Sustainability and OEE gains in manufacturing operations through TPM

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Abstract

Today, the manufacturing sector necessitates a highly-productive system, maintenance-free machinery and multi-skilled operator for enhanced sustainability and productivity gains. The total productive maintenance (TPM) can serve as a means of attaining these goals as well as increased productivity for industries. In this study, TPM is implemented in the manufacturing industry and overall equipment effectiveness (OEE) is calculated for machinery performance. The data is collected through a questionnaire study conducted for the employees as well as breakdown summary sheets of the industry. In the analysis, it has been observed that the forging machine takes long setup time and have a maximum number of non-value-added movements in processes. A single minute exchange of die (SMED) tool is implemented to reduce the setup time of forging machine to 67 minutes per setup which in turn allows producing approx. 984 more products per day. A sustainable maintenance schedule is implemented for better performance of machinery and to train the workers to detect faults in the machine. A comparison of OEE before & after TPM implementation is carried out and found a significant improvement, and hence concluding that TPM helps the industry to achieve sustainability in the manufacturing industry.

Keywords: Sustainability, total productive maintenance (TPM), overall equipment effectiveness (OEE), single minute exchange of die (SMED), manufacturing operations.

1. Introduction

Total productive maintenance in a manufacturing industry plays a vital role in enhanced competitiveness and to achieve a minimum breakdown of machinery and high-quality products. TPM is the Japanese innovative concept that is traced back to 1951 when preventive maintenance was introduced in Japan. Nippondenso was the first industry to implement preventive maintenance technique and thereafter they combine autonomous maintenance and preventive maintenance to achieve high success (Mor et al., 2019). Brah and Chong (2004), Agustiady and

Cudney (2018) stated that total productive maintenance builds a close relationship between maintenance and productivity that shows how good care and maintenance of equipment is done. Ahuja and Khamba (2009), Samadhiya and Agrawal (2020) depict that TPM leads industry towards growth and sustainability by lowering the maintenance cost and increasing efficiency as well as increasing available time for production. Sahoo (2020) explored the utilization of TQM and maintenance and found the best way to improve the sustainability of Indian manufacturing industries. Maalem et al. (2020), Adhiutama et al. (2020) applied TPM to increase the business sustainability of the industry. Borris (2006) mentioned that TPM as a manufacturing strategy is highly competitive against a series of new rivals for years. Another approach of TPM is the reliability-centered maintenance and these methods started their lives in America. In the United State, it was known as PM (no "T") i.e. Preventive Maintenance (Nakajima, 1988; Bhardwaj et al., 2018). Three words of TPM indicates that:

- Total: Total means involvement of all employees of the system from the top management level to shop floor level, which gives strong coordination between high authority levels to a low-level employee of the system.
- Productive: Productive means there is no activity, which produces any loss in the production of goods and services that meet or fulfill customer requirements.
- Maintenance: keep all the equipment of industry in good working condition. This aim to achieve maximum availability of the machine, high-quality product, and zero breakdowns of machines at low maintenance cost.

Huang et al. (2003) concludes that the industries should be a part of the qualitative competition to improve and optimize their productivity. It will lead to improved skilled employees and efficient machines. Nakajima (1988) introduced OEE as a key performance indicator for the performance measure of TPM. Solke and Singh (2018) concluded that TPM helps in the effective utilization of resources and continuous product improvement in the industry. Mwanzaa and Mbohwa (2015), Chaudhuri and Jayaram (2019), Chen et al. (2019) stated that TPM implementation reduces in-process defects and losses that will help to improve business sustainability of the industry as well as lead to increase in profit of company and competitiveness. Ibrahim et al. (2019) state that the industry moves towards sustainability by improving its maintenance schedule and reducing losses. Hami et al. (2019), Gupta et al. (2015) developed a framework and establish a relationship between sustainable maintenance & manufacturing and social sustainability. Many other authors implemented TPM in the auto part industry for improving productivity and applied TPM in the garment industry to improve OEE. Another key problem in decreasing the lot sizing is higher die setup time and it must be minimum possible for producing at a competitive costs (Kumar et al., 2017; Kigsirisin et al., 2016; Ahmad et al., 2018; Mor et al., 2018; Wudhikarn, 2012).

