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Overall Equipment Effectiveness and the Six Big Losses in Total Productive Maintenance

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Abstract Maintenance philosophies have evolved over a period of time. These philosophies have developed from breakdown maintenance to Reliability Centred Maintenance (RCM). By performing proper maintenance on plant equipment, manufacturing goals can be achieved. This forms the basis of Total Productive Maintenance (TPM) strategy, which aims at supporting manufacturing goals, as it is based on the integrated manufacturing system approach that includes process control, quality assurance, safety and maintenance. The paper reviewed the literature and provided a detailed definition of TPM, and also identified 5S as its foundation with eight supporting functions usually referred to as the pillars. Apart from reducing equipment breakdowns and defects, enhancing productivity, throughput, and profitability, the following were listed as some of the benefits of successful TPM Implementation: quality improvement, reduction of production cost, inventory, set up time, accidents, and labour costs. Before discussing the six big losses in details, the paper pointed out that the losses can be resolved by implementing the overall equipment effectiveness, and that the measurement of OEE assists manufacturers to trace the benefits inherent in TPM implementation, and also in the identification of production losses.

Keywords Total Productive Maintenance, Overall Equipment Effectiveness, six big losses, breakdown, equipment, defect, downtime, performance, quality, availability

1. Introduction

Developed for overall enhancement of productivity by ensuring waste reduction and more reliable manufacturing processes, Total Productive Maintenance (TPM) is an all-encompassing methodology of equipment maintenance that aims at perfect production.

Okpala and Egwuagu [1], noted that TPM is often referred to as the medical science of machines, as it is a “philosophy of machine maintenance that entails active participation of employees to ensure the improvement of the general effectiveness of a plant, by eliminating or reducing resources and time wastage through the incorporation of the skills of the workforce.” They explained that as a maintenance programme that entails a modern approach for equipment and plant maintenance, TPM aims to integrate maintenance and services of machines into a plant’s daily routine, thereby reducing unscheduled and emergency stoppages and repairs to the barest minimum.

Total Productive Maintenance is an organized machines and equipment maintenance system that focuses on continuous improvement through teamwork; it fixes all identified potential causes of problems to forestall breakdowns. According to Wakjira and Singh [2], Total Productive Maintenance is an attitude, concept and process of continuous improvement in maintenance and manufacturing processes to improve overall equipment effectiveness, operating efficiency, output quality and workers safety.

The overall goal of TPM is to provide a safe working environment, ensure that production targets are met and that quality products are supplied to customers. Although these areas have always been important, TPM, as opposed to other initiatives such as Predictive Maintenance or Preventative Maintenance, seeks to provide a holistic and more integrative approach to running and maintaining plant operations. As a result, local manufacturing industries are improving their operations to become more competitive by enlisting the help of experts in the field of plant maintenance to assist their organisations in implementing TPM.

Venkatesh [3], noted that the origin of TPM can be traced back to 1951 when preventive maintenance was introduced in Japan, when Nippondenso was the first company to introduce plant wide preventive maintenance. He observed that with the automation of Nippondenso, maintenance became a problem as more maintenance personnel were required. So the management decided that the routine maintenance of equipment would be carried out by the operators.

Thus, the company which already followed preventive maintenance also added Autonomous maintenance, done by production operators. This led to maintenance prevention, as preventive maintenance alongside Maintainability Improvement gave birth to Productive maintenance, which aimed at the maximization of plant and equipment effectiveness to achieve optimum life cycle cost of production equipment.

TPM represents a shift in the way progressive world-class companies think about maintenance, as it is a radical departure from the traditional view of breakdown maintenance. As a methodology and philosophy of strategic equipment management focused on the goal of building product quality by maximising equipment effectiveness, TPM was originally introduced as a set of practices and methodologies focused on manufacturing equipment performance improvement. However, over the years according to Ahuja and Kumar [4], TPM has matured into a comprehensive equipment-centric effort to optimize manufacturing productivity. It embraces the concept of continuous improvement and total participation by all employees and departments.

The objective of TPM is to attain autonomous maintenance through the improvement of equipment effectiveness. This could be achieved by enhanced throughput and product quality, as well as the reduction of production cost and inherent wastes in manufacturing processes.

