OVERALL EQUIPMENT EFFECTIVENESS OF CRITICAL MACHINES IN MANUFACTURING INDUSTRIES – A PRACTICAL ANALYSIS

B.C. Ashok¹, Dr. T.R. Srinivas²

¹(Department of Mechanical Engineering, Vidyavardhaka College of Engineering, Mysore, Karnataka, India)
²(Department of Industrial Production & Engineering, Sri Jayachamarajendra College of Engineering, Mysore, Karnataka, India)

ABSTRACT

Overall Equipment Effectiveness (OEE) is a measure used in Total Productive Maintenance (TPM), a maintenance program which involves a newly defined concept for maintaining plants and equipment, to calculate the percentage of actual effectiveness of the equipment, taking into consideration the availability of the equipment, the performance rate when running and the quality rate of the manufactured product measured over a period of time (days, weeks or months). The equipment criticality is decided by considering how and how much the equipment affects the production volume and quality. The scale of damage incurred by breakdowns of the equipment is also considered. The purpose of this paper is to assess the application of OEE to evaluate the performance of critical machines and to determine to what extent the TPM implementation affects the OEE. The procedure to estimate OEE has also been presented through numerical examples. A case study was carried out in two large scale industries, one that manufactures Tyres for heavy vehicles and the second an automobile industry that manufactures heavy-duty drive axle assemblies. The data collected for two critical machines over a period of one year are statistically analysed to identify the influence of major losses on OEE.

Keywords: Total Productive Maintenance (TPM), Effectiveness, Equipment, Performance

1. INTRODUCTION

Overall Equipment Effectiveness (OEE) being performance measure of Total Productive Maintenance (TPM) could be used to evaluate the performance of critical/key equipments of the manufacturing industry. It reflects the performance of all the equipments in the manufacture line. The goal of TPM is to increase equipment effectiveness so each piece of equipment can be operated to its full potential and maintained at that level. The OEE is a measure of the value added to production through equipment, which is a function of machine availability, performance efficiency and the rate of quality.

Overall Equipment Effectiveness is a very simple metric that immediately indicates the current status of a manufacturing process. Somehow it also becomes a multifaceted tool allowing one to understand the effect of the various issues in the manufacturing process and their effect on the entire process. The biggest advantage of OEE is that it allows companies to have separate business functions by applying/using a single, easy-to-understand formula. OEE is by far the most effective benchmarking tool in making sound management decisions.

Overall Equipment Effectiveness depends on three parameters: Availability of the equipment, Performance of the equipment and the Quality of the product. It is given by:

\[ OEE = \text{Availability Ratio} \times \text{Performance Ratio} \times \text{Quality Ratio} \]
Availability Ratio - the share of the actual production time and the planned production time. All planned stops and breakdowns will reduce the availability ratio, including setup times, preventive maintenance, breakdowns and lack of operators. The only time that one may choose to deduct from the availability ratio is lack of orders.

Performance Ratio - Loss of production due to underutilization of the machinery. In other words, losses are incurred when the equipment is not run with full speed. Short, unregistered, stops may affect the performance ratio as well.

Quality Ratio - the amount of the production that has to be discharged or scrapped.

A large scale Tyre manufacturing industry which has implemented TPM to full extent and heavy-duty Axle assembles automobile industry which has partially implemented TPM were selected as case studies and two critical equipments from different sectors of the industry were chosen for the study. This paper investigates OEE calculation of Banbury, 4 Roll Calender Machine in Tyre industry and Straddle Facing, Centerless Grinding Machine in Automobile industry by taking readings directly and hence the performance of equipments is analysed.

2. RELATED WORKS

OEE was proposed by Nakajima [1] as an approach to evaluate the progress achieved through the improvement initiatives carried out as part of his proposed total productive maintenance (TPM) philosophy. He defines OEE as a metric or measure for the evaluation of equipment effectiveness. In considering OEE, Nakajima defines six big equipment losses, which include equipment downtime loss, performance loss, and defect loss as shown in Fig. 1.

![Fig. 1: Major losses limiting equipment efficiency](image)

- Equipment failure or breakdown losses: These losses are categorized as time losses when productivity is reduced, and quality losses caused by defective products.
- Set-up and adjustment time losses: These losses result from downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirements of another item.
- Idling/minor stop losses: These losses occur when the production is interrupted by a temporary malfunction or when a machine is idling.
- Reduced speed losses: These losses refer to the difference between equipment design speed and actual operating speed.
- Quality defects and rework: Defect/rework losses are defined as volume losses due to defects and rework.
- Reduced yield or Start-up: Reduced yield/Start-up losses are defined as time losses (output decline).

