2 The Six Major Losses

i. Breakdown: Breakdown refers to a type of failure that occurs randomly due to machinery or equipment malfunction. It occurs when unexpected events halt production, such as equipment malfunctions, objects falling, or emergency maintenance [21].

ii. Setup and Adjustment: The terms "setup" and "adjustment" pertain to the duration of production delays caused by alterations made to equipment. The adoption of the Single Minute Exchange of Dies (SMED) tool developed by the Total Productive Maintenance (TPM) methodology has a substantial impact on the reduction of setup time. By leveraging SMED, manufacturing companies can effectively boost their competitive edge through various means, including minimizing batch production size, reducing setup time and project scheduling costs, curbing waste generation, and optimizing material resource management. The ultimate outcome of these efforts is the production of superior-quality products that precisely align with client specifications [16].

iii. Defects and Rework: Defects and Rework encompass losses incurred when machinery and equipment fail to produce products of the desired quality according to predetermined standards. This includes losses in volume, time, and money due to product degradation, as well as the time required to rectify defective components and transform them into finished products [22].

iv. Start-up: Start-up refers to the losses experienced by a machine while it generates new items of the expected quality. Unstable working conditions, improper equipment handling, and installation are factors that contribute to start-up losses [23].

v. Reduced Speed: The phenomenon of reduced speed arises when there exists a disparity between the designated speed of a machine and its effective operational speed. Factors such as inadequate environmental facilities and insufficient equipment maintenance can result in reduced speed [24].

vi. Idling and Minor Stoppage: Idling or minor stoppage pertains to short intervals or minor disruptions in the functioning of machinery. Various factors can be attributed to the occurrence of issues, including blockages, flow obstructions, incorrect settings, or inadequate cleaning procedures [25].

2.3 Novelty of Present Case Study

The present case study highlights a significant improvement in machine production efficiency that was attained through the implementation of Total Productive Maintenance (TPM). Within the realm of the automotive sector, the implementation of Total Productive Maintenance (TPM) entails the amalgamation of diverse hierarchical strata within an organization, encompassing the formulation of strategies and the perpetuation of operational procedures. The support of a steering committee composed of senior management is crucial to overcome opposition on the shop floor and successfully drive the TPM initiative. A meticulous TPM pilot program facilitated the development of expertise and increased confidence among staff members, leading to expedited installation of essential equipment. Consequently, the implementation of TPM has enhanced the dimensional accuracy of the product.

Figure 3 effectively demonstrates the impact of implementing Total Productive Maintenance (TPM) on the desired level of precision in the nominal diameter of the RA Shaft, as analyzed using the 3 Sigma method. Following TPM implementation, the upper control limit of the shaft has been reduced from 42.09mm to 40.33mm, while the lower control limit has improved from 39.18mm to 40.09mm. Moreover, the control limit of the RA shaft has improved from 40.64mm to 40.21mm, which is very close to the nominal diameter of 40mm. The range of the control limit for the RA shaft has also significantly improved from 3.462 to 0.2883, indicating that a majority of the finished products now meet the desired specifications. These improvements in accuracy have positively impacted the outcome products of JMT Auto LTD through TPM implementation, underscoring the novelty of this research article.

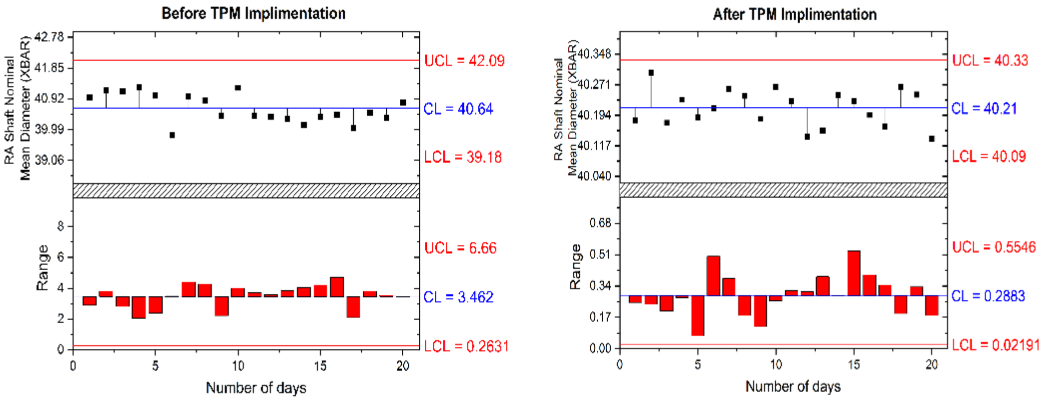


Figure 3. Variation in RA Shaft nominal mean diameter before and after TPM implementation.