The Pillars of TPM

For an effective implementation of TPM in manufacturing companies, the entire work force must be informed and carried along right from the commencement of the exercise; this is because TPM entails setting up anticipatory measures to enable operators to enhance equipment's effectiveness. According to Vorne [5], Involving operators in maintaining their own equipment, and emphasizing proactive and preventive maintenance will lay a foundation for improved production, leading to fewer breakdowns, stoppages, and defects.

As shown in figure 1, the traditional TPM has the 5S which consists of Sort, Straighten, Shine, systemize, and sustain as its foundation and eight supporting functions usually referred to as the pillars, and when successfully implemented the end result will be world class result.

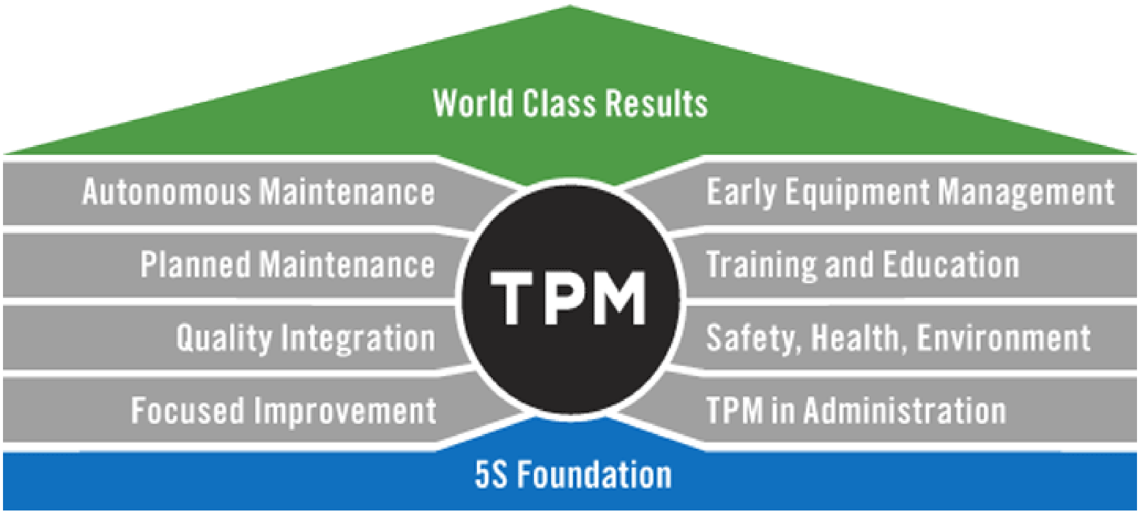

Figure 1: The Traditional TPM Model

Ihueze and Okpala [6], noted that 5S practice that adopts the use of visual signs to ensure greater benefits is targeted at improving productivity by sanitizing as well as ensuring a neat and well arranged shop floor. They pointed out that the 5Swhich were originally Japanese words are:

- Seiri (Sort): Isolate and get rid of all material sthat are not useful;
- Seiton (Straighten): Systemize the important materials and arrange them properly for better retrieval when they are required;
- Seiso (Shine): Clean-up the entire shop floor to maintain a conducive environment for manufacturing;
- Seiketsu (Systemize): Maintain a constant cleaning of the surroundings;
- Shitsuke (Sustain): Involve all the employees and ensure that the constant cleaning is maintained.

The eight pillars of TPM which emphasizes mainly on achieving equipment effectiveness through preventative techniques is shown in Table 1.

Table 1: The Eight Pillars of TPM [5].

