Total Productive Maintenance

Sagar Suryakant Nikam

Abstract— Importance of TPM, which stands for Total Productive maintenance for Liberalization of global economy, has resulted tough competition in global market and for the sustainability in market for any product or service, the optimization of resources and costs in all sorts is required. The global competition is based on the innovation of advanced products, processes etc. and technology support is the essential requirement for any advancement in product or process where concept of Total productive maintenance has very much relevance today where it focus on improvement in equipment availability, performance and quality with assuring health and safety of employees and protection of environment. TPM provides a method for the achievement of excellent levels of overall equipment effectiveness through people and not through technology or systems alone. It includes the organizational structures, human interactions, analytical tools and success criteria associated with the implementation of Total Productive Manufacturing programs.

Index Terms— Breakdown maintenance, Maintenance manuals, Maintenance management information system, Overall equipment effectiveness, Pillars, TPM implementation, Total Productive maintenance.

1 Introduction

The manufacturing industry has experienced an unprecedented degree of change in the last three decades, involving drastic changes in management approaches, product and process technologies, customer expectations, supplier attitudes as well as competitive behavior. In today's highly dynamic and rapidly changing environment, the global competition among organizations has led to higher demands on the manufacturing organizations. The global marketplace has witnessed an increased pressure from customers and competitors in manufacturing as well as service sector. The rapidly changing global marketplace calls for affecting improvements in a company's performance by focusing on cost cutting, increasing productivity levels, quality and guaranteeing deliveries in order to satisfy customers. Organizations that want to survive in today's highly competitive business environment must address the need for diverse product range with state-of-the-art product features, coupled with high quality, lower costs, and more effective, swifter Research and Development. In today's fast-changing marketplace, slow, steady improvements in manufacturing operations do not guarantee sustained profitability or survival of an organization. Thus, the organizations need to improve at a faster rate than their competitors, if they are to be-come or remain leaders in the industry.

With increased global competition, attention has been shifted from increasing efficiency by means of economies of scale and internal specialization to meeting market conditions in terms of flexibility, delivery performance and quality. The changes in the current business environment are characterized by intense competition on the supply side and heightened volatility in customer requirements on the demand side. These changes have left their unmistakable marks on the different facets of the manufacturing organizations. To meet the challenges posed by the contemporary competitive environment, the manufacturing organizations must infuse quality and performance improvement initiatives in all aspects of their operations to improve their competitiveness. In an increasing global economy, cost effective manufacturing has become a necessity to stay competitive.

The nature of production technologies has changed tremendously because of the implementation of advanced manufacturing technologies and Just-In-Time (JIT) manufacturing. However, benefits from these programs have often been limited because of unreliable or inflexible equipment. Historically, management has devoted much of its effort in improving manufacturing productivity by probing, measuring, reporting and analyzing manufacturing costs. Similar efforts in regard to maintenance function productivity are long overdue.

It is observed that there has been a general lack of synergy between maintenance management and quality improvement strategies in the organizations, together with an overall neglect of maintenance as a competitive strategy. Thus, the inadequacies of the maintenance practices in the past, have adversely affected the organizational competitiveness thereby reducing the output and reliability of production facilities, leading to fast deteriorations in production facilities, lowering equipment availability due to excessive system downtime, lowering production quality, increasing inventory, thereby leading to unreliable delivery performance.

2 Challenge of Maintenance Function

Maintenance is normally perceived to have a poorer rate of return than any other major budget item. Yet, most companies can reduce maintenance costs by at least one-third, and improve the level of productivity, by giving maintenance the management priority it requires. That priority must span all levels of an organization's management structure to develop an understanding at each level of the significance maintenance can have upon the success or failure of organization objectives. The maintenance processes can be streamlined to eliminate waste and produce breakthrough performance in areas valued by customers.