2.4 Objectives of the Present Case Study

The primary purpose of this study is to achieve a set of overarching goals through the application of the Total Productive Maintenance (TPM) methodology. Specifically, the study will concentrate on one of the pillars of TPM, known as Kaizen, which functions as a strategic instrument for facilitating ongoing enhancements.

i. To measure and compare the Overall Equipment Efficiency (OEE) between

machines using TPM and those without TPM, in order to identify the sources of losses that contribute to lower OEE.
ii. To identify the main causes of stoppage losses within the production process.

3. PROCESS STUDY

The manufacturing process initiates by performing machining operations on the raw material in accordance with the specifications provided by the customer. Following the machining process, the material undergoes a cleaning procedure prior to undergoing a final inspection. Once all the necessary criteria are met, the item is deemed ready for distribution. The Current State Value Stream Mapping (CSVSM) was developed by utilizing important data including Demand, Net Available Time, Number of Shifts, and Cycle Time. In this study, a particular machine was selected for in-depth analysis based on the results obtained from the CSVSM. The Overall Equipment Efficiency (OEE) of the machine was computed and the results were thoroughly analyzed in order to propose suggestions for improving its OEE. The procedural sequence employed in this investigation is illustrated in Figure 2.

In order to assess the overall operational equipment effectiveness (OEE) of the plant and address and mitigate any excessive losses, the automotive industry company selected for this study, JMT Auto LTD, engaged the participation of a dedicated and driven workforce, all striving to meet the specific requirements of their clients. This industry specializes in the manufacturing of various automotive parts, including gears, shafts, rocker levers, crankshaft gears, coupling flanges, shifter forks, RA Shafts, housings, planet wheels, drums, covers, axle pin bodies, spindles, carriers, bearings, flanges, bushes, and flywheels. For the research work, appropriate machines known as TPM management model machines were selected. The chosen automotive industry employed three types of automotive manufacturing machines as TPM management models.

3.1 CNC lathe machine with SAP machine no. (9601431)

Figure 4. CNC Lathe machine SAP machine no. (9601431) in JMT Auto ltd.

3.2 Milling machine with SAP machine no. (9601462)

Figure 5. Milling machine SAP machine no. (9601462) in JMT Auto ltd.

3.3 Rack and Pinion Systems machining machine with SAP machine no. (9601486)

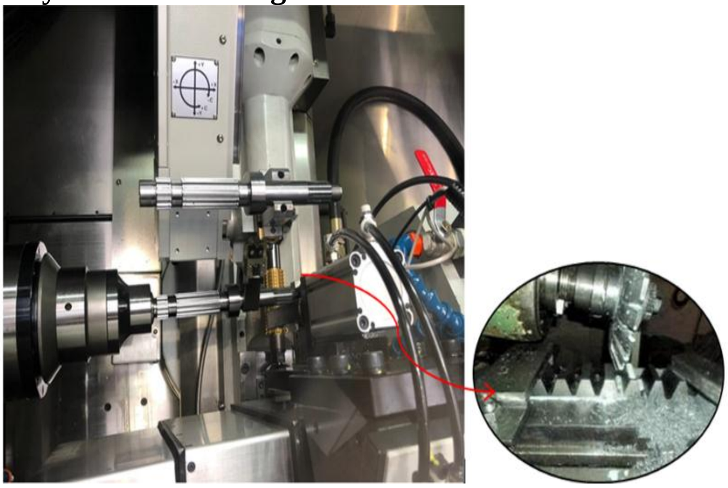


Figure 6. Rack and Pinion Systems machining machine SAP machine no. (9601486) in JMT Auto ltd.