For better organization, this chapter is divided in five sections, section 1 is the introductory part. Section 2 dicsusses the problem formultion, scope of study and methodology. Section 3 is the analysis and implementation of TPM and SMED alongwith Cause-effect analysis. Section 4 is the results and discussion, the benefits ensued from TPM, SMED implementation, whereas the final section 5 concludes the research undertaken and future research directions in the area.

2. Problem formulation

A questionnaire is developed by visiting the industry and assessing the current situation. All the relevant data of the industry is obtained through the scheduled questionnaire based on current working conditions. The procedure is mentioned below.

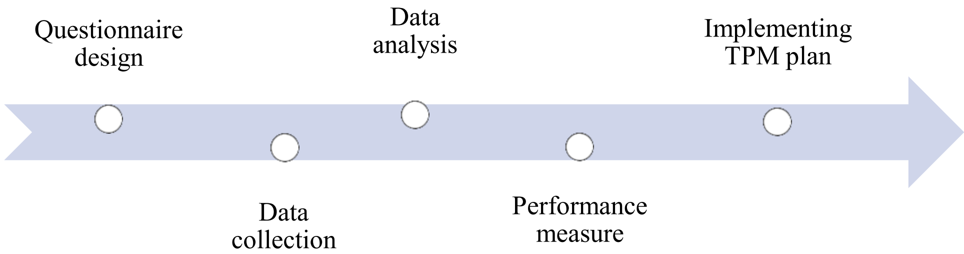

Figure 1. Research Methodology

Following methods are used to collect data:

- Questionnaire survey,
- Interview with the employee,
- Company records,
- Breakdown summary sheet

The sampling test is used to minimize the error in data collection through a set of questions. A 25% sampling intensity has been used for minimum sample error, as suggested by Gupta and Vardhman (2016). The responses from 60 employees are considered as a sample out of 180 employees in the industry.

$$\frac{n}{N} \times 100 = C \quad \ldots\ldots\ldots\ldots\ldots\ldots.. (1)$$

n= 180 × 30/100 = 60

Questions are asked in the questionnaire from all TPM pillars assuming that all the pillars are of equal importance towards the successful implementation of TPM. A breakdown data of each equipment has been collected through a breakdown summary sheet for one month period available in the industry. The failure causes of each machine are identified and analyzed with the help of the Pareto diagram and the Cause-effect diagram. Further, the data regarding six big losses in the industries at the time of production is collected through OEE/loss summary sheet available in the industry. OEE is calculated for all machines as a performance measure. OEE of machines is calculated two times i.e. before & after TPM implementation on selected machines. Machines having minimum availability and lesser performance rate are analyzed through the implementation of 5'S, autonomous maintenance, and TPM pillars.

The collected data is analyzed using a Pareto chart and a Cause-effect diagram is prepared for detailed analysis of machines and their failure. A performance assessment of equipment is also carried out based on the analysis. The key performance indicator used to measure performance is OEE since it measures the performance of equipment based on three different aspects i.e. availability, production rate and quality rate that contain all six main losses. After performance measures through OEE, a TPM plan is implemented initially in the critical section of the industry and then expanded on the whole industry.

3. Analysis

a. Questionnaire Data analysis

The important questions from the questionnaire are discussed in this section. After data collection for TPM pillars, some findings are indicated. It is observed that no department of the industry has a robust maintenance plan. Only 39% of the respondent agreed of having a proper maintenance plan weekly or monthly. The improper maintenance planning leads to frequent breakdowns of machinery. The results are shown below in Figure 2.