Equipment maintenance represents a significant component of the operating cost in transportation, utilities, mining, and manufacturing industries. The potential impact of

maintenance on the manufacturing performance is substantial. Maintenance is responsible for controlling the cost of manpower, material, tools, and overhead. In financial terms, maintenance can represent 20 to 40 per cent of the value added to a product as it moves through the plant. Further, a survey of manufacturers found that full-time maintenance personnel as a percentage of plant employees averaged 15.7 per cent of overall staffing in a study involving manufacturing organizations, whereas in refineries, the maintenance and operations departments are often the largest and each may comprise about 30 per cent of total staffing. It has been found that in the UK manufacturing industry, maintenance spending accounts for a significant 12 to 23 per cent of the total factory operating costs. With significant figures like these, manufacturers are beginning to realize that maintenance organization and management, and design for maintainability and reliability are strategic factors for success in 1990s. Thus, the effectiveness of maintenance function significantly contributes towards the performance of equipment, production and products.

The rapidly changing needs of modern manufacturing and the ever-increasing global competition has emphasized upon the re-examination of the role of improved maintenance management towards enhancing organization's competitiveness. Confronted with such reality, organizations are under great pressure to enhance their competencies to create value to customers and improve the cost effectiveness of their operations on a continuous basis. In the dynamic and highly challenging environment, reliable manufacturing equipment is regarded as the major contributor to the performance and profitability of manufacturing systems. Its importance is rather increasing in the growing advanced manufacturing technology application stages. Therefore, equipment maintenance is an indispensable function in a manufacturing enterprise. For maintenance to make its proper contribution to profits, productivity, and quality, it must be recognized as an integral part of the plant production strategy. Thus, achieving excellence in maintenance issues has to be treated as a strategic issue for manufacturing organizations to create world-class-manufacturers.

In the highly competitive environment, to be successful and to achieve world-class-manufacturing, organizations must possess both efficient maintenance and effective manufacturing strategies. The effective integration of maintenance function with engineering and other manufacturing functions in the organization can help to save huge amounts of time, money and other useful resources in dealing with reliability, availability, maintainability and performance issues. Strategic investments in the maintenance function can lead to improved performance of manufacturing system and enhance the competitive market position of the organization. This has provided the encouragement to the leading organizations worldwide to adopt effective and efficient maintenance strategies such as Condition Based Maintenance (CBM), Reliability Centered Maintenance (RCM) and Total Productive Maintenance (TPM).

The changing needs of the physical assets and equipment over time have been putting tremendous pressures on the maintenance management to adapt proactively Total productive maintenance for meeting the fast-changing requirements of the production systems. Maintenance, being an important support function in businesses with significant investments in plants and machinery, plays an important role in meeting this tall order. Consequently, the equipment management has passed through significant changes in the recent times. In the present manufacturing scenario, the maintenance function has become an integral part of the overall profitability of an organization. It has been accepted beyond any doubt that maintenance, as a support function in businesses, plays an important role in backing up many emerging business and operation strategies like lean manufacturing, just-in-time production, total quality control and six-sigma programs. To that end, the effectiveness of maintenance needs to be improved.

3 Evolution of Equipment Management

To begin with, there is a need to develop an understanding of the basic perception of the maintenance function. Here, it is pertinent to note that the maintenance function has undergone serious change in the last three decades. The traditional perception of maintenance's role is to fix broken items. Taking such a narrow view, maintenance activities have been confined to the reactive tasks of repair actions or item replacement. Thus, this approach is known as reactive maintenance, breakdown maintenance or corrective maintenance. Gits (1992) as define a more recent view of maintenance: "All activities aimed at keeping an item in or restoring it to, the physical state considered necessary for the fulfilment of its production function". Obviously, the scope of this enlarged view also includes the proactive tasks such as routine servicing and periodic inspection, preventive replacement, and condition monitoring. In order to "retain" and "restore" equipment, maintenance must undertake a number of additional activities. These activities include the planning of work, purchasing and control of materials, personnel management, and quality control. This variety of responsibilities and activities can make maintenance a complex function to manage.

To support production, maintenance must ensure equipment availability in order to produce products at the required quantity and quality levels. This support must also be performed in a safe and cost-effective manner. The Maintenance Engineering Society of Australia (MESA) recognizes this broader perspective of maintenance and defines the maintenance function as "The engineering decisions and associated actions necessary and sufficient for the optimization of specified capability". "Capability" in this definition is the ability to perform a specific action within a

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range of performance levels. The characteristics of capability include function, capacity, rate, quality, responsiveness and degradation. The scope of maintenance management, therefore, should cover every stage in the life cycle of technical systems (plant, machinery, equipment and facilities), specification, acquisition, planning, operation, performance evaluation, improvement, and disposal.

