OEE—A tool for Implementation of TPM—A Case Study

B.K. Mawandiya[1], V.R. Iyer[1] and U.S. Chotalia[2]

[1]Institute of Technology, Nirma University, Ahmedabad
[2]Government Polytechnic, Junagadh

Abstract—The increased dependence on the production equipment to reliably and repeatedly manufacture high quality products has created the need for a new approach to equipment management. Total Productive Maintenance (TPM) is an effective method for addressing this equipment management challenge.

Forging Companies are currently undertaking a metamorphosis in order to become more competitive in the commercial market. A large component of this change is an effort to improve manufacturing capabilities and reduce waste, which reduce overall production costs. To accomplish these goals, any forging company must improve both the quality of their products and the reliability of their production equipment. The implementation of Total Productive Maintenance (TPM), in the proper environment, can provide on an effective set of processes to drastically improve their manufacturing effectiveness through more reliable production equipment. An effort was made to implement some principles of TPM in a forging industry.

This paper presents how the Overall Equipment Effectiveness (OEE) is measured in the forge shop and how a computer program developed helps to find out systematic stoppage analysis & OEE of hammer and other forging equipments. By considering shift data, number of good products, rejection, rework and reason for break down, OEE is calculated and a report is automatically generated and updated.

By implementing TPM in these situations, the down time (manufacturing costs) associated with six big losses (variability in both product quality and production schedules) can be reduced and OEE can also be improved.

By analyzing the results, conclusions have been drawn and suggestions for further scope for future work have been provided.

Index Terms: Total Productive Maintenance, Metamorphosis and Overall Equipment Effectiveness.

I. Introduction

Increasing competition to produce reliable products at lower costs and customer driven specification has led to implementation of techniques like Just In Time (JIT), Kanban and Total Productive Maintenance (TPM) in to the manufacturing systems. Companies face dilemma due to the manufacturing constraints and high equipment cost. Should they go for increasing the plant capacity or study the current equipments for their performance efficiency, quality and utilization in optimal working conditions? The motivation is to reduce the Cost of Ownership (COO).

TPM typically addresses these concerns by optimizing the use of manufacturing resources including the tools. TPM involves all functions of the organization, from top management to the shop floor worker. Overall Equipment Effectiveness (OEE) is the key metric of TPM. OEE monitors the actual performance of a tool relative to its performance capabilities under optimal manufacturing conditions. It not only measures the utilization but also production efficiency due to various metrics and quality of the final product of the process. Various functional departments have different metric to measure their performance but the overall performance of the system depends on balancing the various metrics to arrive at an optimal solution and to avoid trade off's. Implementing OEE, hence, requires cross-functional teams to achieve its goal. OEE uses various tools to analyze the bottleneck operations that define the plant capacity.

Since, OEE requires lots of data related to shop floor control parameters and their dependence on various performance metrics, a dynamic statistical data collection is suggested. This data when used in simulation of the processes and the plant layout should give us the overall system view which helps in visualizing the key processes and their impact on overall plant effectiveness.

Problem Statement

The forging company under study, expending considerable energy to improve their production processes, through their experience in the field of forging, did not employ a reliable and repeatable method for implementing any process improvement tool.

Within the company's manufacturing operations, there is no well-defined manufacturing strategy evident at the lower levels of the organization. This situation is more serious by a shortage of useful and reliable data available to the manufacturing managers. Without reliable data and a well defined strategy, the factory managers are unable to identify their critical processes, let alone focus their scarce resources on improving these processes. Thus, production worker activities and production equipment utilization could well be sub-optimized.

The Existing approach of this company for equipment maintenance does not focus on maximizing the effectiveness of this equipment as part of an overall manufacturing system. The current level of maintenance of the equipments is not driven by an understanding of the important role that the manufacturing equipment has. Hence a study was made for initializing implementation of the TPM by determining OEE and methodology to improve the same. In the short-term, TPM activities include an autonomous maintenance program for the production department and a planned maintenance program for the maintenance department.

II. Total Productive Maintenance (TPM)

TPM has a strict definition in five steps

1. Maximizing equipment effectiveness through optimization of equipment availability, performance, efficiency and product quality.
2. Establishing a maintenance strategy (level and type of classical preventive maintenance) for the life of the equipment.
3. Covering all departments such as the planning, the user and the maintenance department.
4. Involving all staff members from top management to shop-floor workers.
5. Promoting improved maintenance through small-group autonomous activities.