Pillar	What is it?	How does it help?
Autonomous Maintenance	Places responsibility for routine maintenance, such as cleaning, lubricating, and inspection, in the hands of operators.	• Gives operators greater "ownership" of their equipment. • Increases operators' knowledge of their equipment. • Ensures equipment is well-cleaned and lubricated. • Identifies emergent issues before they become failures. • Frees maintenance personnel for higher-level tasks.
Planned Maintenance	Schedules maintenance tasks based on predicted and/or measured failure rates.	• Significantly reduces instances of unplanned stop time. • Enables most maintenance to be planned for times when equipment is not scheduled for production. • Reduces inventory through better control of wear-prone and failure-prone parts.
Quality Maintenance	Design error detection and prevention into production processes. Apply Root Cause Analysis to eliminate recurring sources of quality defects.	• Specifically targets quality issues with improvement projects focused on removing root sources of defects. • Reduces number of defects. • Reduces cost by catching defects early (it is expensive and unreliable to find defects through inspection).
Focused Improvement	Have small groups of employees work together proactively to achieve regular, incremental improvements in equipment operation.	• Recurring problems are identified and resolved by cross-functional teams. • Combines the collective talents of a company to create an engine for continuous improvement.
Early Equipment Management	Directs practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment.	• New equipment reaches planned performance levels much faster due to fewer startup issues. • Maintenance is simpler and more robust due to practical review and employee involvement prior to

		installation.
Training and Education	Fill in knowledge gaps necessary to achieve TPM goals. Applies to operators, maintenance personnel and managers.	• Operators develop skills to routinely maintain equipment and identify emerging problems. • Maintenance personnel learn techniques for proactive and preventative maintenance. • Managers are trained on TPM principles as well as on employee coaching and development.
Safety, Health, Environment	Maintain a safe and healthy working environment.	• Eliminates potential health and safety risks, resulting in a safer workplace. • Specifically targets the goal of an accident-free workplace.
TPM in Administration	Apply TPM techniques to administrative functions.	• Extends TPM benefits beyond the plant floor by addressing waste in administrative functions. • Supports production through improved administrative operations (e.g. order processing, procurement, and scheduling).

The Need for TPM in Manufacturing

According to Tripathi [7], TPM implementation in a manufacturing company leads to higher productivity, better quality, fewer breakdowns, lower costs, reliable deliveries, motivating working environments, enhanced safety and improved morale of the employees. The ultimate benefits that can be obtained by implementing TPM are enhanced productivity and profitability of the manufacturing organisation.

TPM aims to increase the availability of existing equipment in a given situation, reducing in that way the need for further capital investment. According to Bohoris et al, [8], instrumental to its success is the investment in human resources, which further results in better hardware utilization, higher product quality and reduced labour costs.

Suzuki [9], opined that manufacturing organisation practicing TPM invariably achieve startling results, particularly in reducing equipment breakdowns, minimizing idling and minor stops (indispensable in unmanned plants), lessening quality defects and claims, boosting productivity, trimming labour and costs, shrinking inventory, cutting accidents, and promoting employee involvement. When the breakdowns and defects are eliminated, many benefits are presented: equipment productivity improvement, cost reduction, quality improvement, and inventory reduction, etc. The TPM approach helps increase uptime of equipment, reduce machinery set-up time, enhance quality, and lower costs. Through this approach, maintenance becomes an integral part of the team.

In addition, TPM implementation in a manufacturing organization can also lead to realization of intangible benefits in the form of improved image of the organization, leading to the possibility of increased orders. After introduction of autonomous maintenance activity, operators take care of machines by themselves without being ordered to Dossenbach [10], pointed out that with the achievement of zero breakdowns, zero accidents and zero defects, operators get new confidence in their own abilities and the organizations also realize the importance of employee contributions towards the realization of manufacturing performance.

TPM implementation also helps to foster motivation in the workforce, through adequate empowerment, training and felicitations, thereby enhancing the employee participation towards the realization of manufacturing companies' goals and objectives. Ideally, TPM provides a framework for addressing the manufacturing organisational objectives. The other benefits include favourable changes in the attitude of the operators, achieving goals by working in teams, sharing knowledge and experience and the workers getting a feeling of owning the machine.

Overall Equipment Effectiveness and the Six Bog Losses in TPM

Often regarded as one of the best measurements of Total Productive Maintenance, Overall Equipment Effectiveness (OEE) is a technique applied for the measurement of major production features which include performance efficiency, rate of quality and availability. It aims at speed increment, and the reduction of defective products, machines stoppages (downtime), and poor quality products by machines, as well as machines and equipment that work below their production capacity.

The OEE model that depicts the losses and target is shown in figure 2.