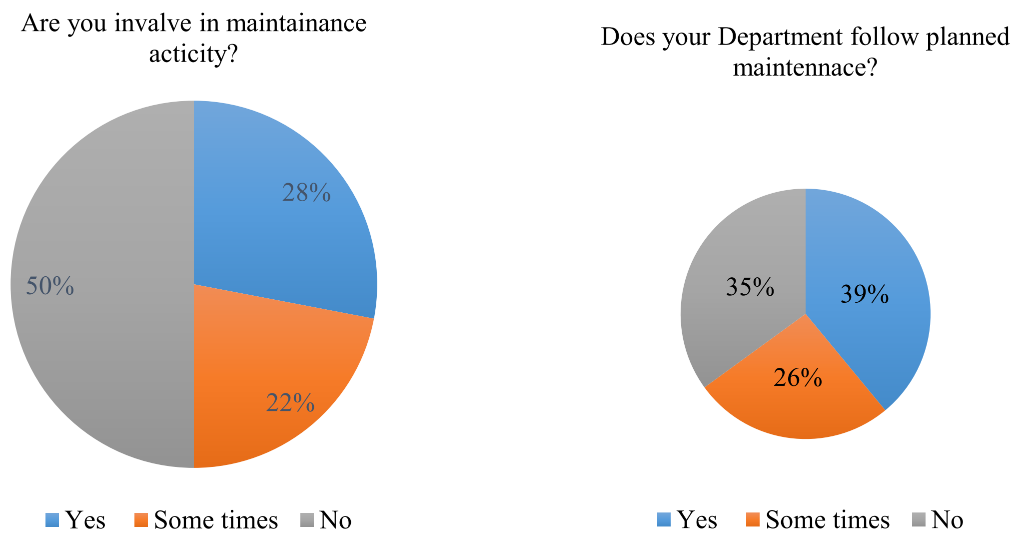

Figure 2. Maintenance planning and worker involvement

The next important question is about the involvement of workers in maintenance activities. This question is asked to know about the autonomous maintenance schedule of the industry. The responses observed only 28% of the worker involvement activity in maintenance activity and the most surprising that only 22% of workers get involved sometimes.

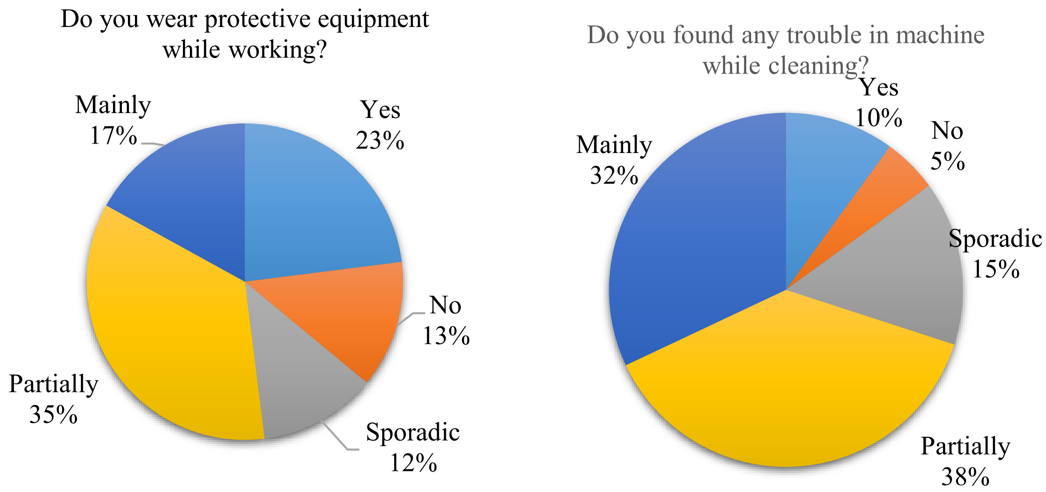

Figure 3. Safety and Autonomous Maintenance

The third question is asked about the worker's capability and training to find the major and minor problem regarding the cleanliness of the machine. The response found that only 10% of workers were confident to locate a problem while cleaning. The fourth question is framed to know about worker safety and the usability of safety equipment because there exist major machines where the worker needs protective equipment. The responses found that only 23% of workers use protective equipment while working on the machine, as shown in Figure 3. Many questions are asked related to all major pillars of TPM, the distribution of question on TPM pillars are shown below in Figure 4.