III. Objectives of TPM

The ideal goals of TPM are to achieve Zero Failures, Zero Defects, and Zero Accidents. Although these goals are extremely difficult to achieve, and in many cases may not be economically feasible due to the high cost of eliminating all failures, defects, and accident; they provide a directional target that the organization can shoot for. To move an organization toward these goals, TPM provides the means to increase the amount of time that a piece of equipment is reliably available for production use. This requires significant effort to reduce the equipment degradation that may lead to equipment failures or production part variation. Additionally, TPM affects the equipment operator by providing an increased awareness, sense of ownership, and responsibility for the production equipment.

IV. Overall Equipment Effectiveness

Introduction

OEE is the best practice to monitor and improve the efficiency of manufacturing processes (e.g. machines, manufacturing cells, assembly lines). OEE is frequently used as a key factor in Total Productive Maintenance (TPM) programs.

TPM programs improve the overall effectiveness and efficiency of manufacturing plants by creating a joint responsibility between operators and maintenance personnel to achieve zero product defects, zero mechanical breakdowns, and greatly reduced changeover times.

OEE gives a consistent way to measure the effectiveness of TPM programs and other initiatives by providing an overall framework for measuring production efficiency.

Definition of Overall Equipment Effectiveness (OEE)

According to Nakajima, Total Productive Maintenance (TPM) is based on three interrelated concepts:

1. Maximizing equipment effectiveness;
2. Autonomous maintenance by operators; and
3. Small group activities.

Within this context OEE can be considered to combine the operation, maintenance and management of manufacturing equipment and resources. Recent research reports show that accurate equipment performance data is essential to the success and long-term effectiveness of TPM activities. If the extent of equipment failures and reasons for production losses are not entirely understood, then any TPM action cannot be deployed optimally to solve major problems or arrest deteriorating performance. Production losses, together with other indirect and hidden costs, constitute the majority of the total production costs. Nakajima therefore suggests that OEE is: "A measure that attempts to reveal these hidden costs".

Purpose of OEE

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 entity. 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.

Six Big Losses

One of the major goals of TPM and OEE programs is to reduce and/or eliminate what are called the **Six Big Losses** – the most common causes of efficiency loss in manufacturing. The table 1 shows lists of the Six Big Losses, and shows how they relate to the OEE loss categories. Categorizing data this way makes analysis very simple. It also makes it easy to collect and display this data so that it can be put to use throughout the day.

Table 1: Six Big Losses, OEE loss categories

Six Big Losses	OEE Category	Comment
Break-downs	Down Time Loss	There is flexibility on where to set the threshold between a Breakdown (Down Time Loss) and a Small Stop (Speed Loss).
Setup and Adjustme-nts	Down Time Loss	Includes tool change over.
Small Stops / Idling	Speed Loss	Typically only includes stops that are under five minutes and that do not require maintenance personnel.
Reduced Speed	Speed Loss	Anything that keeps the process away from running at its theoretical maximum speed (minimum cycle time).
Startup Rejects	Quality Loss	Rejects during warm-up, startup or other early production.
Production Rejects	Quality Loss	Rejects encountered during steady-state production.

Method of Eliminating/Minimizing Losses

TPM aim is to programme of zero breakdown this can be achieved through five activities and four phase or implementation of programme. Five activities, which are necessary for zero breakdowns, are follows:

- Maintain basic equipment conditions.
- Maintain operating standards and improve operating conditions.
- Restore equipment to optimum functioning.
- Improve design weaknesses.
- Improve operating and maintenance skills.

Establishing an OEE Figure

In order to establish an accurate OEE figure the six big losses must be measured accurately. The OEE Fig. 1 is the product of the values for availability, performance and quality, as shown below.

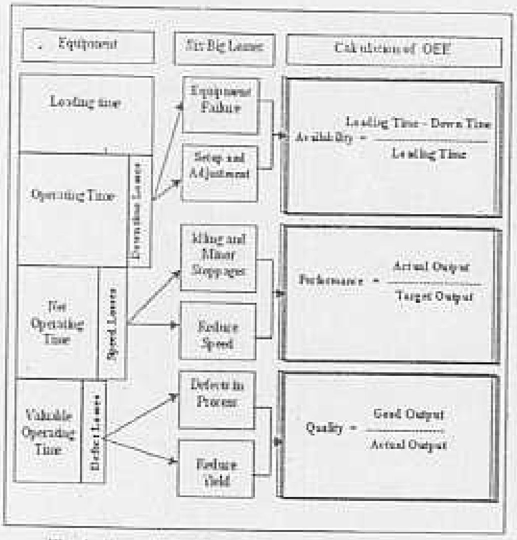


Fig. 1: Overall Equipment Effectiveness and Goals

Calculation of OEE components

The following section provides the formulae for each element of the OEE calculation. The first of these elements is machine or process availability. The availability element of the OEE measure is concerned with the total stoppage time resulting from unscheduled downtime, process set-up and changeovers, and other unplanned stoppages.