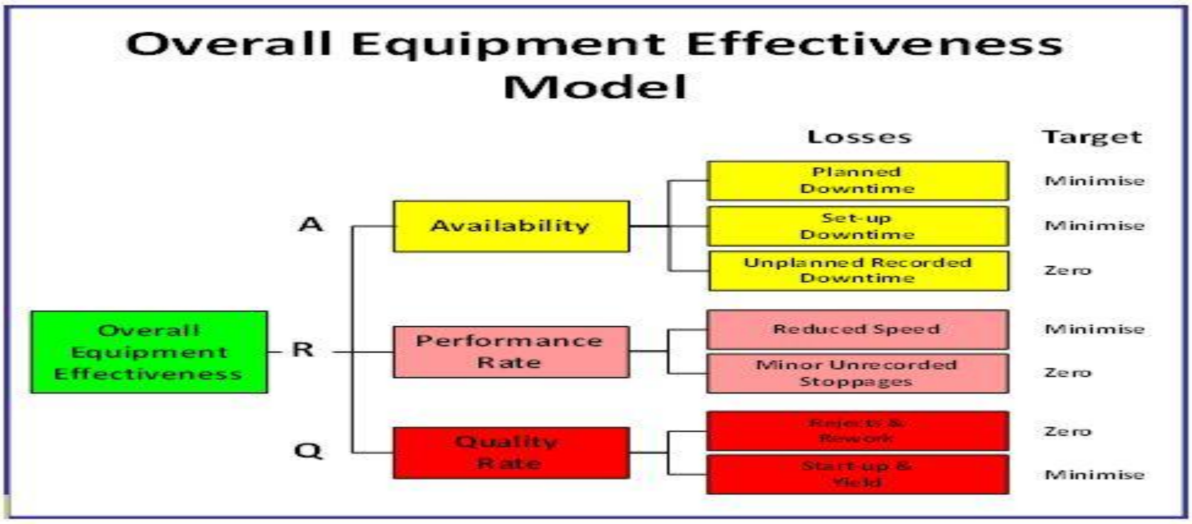

Figure 2: The OEE Model

OEE according to Leanproduction [11], is a metric that identifies the percentage of planned production time that is truly productive, and was developed to support TPM initiatives by accurately tracking progress towards achieving "perfect production". It observed that it is of utmost important to measure OEE in order to expose and quantify productivity losses, and also measure and track improvements resulting from TPM initiatives.

As shown in Table 2, OEE is associated with the goals of TPM of no stoppages measured by availability, no defective products measured by quality, and no small stops measuredby performance.

Table 2: Components of OEE [11]

Component	TPM Goal	Type of Productivity Loss
Availability	No Stops	Availability takes into account **Availability Loss**, which includes all events that stop planned production for an appreciable length of time (typically several minutes or longer). Examples include Unplanned Stops (such as breakdowns and other down events) and Planned Stops (such as changeovers).
Performance	No Small Stops or Slow Running	Performance takes into account **Performance Loss**, which includes all factors that cause production to operate at less than the maximum possible speed when running. Examples include both Slow

		Cycles, and Small Stops.
Quality	No Defects	Quality takes into account **Quality Loss**, which factors out manufactured pieces that do not meet quality standards, including pieces that require rework. Examples include Production Rejects and Reduced Yield on startup.
OEE	Perfect Production	OEE takes into account all losses (Availability Loss, Performance Loss, and Quality Loss), resulting in a measure of truly productive manufacturing time.

The OEE is applied in the enhancement of machine performance and related processes through the identification of performance opportunities that imparts heavily on the bottom line. The OEE metric which is the ratio of actual output of equipment to its greatest theoretical output, measures and enhances the reliability of machine, products' quality, and changeovers' improvements.

OEE is calculated with the following formulae:

$$\boldsymbol{OEE = Availability \times PerformanceRate \times QualityRate}$$

$$\text{Availability (in percent)} = \frac{\text{Actual Running Time}}{\text{Scheduled Running Time}} \times 100$$

Whereas Actual Running Time =scheduled running time-unplanned stoppages

$$\textbf{Availability} = \frac{\textbf{scheduledrunningtime} - \textbf{unplannedstoppages}}{\textbf{scheduledrunningtime}} \times \mathbf{100}$$

$$\textbf{Performance Rate (in percent)} = \frac{\textbf{Actualaverageproduction}}{\textbf{standardproduction}} \times \mathbf{100}$$

$$\textbf{Average production rate} = \frac{\textbf{averageproductionincycle}}{\textbf{noofworkingdaysinacycleperiod}}$$

$$\textbf{Quality rate (in percent)} = \frac{\textbf{noofprocessed} - \textbf{noofproductsrejected}}{\textbf{noofproductsprocessed}} \times \mathbf{100}$$

The framework of production loss is depicted in figure 3.