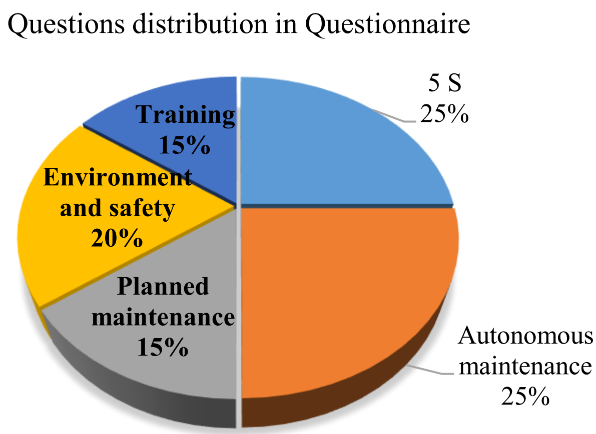

Figure 4. Analysis of TPM Pillars

b. Breakdown analysis of equipment

The analysis of machinery breakdown data is shown in Figure 5 and the results show that the machines from forging, broaching, and shot blasting are critical and a strong maintenance plan is needed to avoid a frequent breakdown in this section. These machines are further investigated to find out their cause of failure and correct measures.

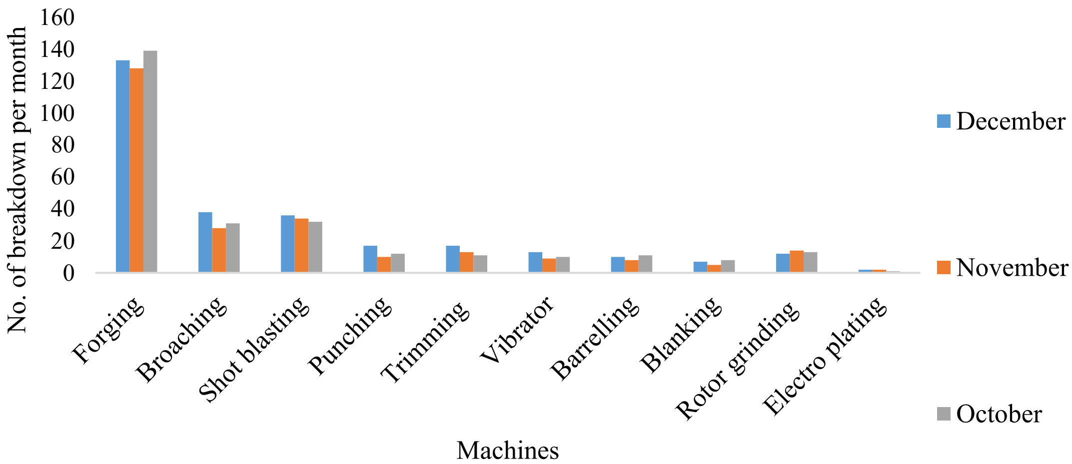

Figure 5. Breakdown/Failure Analysis

i. Analysis of the cause of machine Breakdown.

Three critical machines having frequent failures are analyzed for a month. The machines forging hammer, broaching, and shot blasting are having a maximum breakdown. Figure 6 shows the reasons for failure and the number of breakdowns per month for shot blasting machines. The Cause-effect diagram is used for further investigation of the machine. The main failure in shot blasting machine is identified as the failure of the elevator, conveyor, and rotors.

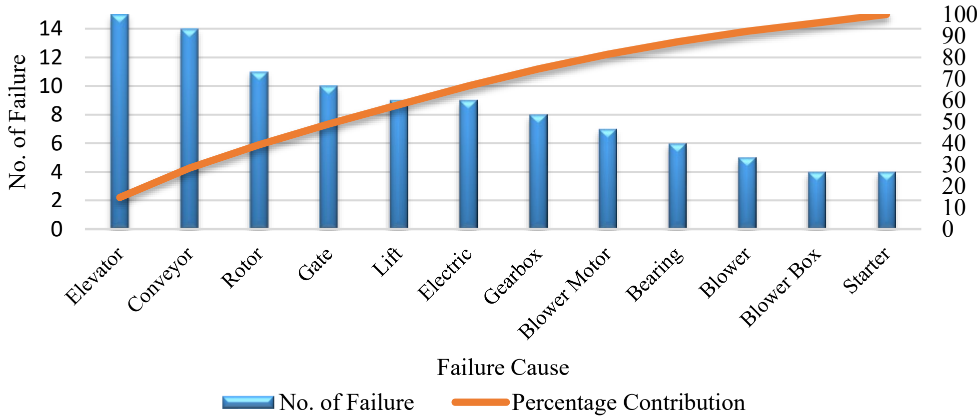

Figure 6. Failure cause of shot blasting machine

The main reason the stoppage at forging hammer is the die rib, metal sticking and high die setting time. The machine availability gets poorer due to frequent stoppages in forging hammer. The causes of failure in the forging hammer are shown in Figure 7. The high setting time has been reduced by implementing a single minute exchange of die, a lean manufacturing tool.