In simple terms, it is the ratio of actual operating time to the planned operating time, and takes into account the theoretical production time against which unplanned downtime is highlighted. Planned preventative maintenance is not therefore regarded as a loss in this respect. The calculation of availability in this manner might lead to excessively long preventative maintenance activities, or excessive process set-up times. In such instances, however, the OEE calculated figure would still appear low, therefore indicating the need to decrease the planned maintenance by applying more efficient and effective TPM activities.

An important factor within the availability element is loading time. Loading time can be defined as the total length of the shift after any deductions for planned downtime. Planned downtime can typically include the following activities:

- Waiting due to completion of current orders;
- No labor available due to operator breaks;
- Planned maintenance activities;
- Equipment trials and process improvement activities;
- Machine cleaning and general operator maintenance; and
- Operator training.

$$\text{Availability} = \frac{\text{Actual operating time (mins)}}{\text{Planned operating time (mins.)}} \times 100$$

Where,

Planned operating time = Total shift time – Planned maintenance

And,

Actual operating time = Planned operating time – Unplanned maintenance – Minor stoppages – Setup & changeover

The second element of the OEE calculation is "performance rate". This measures the ratio of the actual speed of the equipment to the ideal speed. The performance rate element of OEE may be calculated in a number of different ways. Nakajima measures a fixed amount of output, and in his definition "performance" indicates the actual deviation in production in time from ideal cycle time. De Groote on the other hand, focuses on a fixed time, and calculates the deviation in production from that planned. Both definitions however measure the actual amount of production.

Performance efficiency is the product of the operating speed rate and net operating rate. The operating speed rate of equipment refers to the discrepancy between the ideal speed and its actual operating speed.

The net operating rate measures the achievement of a stable processing speed over a given period of time, for example a production shift of 12 hours, rather than whether the actual speed is faster or slower than the design standard speed. This calculates losses resulting from minor recorded stoppages, as well as those that go unrecorded on daily logs, such as small problems and adjustment losses.

Performance efficiency = (Net operating rate × Operating speed rate) × 100

Where,

Net operating rate = (No: produced × Actual cycle time) / Operation time

and,

Operating speed rate = (Theoretical cycle time × Actual cycle time)

Or, Performance rate may be defined as,

$$\text{Performance rate} = \frac{\text{Actual Output}}{\text{Target Output}} \times 100$$

The third and final element of the OEE calculation is the "quality rate", and is used to indicate the proportion of defective production to the total production volume. It should be noted, however, that the quality rate involves defects that occur only in that designated stage of production, usually on a specific machine or production line. The related formulae for the calculation of availability, performance and quality are given below respectively.

$$\text{Quality rate} = \frac{\text{Total No. Good Output}}{\text{Total No. Actual Output}} \times 100$$

OEE is measured in terms of these six big losses, which are essentially a function of the availability, performance rate and quality rate of the machine, production line, or factory, whichever is the focus of OEE application [34].

OEE = Availability × Performance × Quality

Initial Data Collection for OEE

The critical parameters of the six big losses require detailed performance data. This can result initially in overly complex data collection requirements, since the OEE performance data requirement is likely to be much more detailed than any previous performance measurement requirements. Such data may be simplified. Rather than recording the actual time of each downtime and speed loss for example, the frequency of these losses can be recorded initially. Although the former situation is more precise, the latter can be adapted as an initial step by process operatives. It should not be forgotten that: the most important objective of OEE is not to get an optimum measure, but to get a simpler measure that indicates the areas for improvement.

Software Development

OEE is probably the most important tool in the TPM program. Calculating the OEE is essential to get focus of the operator and equipment. The supervisor or line-manager processes all the data he receives from the operators. Soon he gets an overview of what's happening on his equipment. With this information he gives a feedback to the operator and informs his management. The OEE-software helps to get the best information out of OEE. Software is developed to calculate OEE with the help of Visual basic, MSSQL and Crystal Report. Data entry form has been designed in such a way that minimum data entry is required. Following section gives a description about the Input and pre defined data required in the calculation of OEE and stoppage analysis report.