Equipment management has gone through many phases. The progress of maintenance concepts over the years is explained below:

- **Breakdown maintenance (BM):** This refers to the maintenance strategy, where repair is done after the equipment failure/stoppage or upon occurrence of severe performance decline. This maintenance strategy was primarily adopted in the manufacturing organizations, worldwide, prior to 1950. In this phase, machines are serviced only when repair is drastically required. This concept has the disadvantage of unplanned stoppages, excessive damage, spare parts problems, high repair costs, excessive waiting and maintenance time and high trouble shooting problems.

- **Preventive maintenance (PM):** This concept was introduced in 1951, which is a kind of physical checkup of the equipment to prevent equipment breakdown and prolong equipment service life. PM comprises of maintenance activities that are undertaken after a specified period of time or amount of machine use. During this phase, the maintenance function is established and time-based maintenance (TBM) activities are generally accepted. This type of maintenance relies on the estimated probability that the equipment will breakdown or experience deterioration in performance in the specified interval. The preventive work undertaken may include equipment lubrication, cleaning, parts replacement, tightening, and adjustment. The production equipment may also be inspected for signs of deterioration during preventive maintenance work.

- **Predictive maintenance (PdM):** Predictive maintenance is often referred to as condition-based maintenance (CBM). In this strategy, maintenance is initiated in response to a specific equipment condition or performance deterioration. The diagnostic techniques are deployed to measure the physical condition of the equipment such as temperature, noise, vibration, lubrication and corrosion. When one or more of these indicators reach a predetermined deterioration level, maintenance initiatives are undertaken to restore the equipment to desired condition. This means that equipment is taken out of service only when direct evidence exists that deterioration has taken place. Predictive maintenance is premised on the same principle as preventive maintenance although it employs a different criterion for determining the need for specific maintenance activities. The additional benefit comes from the need to perform maintenance only when the need is imminent, not after the passage of a specified period of time.

- **Corrective maintenance (CM):** This is a system, introduced in 1957, in which the concept to prevent equipment failures is further expanded to be applied to the improvement of equipment so that the equipment failure can be eliminated (improving the reliability) and the equipment can be easily maintained (improving equipment maintainability). The primary difference between corrective and preventive maintenance is that a problem must exist before corrective actions are taken. The purpose of corrective maintenance is improving equipment reliability, maintainability, and safety; design weaknesses (material, shapes); existing equipment undergoes structural reform; to reduce deterioration and failures, and to aim at maintenance-free equipment. Maintenance information, obtained from CM, is useful for maintenance prevention for the next equipment and improvement of existing manufacturing facilities. It is important to form setups to provide the feedback of maintenance information.

- **Maintenance prevention (MP):** Introduced in 1960s, this is an activity wherein the equipment is designed such that they are maintenance free and an ultimate ideal condition of "what the equipment and the line must be" is achieved. In the development of new equipment, MP initiatives must start at the design stage and should strategically aim at ensuring reliable equipment, easy to care for and user friendly, so that operators can easily retool, adjust, and otherwise run it. Maintenance prevention often functions using the learning from earlier equipment failures, product malfunctioning, feedback from production areas, customers and marketing functions to ensure the hassle-free operation for the existing or new production systems.

- **Reliability centered maintenance (RCM):** Reliability Centered Maintenance was also founded in the 1960s but initially oriented towards maintaining airplanes and used by aircraft manufacturers, airlines, and the government. RCM can be defined as a structured, logical process for developing or optimizing the maintenance requirements of a physical

resource in its operating context to realize its "inherent reliability", where "inherent reliability" is the level of reliability which can be achieved with an effective maintenance program. RCM is a process used to determine the maintenance requirements of any physical asset in its operating context by identifying the functions of the asset, the causes of failures and the effects of the failures. RCM employs a logical seven-review step philosophy to meet these challenges. The steps include selecting plant areas that are significant, determining key functions and performance standards, determining possible function failures, determining likely

failure modes and them effects, selecting feasible and effective maintenance tactics, scheduling and implementing selected tactics, and optimizing tactics and programs. The various tools employed for affecting maintenance improvement includes Failure mode and effect analysis (FMEA), Failure mode effect and criticality analysis (FMECA), Physical Hazard Analysis (PHA), Fault Tree Analysis (FTA), Optimizing Maintenance Function (OMF) and Hazard and Operability (HAZOP) Analysis.