The process map of Automobile industry is shown in figure 7.

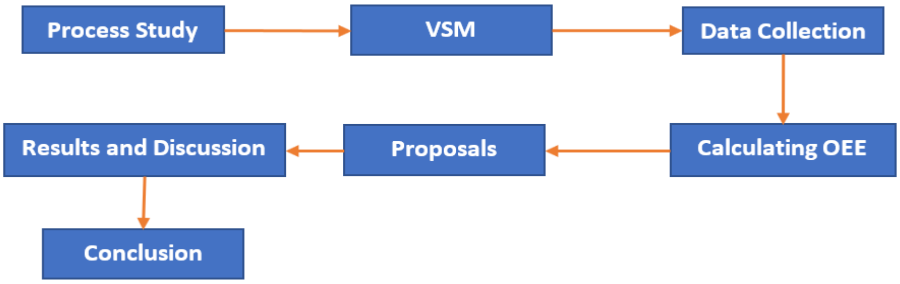


Figure 7. Process Map of Machining Process in Automobile Industry

Figure 8 displays the process map for the milling machine, CNC Lathe machine, and rack and pinion systems machine.

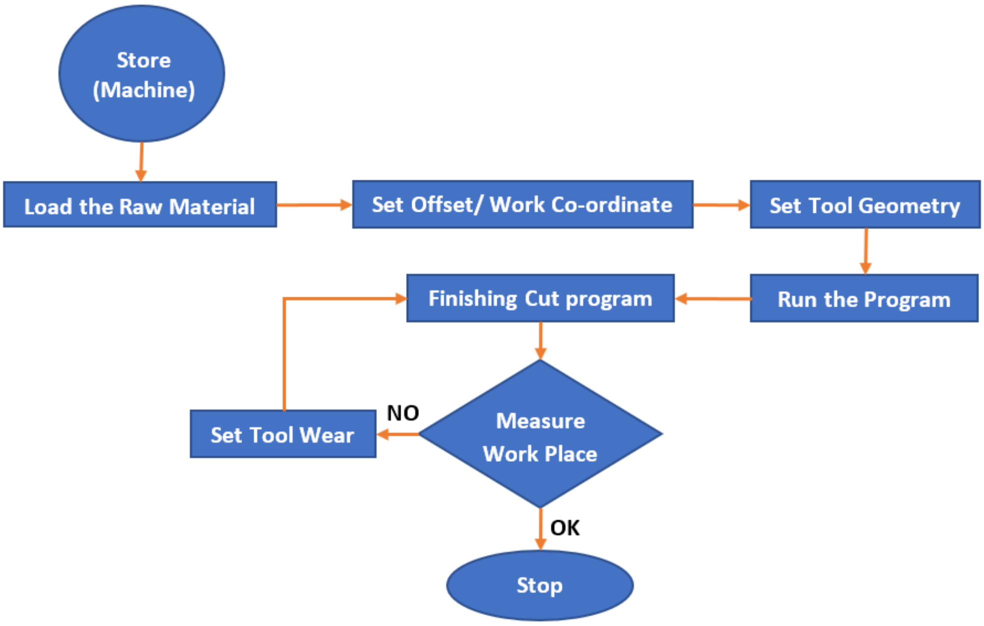


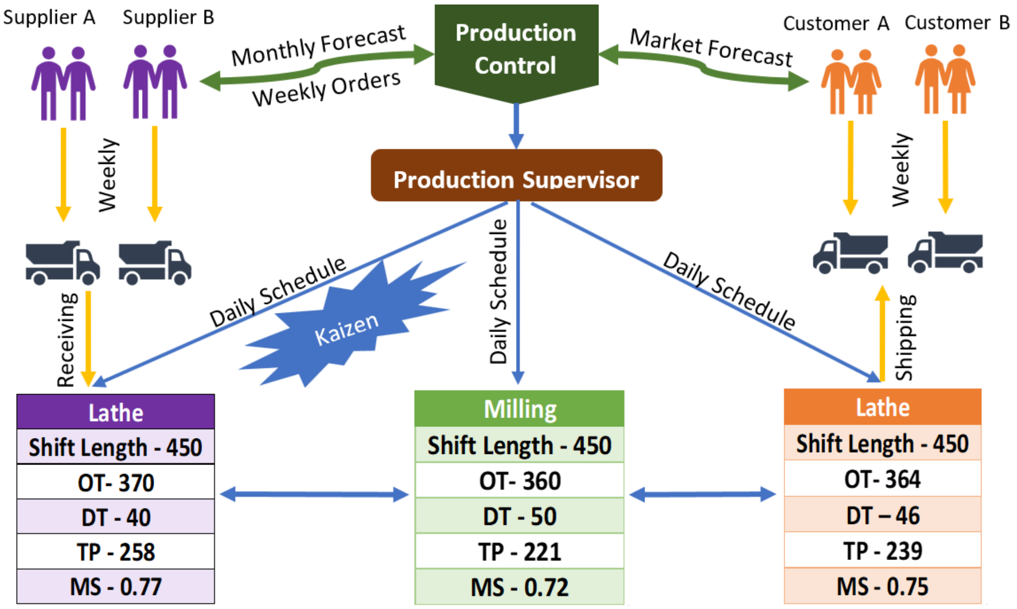
Figure 8. Process Map of CNC Lathe Machine in Automobile Industry

The primary purpose of this study is to gather and compute the OEE and productivity index for all system components, which play a crucial role in evaluating the effectiveness of the existing system. This study focuses on the two-wheeler automotive sector, which encompasses a total of approximately 280 distinct types of equipment. The facility is comprised of various divisions, namely machine shops, weld shops, paint shops, engine assembly, and frame assembly, where the execution of production processes takes place. The machine shop division is notable for its flexible manufacturing structure, which enables the production of multiple engine models. Additionally, the division employs robotic systems to facilitate the loading and unloading operations. In the context of this particular case study, the machine shop area utilized TPM manager model machines.

3.4 Value Stream Mapping (VSM)

Value Stream Mapping (VSM) is an integral component in the process of implementing lean principles within organizations. The strategic development, execution, and improvement of operational procedures are of utmost importance [26], [27]. The utilization of Vector Space Model (VSM) results in the generation of a visual representation that systematically depicts each procedure, commonly referred to as a movement plan. The primary objective of Value Stream Mapping (VSM) is to identify and address obstacles within various processes by employing lean methodologies and visualizing an enhanced future value stream mapping. The main aim of Value Stream Mapping (VSM) is to identify and eliminate non-value-added activities that do not contribute to meeting customer requirements. In order to perform a thorough evaluation of the