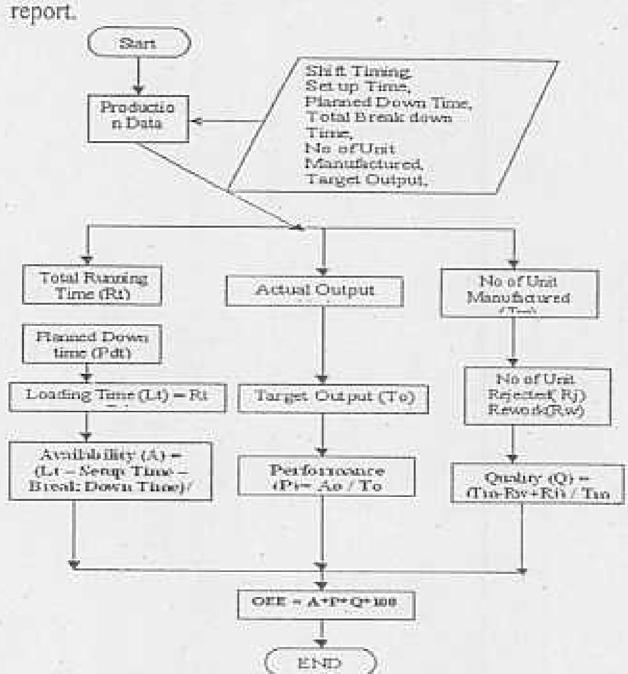


Fig. 2: Flowchart to calculate OEE

The Problems while Implementing the OEE

Masses of data need to be processed to calculate OEE manually. Soon the supervisor gets overloaded with data. The longer he waits with processing, the lesser his motivation. Although huge piles of data are available, the question will be how to get information out of it. Extracting information is usually very time consuming and hence costly. The masses of data coming in from the operators are no longer to handle without some kind of automation. Implications of these solutions need the tool which is,

- Flexible to the need of the user.
- Without interference of software programming.
- Easy to use.
- Expandable to future needs.
- Minimal input, maximal information.

Data-Collection and Input in Software

Data collecting is a part of creating operator awareness. There are several data-collection strategies possible. Screen is designed for optimal speed and ease of use. Almost no typing is required since the system knows most of the data already. Just Click-and-Pick. One screen gives all the information of one OEE-calculation to the operator or line-manager. Many reports are instant-ready, and directly available for shortest feedback. The operator/line manager immediately gets feedback on the data.

- Availability, Performance- and Quality rates and OEE
- Graphical presentation of the stoppage reasons Provides up to date shift report.

Out Put from OEE Software

The reason to collect data is to get information. The OEE software helps to get as much information as possible out of the collected data. Information can always be produced over a predefined range of time, a day, a week, a shift or a period.

Several graphs can be generated to show progress in improving the OEE, and stoppage analysis report by the software itself. Reports are also flexible in nature and one can get such report for one shift, one day or one week or month or entire time span. The report shows the OEE, availability, performance and quality rate, and stoppage reason over a time. After systematic observation and critical examination of the reports, number of things uncovers. Like frequency of breakdown over a time, more than expected breakdown time if it is unusual or more than expected, production and maintenance people think over it and find out permanent solutions of problems.

Let's first look at the presentation of the OEE/stoppage reason data itself.

One can present the OEE over any machine or shift in any period. Even a general OEE (of all the machines) is not a problem. Those who ever tried to calculate such by hand, know what this means, since adding several OEE's is not just a matter of summing the OEE value and taking the average. One has to recalculate all the individual values! There is virtually no limit to the data range one wants to (re)calculate. a day, several days, a month. Just pick the first and the last date, the tool does the rest. Lists and Graphs can be printed in full color for presentations on the shop floor. By providing data required to calculate OEE, OEE software calculate OEE, Report of stoppage analysis and shift report.

World Class OEE

OEE is essentially the ratio of **Fully Productive Time** to **Planned Production Time**. In practice, however, OEE is calculated as the product of its three contributing factors:

OEE = Availability × Performance × Quality

This type of calculation makes OEE a *severe* test. For example, if all three contributing factors were 90.0%, the overall OEE would be 72.9%. In practice, the generally accepted *World-Class* goals for each factor are quite different from each other, as is shown in the Table 2 below.

Table 2: World class OEE

OEE Factor	World Class
Availability	90.0%
Performance	95.0%
Quality	99.9%
Overall OEE	85.0%

Worldwide studies indicate that the average OEE rate in manufacturing plants is 60%. As seen in the above table, a World Class OEE is considered to be 85% or better. Clearly, there is room for improvement in most manufacturing plants.