An increase in overall equipment effectiveness, which is a function of down time and other production losses can significantly reduce random machine breakdowns, in turn, inventory, and lead time. Fawaz A. Abdulmalek and Jayant Rajgopal [2] states that machine breakdowns and minor stoppages account for 20–30% of loss in OEE.
I.P.S. Ahuja and J.S. Khamba [3] have suggested that OEE is an all-inclusive benchmarking tool that serves to gauge the various subcomponents of the manufacturing process (i.e., availability, performance and quality) and used to measure actual improvements on 5S, Lean Manufacturing, TPM, Kaizen and Six Sigma. Benchmarking overall equipment effectiveness can facilitate an organization to realization of zero breakdown, zero defect, zero machine stoppage, zero accidents, zero pollution, which serve as the ultimate objective of TPM. When using OEE with these management systems the benefits become tangible and noteworthy.

A.J.de Ron and J.E. Rooda [4] have stated that, manufactured goods are a result of a complex production process and without the proper measuring tools and formula, the business can be expected to run blindly even in the light of day. Having the right metrics, OEE provides a window to analyse out-of-the-ordinary issues and gives an established framework for improving the entire manufacturing process. They further announce that a key performance measure in mass production environments is OEE.

Bulent Dal et al. [5], suggest that the OEE measure can be applied at several different levels within a manufacturing environment. Firstly, OEE can be used as a “benchmark” for measuring the initial performance of a manufacturing plant in its entirety. In this manner the initial OEE measure can be compared with future OEE values, thus quantifying the level of improvement made. Secondly, an OEE value, calculated for one manufacturing line, can be used to compare line performance across the factory, thereby highlighting any poor line performance. Thirdly, if the machines process work individually, an OEE measure can identify which machine performance is worst, and therefore indicate where to focus TPM resources.

Christian N. Madu [6] shows that equipment maintenance and reliability management are importantly associated with an organization’s competitiveness and must be given adequate attention in the organization’s strategic planning. OEE is an effective way of analysing the efficiency of a single machine or an integrated machinery system. However, Alok Mathur et al. [7] implies that the most important objective of OEE is not to get an optimum measure, but to get a simple measure that tells production personnel where to spend their improvement resources. The greatest contribution of OEE is that it is a simple, but still comprehensive, measure of internal efficiency and that it can work as an important indicator of the continuous improvement process.

3. OVERALL EQUIPMENT EFFECTIVENESS (OEE) MEASUREMENT

In this section, the measurement of OEE for the selected critical equipments is presented.

OEE combines the operation, maintenance and management of manufacturing equipment and resources. It takes the most common and important sources of productivity loss, which are called six big losses, shown in Fig. 1. These losses are quantified as Availability (A), Performance (P) and Quality (Q) in order to estimate OEE and OEE calculation is given by:

\[
\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}
\]

According to Nakajima [1] the ideal conditions are: Availability…..greater than 90%, Performance Efficiency…… greater than 95%, Rate of Quality products …… greater than 99%. Therefore, the ideal OEE should be 85+ %. However, literature survey indicates that the exact definition of OEE differs between applications and various authors. For an organization, wishing to measure their OEE, the differences in various approaches of calculating OEE parameters (A, P, Q) could be significant in terms of OEE resultant figures.

3.1 Tyre industry

3.1.1 Banbury

\[
\begin{align*}
\text{Failure Loss (in %):} & \quad 1.782931 \\
\text{Set up & Adjustment Loss (in %):} & \quad 1.59 \\
\text{Shut down Loss (in %):} & \quad 0.638346123 \\
\text{Minor stoppage & Idle Loss (in %):} & \quad 0.02329558 \\
\text{Management Loss (in %):} & \quad 0.07 \\
\text{Line Organization Loss (in %):} & \quad 0.71 \\
\text{Measurement Loss (in %):} & \quad 0.098141 \\
\text{Defect & Rework Loss (in %):} & \quad 6.18
\end{align*}
\]

\[
\begin{align*}
\text{Availability} & = 100 - \frac{(1) + (2) + (3) + (4) + (5)}{5} = 99.17909 \\
\text{Performance} & = 100 - \frac{(6) + (7)}{2} = 99.594 \\
\text{Quality} & = 100 - (8) = 93.82 \\
\text{OEE} & = 100 - \frac{99.17909 \times 99.594 \times 93.82}{100 \times 100 \times 100} = 90.737\%
\end{align*}
\]
3.1.2 4 Roll Calender Machine