process, the VSM methodology necessitates the incorporation of diverse information inputs. The inputs encompass various factors such as customer demand, process cycle time, working time, scheduled downtimes, inventory details, changeover time, machine availability, and other pertinent variables [28], [29]. Figure 9 depicts the present condition of the value stream mapping, commonly known as CSVSM. When formulating a Continuous Shift

Variation Scheduling Model (CSVSM), it is important to consider various variables. These variables include the levels of demand on a daily, weekly, and monthly basis, the duration of shifts in minutes, the total number of shifts needed, the overall duration of operations in minutes, the allocation of downtime, the quantity of production, the availability of resources, and the inventory data pertaining to work in progress.



OT - Operation Time, DT - Down Time, TP - Total Pieces, MS – Machine Speed

Figure 9. Value Stream Mapping in Automobile Industry

3.5 TPM Execution

The phased implementation of TPM demonstrates favorable results through the enhancement of machine availability and the mitigation of unforeseen machine downtime. The implementation of autonomous maintenance is a means by which operators assume accountability for various tasks, including but not limited to dusting, lubrication, bolt tightening, visual inspections, and other related activities. The implementation of effective training programs is crucial in order to enhance the knowledge and skills of operators, thereby facilitating a process of ongoing improvement. Furthermore, the implementation of TPM encompasses the fulfillment of two supplementary pillars, namely quality maintenance and scheduled maintenance. The implementation of TPM has led to an increase in the performance rates of the CNC lathe machine, milling machines, and rack and pinion system machines. Specifically, the performance rate of the CNC lathe machine has risen to 77.91%, while the milling machines have achieved a performance rate of 69.04%. Similarly, the rack and pinion system machines have experienced an improvement in performance, reaching a rate of 74.43%.