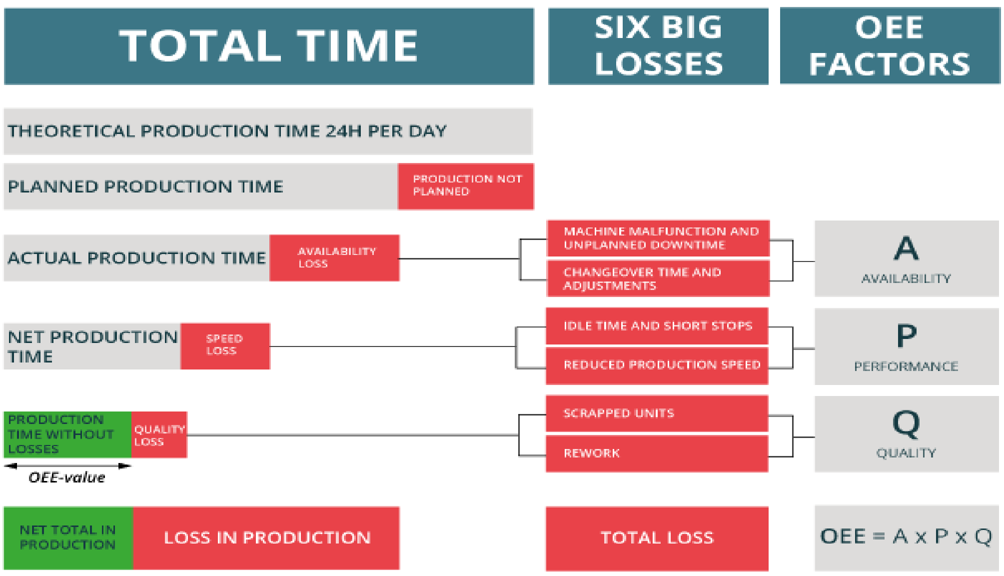

Figure 3: The Framework of Production Loss

The measurement of OEE assists manufacturers to trace the benefits inherent in TPM implementation and also in the identification of production losses. Okpala and Egwuagu [1], noted that "As the important function of production line, rate of production, availability, rate of performance, and machine's quality rate, Overall Equipment Effectiveness is calculated with regards to the six major losses that can result from faulty equipment or operation which include unexpected breakdown, setup and adjustment losses, idling and stoppage losses, speed losses, quality defect and rework losses, as well as equipment and capital investment losses."
The six major losses that can result from faulty equipment or operation is shown in Table 3.

Table 3: Six major losses [12]

S/No.	Loss Category	Costs to Organization
1	Unexpected breakdown losses	Results in equipment downtime for repairs. Costs can include downtime (and lost production opportunity or yields), labor, and spare parts.
2	Set-up and adjustment losses	Results in lost production opportunity (yields) that occurs during product changeovers, shift change or other changes in operating conditions.
3	Idling and Stoppage losses	Results in frequent production downtime and that difficult to record manually. As a result, these losses are usually hidden from efficiency reports and are built into machine capabilities but can cause substantial equipment downtime and lost production opportunity.
4	Speed losses	Results in productivity losses when equipment must be slowed down to prevent quality defects or minor stoppages. In most cases, this loss is not recorded because the equipment continues to operate.
5	Quality defect & Rework losses	Results in low standard production and defects due to equipment malfunction or poor performance, leading to output which must be reworked or scrapped as waste.
6	Equipment and capital investment losses	Results in wear and tear on equipment that reduces its durability and productive life span, leading to more frequent capital investment in replacement equipment.