- **Productive maintenance (PrM):** Productive maintenance means the most economic maintenance that raises equipment productivity. The purpose of productive maintenance is to increase the productivity of an enterprise by reducing the total cost of the equipment over the entire life from design, fabrication, operation and maintenance, and the losses caused by equipment degradation.

The key characteristics of this maintenance philosophy are equipment reliability and maintainability focus, as well as cost conscious of maintenance activities. The maintenance strategy involving all those activities to improve equipment productivity by performing Preventive Maintenance, Corrective Maintenance and Maintenance Prevention throughout the life cycle of equipment is called Productive Maintenance.

- **Computerized maintenance management systems (CMMS):** Computerized maintenance management systems assist in managing a wide range of information on maintenance workforce, spare-parts inventories, repair schedules and equipment histories. It may be used to plan and schedule work orders, to expedite dispatch of breakdown calls and to manage the overall maintenance workload. CMMS can also be used to automate the PM function, and to assist in the control of maintenance inventories and the purchase of materials. CMMS has the potential to strengthen reporting and analysis capabilities.

The capability of CMMS to manage maintenance information contributes to improved communication and decision-making capabilities within the maintenance function. Accessibility of information and communication links on CMMS provide improved communication of repair needs and work priorities, improved coordination through closer working relationships between maintenance and production, and increased maintenance responsiveness.

- **Total productive maintenance (TPM):** TPM is a unique Japanese philosophy, which has been developed based on the Productive Maintenance concepts and methodologies. This concept was first introduced by M/s Nippon Denso Co. Ltd. of Japan, a supplier of M/s Toyota Motor Company, Japan in the year 1971. Total Productive Maintenance is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through day-to-day activities involving total workforce.

A strategic approach to improve the performance of maintenance activities is to effectively adapt and implement strategic TPM initiatives in the manufacturing organizations. TPM brings maintenance into focus as a necessary and vitally important part of the business. The TPM initiative is targeted to enhance competitiveness of organizations and it encompasses a powerful structured approach to change the mind-set of employees thereby making a visible change in the work culture of an organization. TPM seeks to engage all levels and functions in an organization to maximize the overall effectiveness of production equipment (OEE). This method further tunes up existing processes and equipment by reducing mistakes and accidents. TPM is a world class manufacturing initiative that seeks to optimize the effectiveness of manufacturing equipment. Whereas maintenance departments are the traditional center of preventive maintenance programs, TPM seeks to involve workers from all departments and levels, including the plant-floor to senior executives, to ensure effective equipment operation.

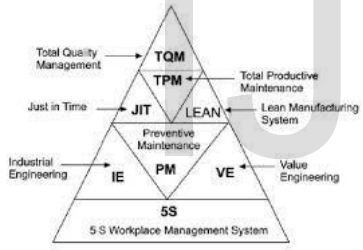
4 TOTAL PRODUCTIVE MAINTENANCE

The manufacturing organizations worldwide are facing many challenges to achieve successful operation in today's competitive environment. Modem manufacturing requires that to be successful, organizations must be supported by both effective and efficient maintenance practices and procedures. One approach to improving the performance of maintenance activities is to implement and develop a TPM strategy. The TPM implementation methodology provides organizations with a guide to fundamentally transform

their shopfloor by integrating culture, process, and technology.

TPM is considered to be Japan's answer to US style productive maintenance. TPM has been widely recognized as a strategic weapon for improving manufacturing performance by enhancing the effectiveness of production facilities. TPM has been accepted as the most promising strategy for improving maintenance performance in order to succeed in a highly demanding market arena. TPM is the proven manufacturing strategy that has been successfully employed globally for the last three decades, for achieving the organizational objectives of achieving core competence in the competitive environment. TPM is a highly influential technique that is in the core of "operations management" and deserves immediate attention by organizations across the globe.