Tables 2, 3, and 4 present a comprehensive analysis of the internal and external factors that impact the Overall Equipment Efficiency (OEE) in the three aforementioned case studies.

Table 2. Measurement of OEE before and after TPM execution for CNC lathe machine

S. No.	**Scheduled Production Time**	**Before TPM Execution (min)**	**After TPM Execution (min)**
1.	Shift Length	450	450
2.	Short Breaks	10	10
3.	Meal Breaks	30	30
4.	Downtime	60	40
5.	Total Pieces	242	258
6.	Reject Pieces	19	12
7.	Machine Speed	0.77	0.77
Support Variables			
8.	Planned Production Time	410	410
9.	Operating Time	350	370
10.	Good Pieces	223	246
OEE Components			
11.	Availability	85.36%	90.24%
12.	Performance Efficiency	89.79%	90.55%
13.	Rate of Quality	89.79%	90.55%
OEE		**70.62%**	**77.91%**

Table 3. Measurement of OEE machine before and after TPM execution for Milling

S. No.	**Scheduled Production Time**	**Before TPM Execution (min)**	**After TPM Execution (min)**
1.	Shift Length	450	450
2.	Short Breaks	10	10
3.	Meal Breaks	30	30
4.	Downtime	72	50
5.	Total Pieces	198	220
6.	Reject Pieces	8	3
7.	Machine Speed	0.72	0.72
Support Variables			
8.	Planned Production Time	410	410
9.	Operating Time	338	360
10.	Good Pieces	190	217
OEE Components			
11.	Availability	82.43%	87.80%
12.	Performance Efficiency	81.36%	84.87%
13.	Rate of Quality	95.95%	98.64%
OEE		**64.34%**	**73.51%**

Table 4. Measurement of OEE before and after TPM execution for CNC Rack and Pinion system machine

S. No.	**Scheduled Production Time**	**Before TPM Execution (min)**	**After TPM Execution (min)**
1.	Shift Length	450	450
2.	Short Breaks	10	10
3.	Meal Breaks	30	30

4.	Downtime	71	46
5.	Total Pieces	216	239
6.	Reject Pieces	8	4
7.	Machine Speed	0.75	0.75
Support Variables			
8.	Planned Production Time	410	410
9.	Operating Time	339	364
10.	Good Pieces	208	235
OEE Components			
11.	Availability	82.68%	88.78%
12.	Performance Efficiency	84.95%	85.27%
13.	Rate of Quality	96.29%	98.32%
OEE		**67.63%**	**74.43%**

Table 5. The visualization of OEE results before and after TPM execution

S. No.	Chosen Plant Machine	OEE Before TPM Execution	OEE After TPM Execution
1.	CNC Lathe Machine	70.62%	77.91%
2.	Milling Machine	64.34%	73.51%
3.	Rack and Pinion System	67.63%	74.43%
4.	Average OEE	67.53%	75.28%

4. RESULTS, DISCUSSION, AND IMPROVEMENT PROSPECTS

The analysis presented in Figure 10 highlights the significant improvements in OEE that occur due to the implementation of strategic TPM. In the context of the lathe machine, the OEE experienced an increase from 70.62% before the execution of TPM to 77.91% following the successful implementation of TPM. In a comparable manner, the OEE of milling machines exhibited an increase from 64.34% to 69.04% subsequent to the execution of TPM. Likewise, the OEE of rack and pinion system machines demonstrated a rise from 67.63% to 74.43% following the implementation of TPM.

Table 5 highlights that prior to TPM deployment, the milling machine had the lowest OEE compared to the CNC lathe and Rack and Pinion System machine.