Failure Loss (in %): 1.729443  
Set up & Adjustment Loss (in %): 0.7791  
Shut down Loss (in %): 0.31279  
Minor stoppage & Idle Loss (in %): 0.046358  
Management Loss (in %): 0.0343

\[
\text{Availability} = 100 - \frac{(1) + (2) + (3) + (4) + (5)}{5} = 99.41926
\]

\[
\text{Performance} = 100 - (6) = 99.95
\]

\[
\text{Quality} = 100 - (7) = 95.57
\]

\[
\text{OEE} = 100 - \frac{99.4196}{100} \times \frac{99.95}{100} \times \frac{95.57}{100} = 90.50\%
\]

3.2 Automobile industry

3.2.1 Straddle Facing

Setup Time (in Hours): 15.1  
Breakdown (in Hours): 2.00

\[
\text{Availability} = \frac{\text{setupTime} - \text{Breakdown}}{\text{setupTime}} = \frac{15.1 - 2}{15.1} = 0.86
\]

Run Rate (in Hours): 2688  
Ideal Run Rate (in Hours): 3262.5

\[
\text{Performance} = \frac{\text{Runrate}}{\text{SetupTime}} = \frac{2688}{3262.5} = 0.82
\]

Production Output (actual): 155  
Production Output (Target): 180

\[
\text{Quality} = \frac{\text{GoodPieces(Actual)}}{\text{TotalPieces(Target)}} = \frac{155}{180} = 0.86
\]

OEE = 0.86 X 0.82 X 0.86 X 100 = 60.64%

3.2.2 Centerless Grinding

Setup Time (in Hours): 35  
Breakdown (in Hours): 4.00

\[
\text{Availability} = \frac{\text{setupTime} - \text{Breakdown}}{\text{setupTime}} = \frac{35 - 4}{35} = 0.88
\]

Run Rate (in Hours): 2368  
Ideal Run Rate (in Hours): 2880

\[
\text{Performance} = \frac{\text{Runrate}}{\text{SetupTime}} = \frac{2368}{2880} = 0.82
\]

Production Output (actual): 138  
Production Output (Target): 160

\[
\text{Quality} = \frac{\text{GoodPieces(Actual)}}{\text{TotalPieces(Target)}} = \frac{138}{160} = 0.86
\]

OEE = 0.88 X 0.82 X 0.86 X 100 = 62.05%

4. ANALYSIS OF RESULTS FOR OEE

This section presents the overall profile of the samples, descriptive statistics and frequency distribution. The results of statistical methods of descriptive statistics, One way Anova, Scheffe’s post hoc test are tabulated in Table 1. Here we have grouped the machines with similar criticality as Machine 1 and Machine 2. Hence Banbury of Tyre industry and Straddle Facing of Automobile industry fall under Machine 1 and 4 Roll Calender Machine of Tyre industry and Centerless Grinding of Automobile industry fall under Machine 2.
Table 1: Descriptive statistics and results of one-way Anova for critical machines to Overall Equipment Effectiveness (OEE) in two industries

<table>
<thead>
<tr>
<th>Machine</th>
<th>Industry</th>
<th>Mean</th>
<th>S.D</th>
<th>F value</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tyre</td>
<td>90.68</td>
<td>0.00</td>
<td>368062E+14</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Automobile</td>
<td>60.66</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>75.67</td>
<td>13.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Tyre</td>
<td>90.40</td>
<td>0.00</td>
<td>355597E+14</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Automobile</td>
<td>60.70</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>75.55</td>
<td>12.18</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall equipment effectiveness of Machine 1

One way ANOVA revealed a highly significant difference between 2 companies in their mean overall equipment effectiveness scores with F value of 368062E+14 and significance (P) of .000. Further, Scheffe’s Post hoc test indicated that Tyre industry has maximum overall equipment effectiveness (mean 90.68%), followed by Automobile industry (mean 60.66%).

Overall equipment effectiveness of Machine 2

One way ANOVA revealed a highly significant difference between 2 companies in their mean overall equipment effectiveness scores with F value of 355597E+14 and significance (P) of .000. Further, Scheffe’s Post hoc test indicated that Tyre industry has maximum overall equipment effectiveness (mean 90.4%) and overall equipment effectiveness for Automobile industry is found to be less (mean 60.7%).