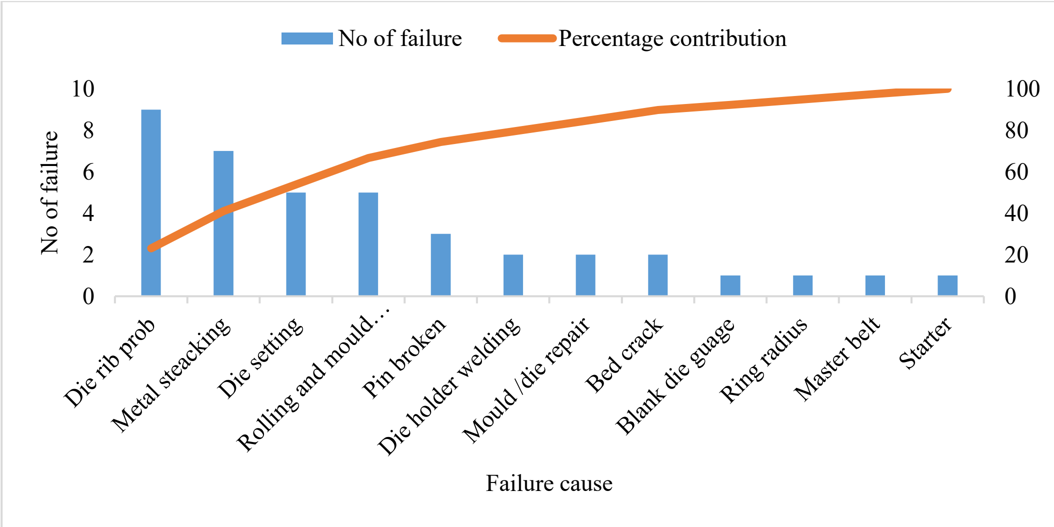

Figure 7. Failure cause of Forging Hammer

In the case of the broaching machine, the failure of control system and hydraulic pump, as well as leakage of coolant, are main causes (Figure 8).

c. Measuring Machine Performance

The performance of machines is calculated through well-known KPI i.e. overall equipment effectiveness. Researches mention that the effectiveness of total productive maintenance is calculated by OEE to measure the performance of machines in the industry.