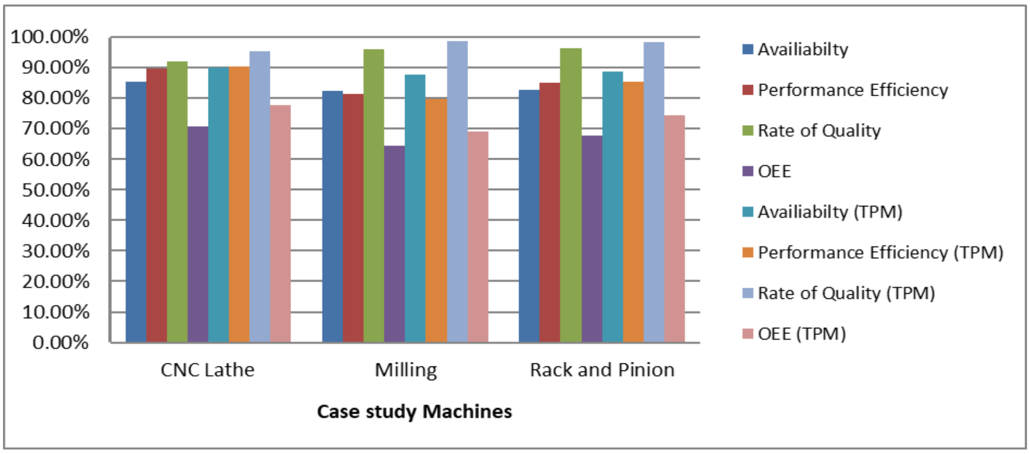


Figure 10. Percentage of OEE and OEE Factors with respect to Machines

In order to optimize OEE, it is imperative to prioritize three fundamental elements: availability, performance efficiency, and rate of quality. Figure 11 depicts the correlation between the aforementioned components and six significant losses. Downtime losses, encompassing breakdown, setup, and adjustment losses, have a direct impact on the availability of machines. The impact of product failure losses, which encompass defects, rework, and start-up losses, has a significant influence on the quality of the product. The machine's performance parameter is affected by speed losses, which include both decreased speed and minor stoppages.

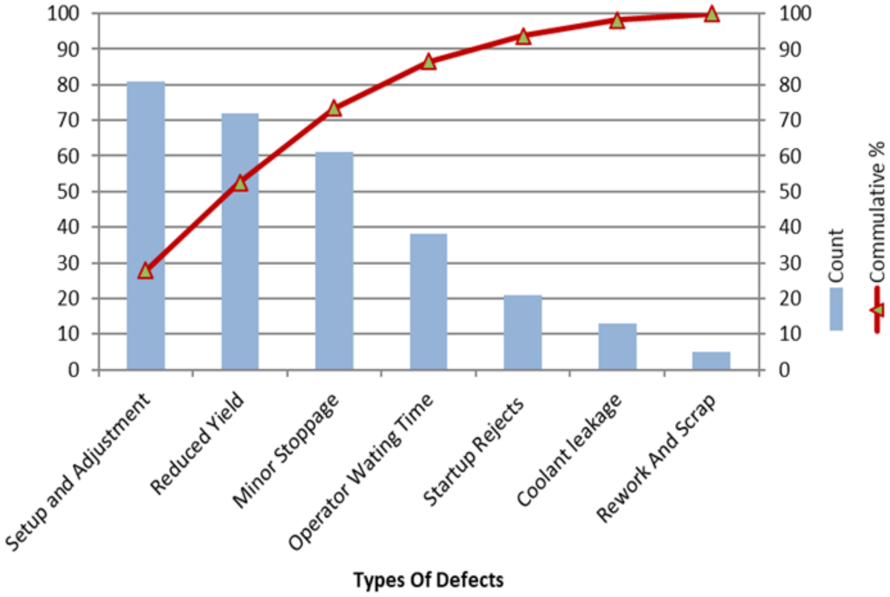


Figure 11. Major losses are depicted in a Pareto chart.

Figure 11 illustrates the common losses that frequently occurred in the CNC lathe, milling machine, and Rack and Pinion system machines, contributing to a decline in Overall Equipment Efficiency (OEE). A dedicated TPM team member closely monitored these losses and proposed Kaizens (continuous improvements) and minor enhancements as part of a systematic and focused improvement initiative. The top three failures that consumed the most time were identified within the categories of availability and performance efficiency, directly impacting the reduction in OEE.