OEE Calculation

The Table 3 below contains hypothetical shift data, to be used for a complete OEE calculation, including calculation of the three contributing factors of *Availability, Performance, and Quality*.

Table 3: Shift Data

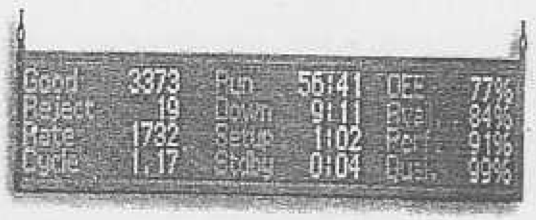
Item	Data
Shift Length	8 Hours (480 minutes)
Short Breaks	(2) 15 minutes each
Meal Break	(1) 30 minutes
Down Time	47 minutes
Ideal Rate	60 ppm
Pieces Produced	19,271
Reject Pieces	423

Visual OEE

"How can management collect and display useful OEE data without reams of paper and a platoon of Industrial Engineers?"

The answer is: Visual OEE.

Figure: Visual OEE



A factory without display of production metrics is like the car with no speedometer!

Real-time display of production metrics enables operators and maintenance people to quickly respond to issues that would otherwise destroy productivity. These metrics serve as a gauge when making adjustments that lead to incremental improvements. Visual OEE displays developed provide the data needed to improve manufacturing efficiency through promoting plant-flow awareness.

The Visual OEE Principle

A barrier between manufacturer and greater productivity is the performance data which they can't see when they need it. OEE information in tomorrow's report is not nearly as useful as instantaneous reporting of key OEE losses in real time. Exciting productivity improvements to be when real-time OEE percentages developed directly from machine or manufacturing cell are monitored.

In other words: A Visual OEE display that is visible to everyone is a simple, effective way to realize immediate improvement in production.

The quickest and most effective way to improve OEE is to attack the "Six Big Losses".

The following Table 4 shows the company performance in terms of OEE:

Table 4: Evaluation of Company's performance compared with World Class Performance

Company's performance	*World-class performance*
75% Availability	>90% Availability
83% Performance efficiency	>95% Performance efficiency
97% Rate of quality	>99% Rate of quality
61% OEE	>85% OEE

If the WCM target of 85% OEE is reached, then in the present case study 32.16% increase from the existing OEE would have represented a potential earning capacity of Rs. 103908 per week.

The efficient maintenance of the production and other plant machinery is crucial in determining the success and overall effectiveness of the manufacturing process. Despite time and money spent on the development/production of the advanced plant and its equipment, there has not been enough attention to defining comprehensive maintenance strategies, practices and policies. However, there are indications that the transition process from reactive (breakdown) maintenance to TPM is already taking place.

V. Conclusions

In the present world of competitive environment, industries have to come out with quality products at lower cost, so as to make customers delighted. In order to do this, various concepts are available out of which Total Productive Maintenance is one of the most efficient, reliable and widely accepted philosophy to fight against the lower productivity.

TPM can be implemented in any industry irrespective of size of the industries. OEE is a tool to measure effectiveness of the equipments used and thus shows the areas that need to be improved first. Training has to be provided to the workers for motivating them, to adopt new methods and concepts for successful implementation of TPM.

For the Case Study

- Software was developed for determination of overall equipment effectiveness and for analyzing down time which facilitates improvements in OEE and reduction in down time in shorter duration.
- A TPM implementation plan was developed for the forge shop.
- The documentation of a comprehensive approach for developing and implementing TPM methods.

Teams that have started implementing TPM have quickly realized that equipment performance is critical in reducing manufacturing costs. In the forging industry where study was conducted OEE was well below 'world class' level. After implementing TPM in the forge shop, improvement in Overall Equipment Effectiveness improved from 52% to 61%, 9% improvement in OEE, Also down time was reduced by approximately 22.5 Hours per month.

Further implementation of the TPM in a continuous manner will facilitate the organization in achieving better results An integrated approach within the organization is necessary for reaping the benefits of TPM fully.

VI. Future Scope

The results of case study provide insight into the requirement for improvement of equipment performance. The following are the areas where research is still needed for full implementation of TPM.

- Research is still required to find new and innovative data collection methods, and data analysis methods.
- Development of Visual OEE system which provide continuous display of OEE data in various departments will motivate management and workers for further improvement in manufacturing performance.

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