Breakdowns

Equipment breakdown also known as unplanned stops is an Availability Loss that occurs whenever an equipment that is scheduled for operation is shut down as a result of a failure. Such failures are unavailability of inventory or operators, forced maintenance, equipment and tool failures, as well as bottlenecks. Reducing and possible elimination of breakdowns is very crucial to enhancing Overall Equipment Effectiveness.

Setup time and Adjustment Losses

Often referred to as planned stops, setup time and adjustment losses is the period when an equipment that has already been scheduled for operation is shut down as a result of equipment repairs, adjustments, cleaning, planned maintenance and lubrication, inspection and changeovers.
Also an Availability Loss, set up time which measured as the period between the last good product produced before setup to the first regular good products produced after setup, can be tackled by the application of the Single Minute Exchange of Dies (SMED) system pioneered by a Japanese – Shingeo Shingo.

Idling and Stoppage Losses

Idling and stoppage losses also referred to as small stops and reduced speeds which are often sorted out by the operator arise when an equipment stops for a short period of less than five minutes. The Performance Loss is usually ignored by operators as they occur intermittently thereby making it a very difficult loss to identify.
Examples include hampered product flow, jammed materials, routine quick cleanings, misfeeds, faulty settings and designs, and obstructed sensors. The loss can be tracked bythe application of Cycle Time Analysis (CPA).

Speed Losses

Speed Losses takes place when equipment runs at reduced speed when compared to the theoretical ideal cycle time. The examples of the Performance Loss which is also called reduced speed or slow cycles are inadequate lubrication, inexperienced operator, low quality inventory, shutdown, as well as dirty equipment.

Quality Defect and Rework Losses

Quality defect and rework losses also known as process defects are defective and faulty products, as well as products that could still be reworked that are manufactured during regular production. The production of a lot of defective products adversely affects manufacturing companies' profitability due to the high cost of rework, hence the need for OEE.

Whenever defects are noticed, it is always advised to track it in order to isolate the possible causes. Considered as a Quality Loss, examples of quality defect and rework losses are operator handling errors, as well as faulty setting of equipment.

Equipment and Capital Investment Losses

According to Gupta, Tewari, and Sharma [12], Equipment and Capital Investment Losses leads to wear and tear on equipment that reduces its durability and productive life span, thereby leading to more frequent capital investment in replacement equipment.

The six big losses and OEE loss category with event examples are shown in Table 4.

Table 4: The Six Big Losses and OEE Loss Category

Six Big Loss Category	OEE Loss Category	Events Example	Comment
Breakdowns	Downtime Loss	Tooling Failures Unplanned Maintenance General Breakdowns Equipment Failure	There is flexibility on where to set the threshold between a breakdown (Downtime loss) and a small stop (Speed loss)
Setup and Adjustments	Downtime Loss	Setup/Changeover Material Shortages Operator Shortages Major Adjustments Warm-up Time	This loss is often addressed through setup time reduction programmes
Small Stops	Speed Loss	Obstructed Product Flow Component Jams Misfeeds Sensor Blocked Delivery Blocked Clearing/Checking	Typically only includes stops that are under five minutes and that do not require maintenance personnel
Reduced Speed	Speed Loss	Rough Running Under Nameplate Capacity Under Design Capacity Equipment Wear Operator Inefficiency	Anything that keeps the process from running at its theoretical maximum speed (Ideal run rate or nameplate capacity)
Start-up Rejects	Quality Loss	Scrap Rework In-process Damage In-process Expiration	Rejects during Warm-up, start-up or other early Production. May be due to improper setup, warm-up period etc.

Production Rejects	Quality Loss	Incorrect Assembly Scrap Rework In-process Damage In-process Expiration Incorrect Assembly	Rejects during steady state production

However, the six major losses can be resolved by implementing the overall equipment effectiveness.

Conclusion

The six big losses which support OEE and offer an outstanding approach to improvement of manufacturing is deeply rooted in TPM, this is because one of the aims of TPM is the identification and subsequent elimination of the six big losses which is an effective approach to equipment based losses categorization.

The right step to achieve sound and verifiable results in TPM implementation is for manufacturing companies to focus on continuous improvement to improve the constraint, which will ultimately lead to the reduction of the six big losses and enhanced profitability and throughput.

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