The identified issues contributing to the decline in Overall Equipment Efficiency (OEE) are as follows:

I. The machine was operating at a speed lower than the ideal speed, resulting in decreased OEE.

II. Minor equipment failures and occasional jams were observed, causing a negative impact on OEE.

III. Unplanned downtime occurrences were a significant factor leading to the decrease in OEE. These interruptions consumed a substantial amount of production time.

IV. OEE was negatively affected by problems with the CNC computer panel system. Frequent faults and bugs necessitated regular updates and reinstallation of the operating system.

V. Manufacturing operators were wasting additional time during breaks, which resulted in delays when restarting the system. This issue was common across all machines.

VI. Improving proper stock management and feed processes could contribute to enhancing OEE for all machines.

Another approach to increase OEE was to incorporate end effectors capable of efficiently handling new products within a few minutes. Addressing these issues collectively will be instrumental in improving the current level of OEE.

5. CONCLUSION AND FUTURE SCOPE

Throughout the course of the investigation, OEE has emerged as a pivotal instrument for assessing and quantifying performance. The function of this metric is to act as a key performance indicator (KPI) in the assessment of the OEE of manufacturing machines. The experiential case study examined the three TPM manager model machines previously mentioned, implementing the devised TPM Master Plan in a partially automated fashion. The research encompassed the computation of all variables related to OEE and the determination of the specific factors contributing to the decrease in OEE.

The implementation of successful TPM activities led to a notable improvement in the average OEE from an initial value of 67.54% to 73.79% over the course of the study. The observed enhancement can be ascribed to a multitude of factors, encompassing the mitigation of minor intermittent equipment interruptions, the reconfiguration and enhancement of the operational framework of the selected plant machinery, and additional focused enhancements.

The primary factors contributing to the decline in OEE in the selected plant machinery were identified as set-up adjustment loss, reduced yield, and short stoppages. The losses were consistently monitored and effectively reduced with the aid of group supporters from the TPM pillar of focused improvement. In conclusion, the implementation of the OEE measurement and loss assessment methodology holds promise for optimizing plant efficiency in various industrial settings.

5.1 Consequence in real-world

The research has several practical implications, including the assessment of the influence of Total Productive Maintenance (TPM) on the overall performance of a plant. Additionally, it highlights the significance of Overall Equipment Efficiency (OEE) as a crucial performance metric for continuous enhancement. Furthermore, it delves into potential avenues for progress within the industry. This study specifically examined the significant advantages associated with the application of Overall Equipment Effectiveness (OEE) calculations in enhancing the maintainability and reliability of equipment. The results confirm the significance of the TPM methodology and OEE measurement as valuable indicators for improving overall plant efficiency, particularly in a dynamic manufacturing setting.

5.2 Drawbacks of TPM during implementation in the Case Study

I. The industry personnel have been observed to lack fundamental knowledge of TPM.
II. There is a need for increased focus on improvement activities during planned production time in the industry.
III. The automobile industry exhibits deficiencies in terms of planned, quality, and autonomous maintenance practices.
IV. The automobile industry is characterized by a lack of early equipment management.
V. There is a shortage of reward systems in the automobile industry.

5.3 Future Recommendation

Based on the findings and limitations of the research, it has been determined that the TPM activities framework developed in this study aligns with the TPM master plan, which focuses on monitoring OEE for specific manager model machines. However, further investigation is needed to validate the effectiveness and feasibility of the framework by measuring OEE and identifying losses across the entire plant. It is important to note that this study was conducted solely in the automotive sector, but future research could explore similar studies in other manufacturing sectors, including the service sector, pharmaceuticals, electronics/electrical, textiles, and more.

In addition, potential avenues for further research may involve examining the evaluation of overall plant efficiency using alternative lean manufacturing philosophies such as Six Sigma, Total Quality Management (TQM), Just-in-Time (JIT) production, Quality Function Deployment (QFD), and other pertinent methodologies. Additionally, the data obtained from TPM performance indicators can be analyzed using statistical tests in order to obtain more profound insights and improve comprehension of the topic.

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Consent for Publication: The publication of this article has been approved by all of the contributors.

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