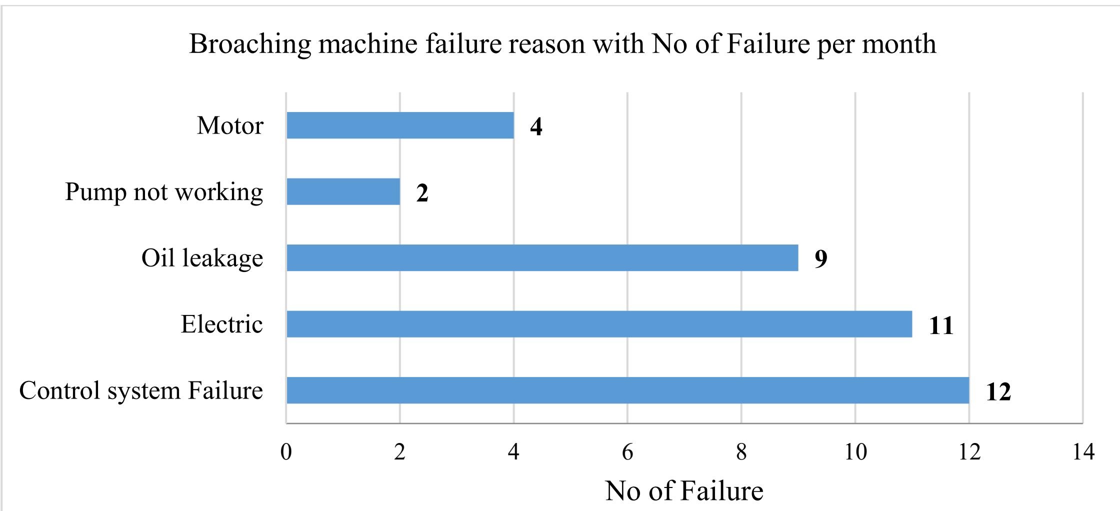

Figure 8. Causes of failure on Broaching machine

4. Results and Discussion

4.1 OEE calculation

OEE is the multiplication factor of these three-factors denoted as availability (A), performance rate (P), and quality rate (Q). It integrates various important aspects of the machine into a single performance-measuring tool. OEE also contains all the production losses in the system.

$$OEE = Availability\ (A) \times Performance\ rate\ (P) \times Quality\ Rate\ (Q)$$

The overall equipment effectiveness in the current study is affected by six main losses of the industry.

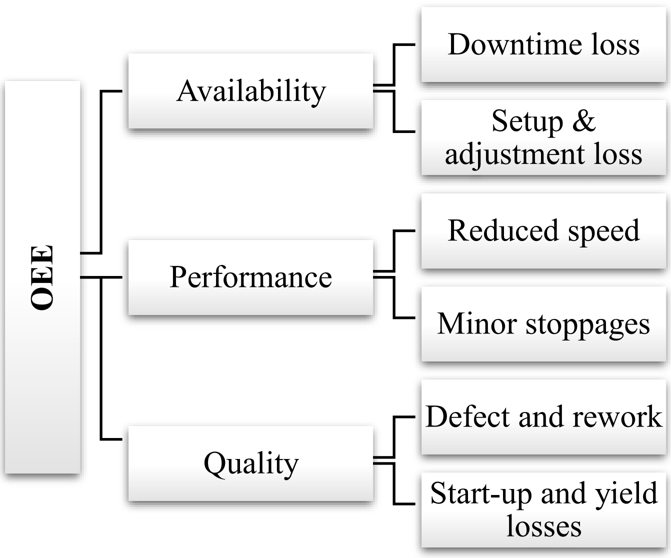

Figure 9. Losses and OEE

The main losses that can occur in the industry are listed in Figure 9 and the data is collected for all the losses parameter.

$$Availability\ (A) = \frac{\text{Effective run time}}{\text{Planned production time}}$$

$$\text{Performance rate (P)} = \frac{\text{Idle Cycle Time} \times \text{Total Production}}{\text{Effective Run Time}}$$

$$\text{Quality Rate (Q)} = \frac{\text{Good production}}{\text{Total production}}$$

$$\text{Effective run time} = \text{Planned time} - \text{Breakdown time}$$

The OEE value of different machines is shown below in Figure 10 for manually operated machines. The data is analyzed daily for one month and a graph has been plotted against OEE and machines.