5. CONCLUSION

The study highlights the accurate estimation of equipment effectiveness that affects the productivity of the organization. As seen from the OEE computation of the equipments, accurate performance measure of the equipment was obtained if all six major losses were considered while computing the three OEE elements Viz., Availability, Performance and Quality Rate. Since Total Productive Maintenance tries to reduce the losses, OEE of critical machines was found to be high in Tyre industry which has implemented TPM to full extent and less in Automobile industry which has partially implemented TPM. It is also found that there are many differing methods of collecting data for the six big losses, and therefore computation of OEE also varies from one organization to another. However, the quality of data collection determines the accuracy of OEE.

6. REFERENCES

### APPENDIX

#### Average OEE for One Year in Tyre Industry

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit of Measurement (UOM)</th>
<th>Average Banbury</th>
<th>Average 4 Roll Calender</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure Loss</td>
<td>%</td>
<td>1.6201</td>
<td>1.5715</td>
</tr>
<tr>
<td>Set up &amp; Adjustment Loss</td>
<td>%</td>
<td>1.3981</td>
<td>0.6851</td>
</tr>
<tr>
<td>Shut Down Loss</td>
<td>%</td>
<td>0.7317</td>
<td>0.3585</td>
</tr>
<tr>
<td>Minor stoppage &amp; Idle Loss</td>
<td>%</td>
<td>0.0233</td>
<td>0.0464</td>
</tr>
<tr>
<td>Management Loss</td>
<td>%</td>
<td>0.0696</td>
<td>0.0341</td>
</tr>
<tr>
<td>A-Availability Factor</td>
<td>%</td>
<td>99.231</td>
<td>99.461</td>
</tr>
<tr>
<td>Line Organization Loss</td>
<td>%</td>
<td>0.7322</td>
<td>---</td>
</tr>
<tr>
<td>Measurement Loss</td>
<td>%</td>
<td>0.1492</td>
<td>0.0731</td>
</tr>
<tr>
<td>B-Performance Factor</td>
<td>%</td>
<td>99.559</td>
<td>99.927</td>
</tr>
<tr>
<td>Defect &amp; Rework Loss</td>
<td>%</td>
<td>5.7486</td>
<td>2.4737</td>
</tr>
<tr>
<td>C-Rate of quality</td>
<td>%</td>
<td>94.251</td>
<td>97.526</td>
</tr>
<tr>
<td>OEE = AXBXC * 100</td>
<td></td>
<td><strong>90.689</strong></td>
<td><strong>90.307</strong></td>
</tr>
</tbody>
</table>

#### Average OEE for One Year in Automobile Industry

<table>
<thead>
<tr>
<th>Description</th>
<th>UOM</th>
<th>Average Straddle Facing</th>
<th>Average Centerless Grinding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Output</td>
<td>Nos.</td>
<td>Actual 158</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Target 184</td>
<td>170</td>
</tr>
<tr>
<td>Quality (Q)</td>
<td>Hrs</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Breakdown Occurrence</td>
<td>Nos.</td>
<td>Actual 2</td>
<td>2.7</td>
</tr>
<tr>
<td>Breakdown Hours</td>
<td>Hrs</td>
<td>Actual 1.25</td>
<td>4.44</td>
</tr>
<tr>
<td>Setup Time</td>
<td>Hrs</td>
<td>Actual 9.15</td>
<td>34</td>
</tr>
<tr>
<td>Availability (A)</td>
<td></td>
<td>0.85</td>
<td>0.86</td>
</tr>
<tr>
<td>Element wise setup</td>
<td>Remove</td>
<td>3.53</td>
<td>9.78</td>
</tr>
<tr>
<td>Detail</td>
<td>Fix</td>
<td>4.92</td>
<td>9.28</td>
</tr>
<tr>
<td></td>
<td>Adjust</td>
<td>0.94</td>
<td>14.9</td>
</tr>
<tr>
<td>Performance rate (P)</td>
<td>Hrs</td>
<td>Actual 2889</td>
<td>2430</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Target 3478</td>
<td>2940</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.83</td>
<td>0.82</td>
</tr>
<tr>
<td>OEE = A*P*Q</td>
<td></td>
<td>Target 85</td>
<td>85</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Actual <strong>60.66</strong></td>
<td><strong>60.7</strong></td>
</tr>
<tr>
<td>Abnormality Correction</td>
<td>Nos.</td>
<td>Attached 169</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Removed 162</td>
<td>63</td>
</tr>
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</table>

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