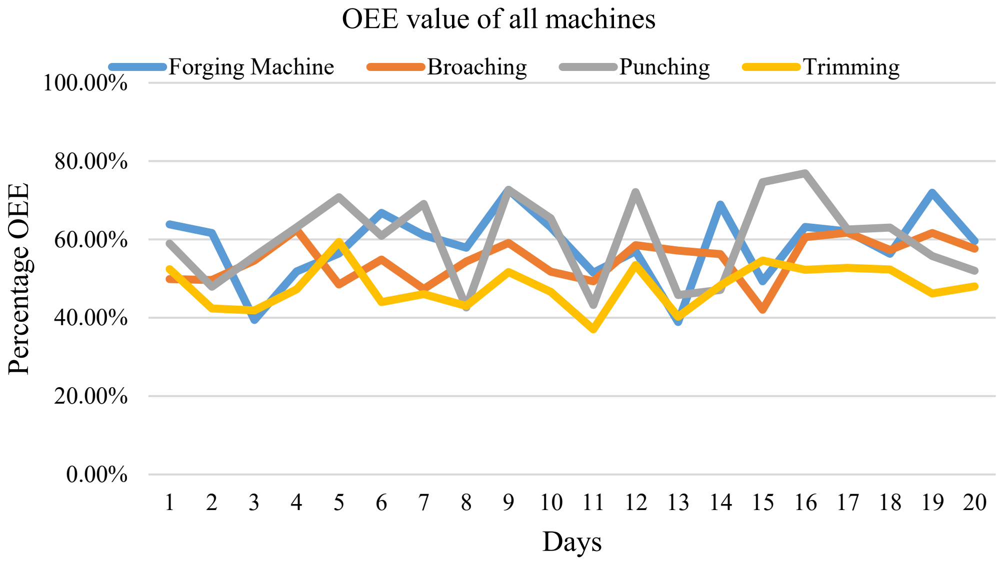

Figure 10. OEE for different machines

The forging and trimming machines are having a maximum variation of OEE due to the high setting time of die and the maximum number of failures or minor stoppages of machines. For high die setting time, a SMED program is introduced to minimize the die set time to a single digit.

4.2 Single minute exchange of die

SMED is a lean tool used to minimize the die exchange time and in the current study, forging hammer takes 3 to 3.5 hours for die set which is reduced by 1 hour after implementation of SMED. The work distribution method is used for arranging tasks for minimizing die setting time. Some internal tasks are externalized and some unnecessary work and operator movement during die setting is eliminated (Figure 12). Die setting time is reduced from 193.2 minutes to 125.6 minutes which means 67.6 minutes of saving in die setting time. The SMED results also affect the availability of the forging hammer. This will indirectly improve the OEE of the forging machine due to increased availability and production rate. By saving 67 minutes per setup, the machine can produce 978 more products per the setup of die.

$$\text{Increase in production per setup } = \frac{67.6 \times 60}{4.12} = 984$$

Here, the cycle time for producing one forging piece is 4.12 second, and it is clear that the machine now has increased flexibility to produce more products in the same available time.

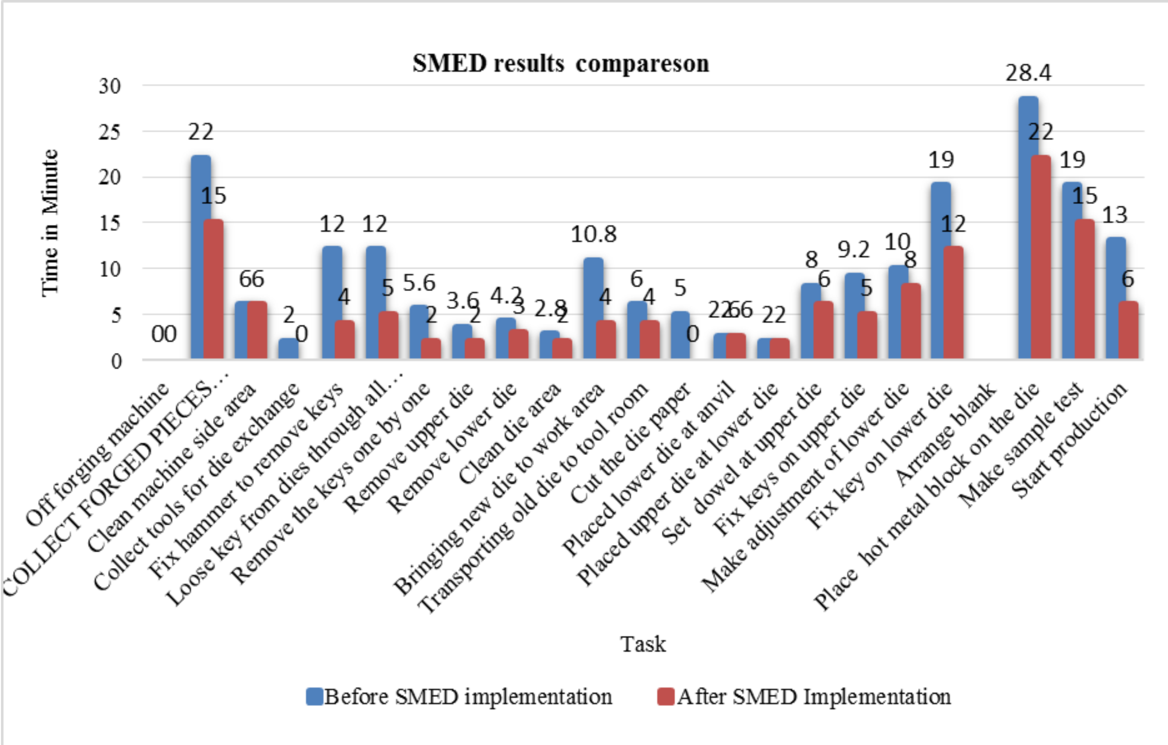

Figure 11. SMED result comparison

4.3 Performance before & after TPM implementation

After the successful implementation of TPM on select machines, the data is collected again and analyzed for an initial comparison (Figure 12). A reasonable improvement is observed, however, the performance will go on improving with time. The below graph shows the OEE improvement.

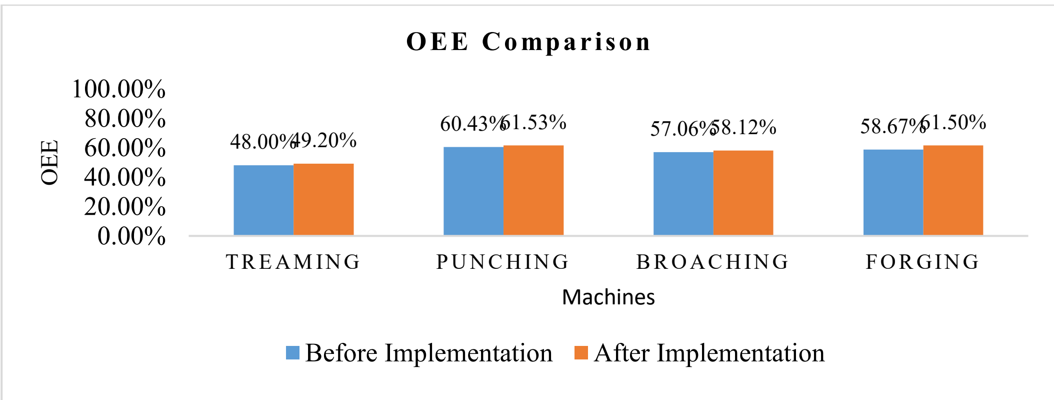

Figure 12. Performance Comparison

4.4 Planned Maintenance

Based on the current analysis, it is evident that the introduction of planned maintenance is highly mandatory, and a planned maintenance period is implemented using the reliability concept. This period will further extend on the performance of the machine goes improving.

Table 1. Time between Maintenance

Machine(s)	MTTF	MTTR	MTBF	Time between maintenance needed (hrs.)
Hammer	64.48	0.48	64.00	22.98
Broaching	126.55	0.45	126.10	77.61
Shot blasting	69.09	0.45	68.64	21.13
Punching	321.23	0.45	320.78	197.45
Trimming	321.19	0.50	320.69	197.39
Vibrator	981.82	0.40	981.42	906.12
Barrelling	626.40	0.33	626.07	578.03
Blanking	232.00	0.48	231.52	95.00
Rotor	214.15	0.47	213.69	87.69
Electroplating	2016.00	0.40	2015.60	310.16

Table 1 indicates that the forging and shot blasting machines need daily maintenance and given the criticality of the problem, immediate autonomous maintenance is proposed in these sections.

5. Conclusion

Total productive maintenance is a powerful tool for the maintenance and care of machinery in any manufacturing industry. This chapter discusses the implementation of TPM in a forging industry to maximize machinery availability, reducing non-value-added movements, and machinery breakdown time. After TPM implementation, OEE is used as a KPI for measuring the performance of a particular machinery section. The SMED approach is also implemented to reduce setup time in forging die setup. A significant savings of 67.6 minutes per setup is achieved that enables to produce 984 more products per day. Training seasons regarding follow autonomous maintenance were proposed to detect a fault on machinery. A significant improvement of OEE is achieved with this effort and most importantly, without any investment from the industry. These improvements are almost the same improvements achieved by Garg et al. (2016), Rodolfo et al. (2015).

Thus, it is concluded that TPM help industry to achieve sustainable production goals by gaining economic and social benefit as a result of the improved effectiveness of machine and self-motive trained workers and fewer wastages. However, given time boundations and limited resources, only those improvements and tools were implemented that involved minimum time and there remain a significant scope of future work in this area.

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