TPM is a methodology originating from Japan to support its lean manufacturing system, since dependable and effective equipment are essential pre-requisite for implementing Lean manufacturing initiatives in the organizations. While Just-In-Time (JIT) and Total Quality Management (TQM) programs have been around for a while, the manufacturing organizations off late, have been putting in enough confidence upon the latest strategic quality maintenance tool as TPM.



It is clearly revealed, that TPM is the corner stone activity for most of the lean manufacturing philosophies and can effectively contribute towards success of lean manufacturing.

TPM has been depicted as a manufacturing strategy comprising of following steps:

- Maximizing equipment effectiveness through optimization of equipment availability, performance, efficiency and product quality.
- Establishing a preventive maintenance strategy for the entire life cycle of equipment.
- Covering all departments such as planning, user and maintenance departments.
- Involving all staff members from top management to shop-floor workers.
- Promoting improved maintenance through small-group autonomous activities.

Nakajima, a major contributor of TPM, has defined TPM as an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns, and promotes autonomous maintenance by operators through day-to-day activities involving the total workforce. The emergence of TPM is intended to bring both production and maintenance functions together by a combination of good working practices, team-working and continuous improvement. TPM is a relatively new and practical application of TQM and suggests that TPM aims to promote a culture in which operators develop "ownership" of their machines, learn much more about them, and in
the process realizes skilled trades to concentrate on problem diagnostic and equipment improvement projects. TPM is not a maintenance specific policy, it is a culture, a philosophy and a new attitude towards maintenance. TPM is a system (culture) that takes advantage of the abilities and skills of all individuals in an organization. An effective TPM implementation program provides for a philosophy based upon the empowerment and encouragement of personnel from all areas in the organization.

TPM is about communication. It mandates that operators, maintenance people and engineers collectively collaborate and understand each other's language. TPM describes a synergistic relationship among all organizational functions, but particularly between production and maintenance, for the continuous improvement of product quality, operational efficiency, productivity and safety. TPM is a maintenance management program with the objective of eliminating equipment downtime. TPM is an innovative approach to plant maintenance that is complementary to Total Quality Management (TQM), Just-in-Time Manufacturing (JIT), Total Employee Involvement (TEI), Continuous Performance Improvement (CPI), and other world-class manufacturing strategies. TPM helps to maintain the current plant and equipment at its highest productive level through the cooperation of all functional areas of an organization.

5 NEED FOR TPM IN MANUFACTURING

TPM harnesses the participation of all the employees to improve production equipment's availability, performance, quality, reliability, and safety. TPM endeavors to tap the "hidden capacity" of unreliable and ineffective equipment. TPM capitalizes on proactive and progressive maintenance methodologies and calls upon the knowledge and cooperation of operators, equipment vendors, engineering, and support personnel to optimize machine performance, thereby resulting in elimination of breakdowns, reduction of unscheduled and scheduled downtime, improved utilization, higher throughput, and better product quality. The principal features of TPM are the pursuits of economic efficiency or profitability, maintenance prevention, improving

maintainability, the use of preventive maintenance, and total participation of all employees. The bottom-line achievements of successful TPM implementation initiatives in an organization include lower operating costs, longer equipment life and lower overall maintenance costs. Thus, TPM can be described as a structured equipment-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life cycle through active team-based participation of employees across all levels of the operational hierarchy.

The following aspects necessitate implementing TPM in the contemporary manufacturing scenario:

- To become world class, satisfy global customers and achieve sustained organizational growth.
- Need to change and remain competitive.
- Need to critically monitor and regulate work-in-process (WIP) out of "Lean" production processes owing to synchronization of manufacturing processes.
- Achieving enhanced manufacturing flexibility objectives.
- To improve organization's work culture and mindset.
- To improve productivity and quality.
- Tapping significant cost reduction opportunity regarding maintenance related expenses.
- Minimizing investments in new technologies and maximizing return on investment ROI.
- Ensuring appropriate manufacturing quality and production quantities in JIT manufacturing environment.
- Realizing paramount reliability and flexibility requirements of the organizations.
- Optimizing life cycle costs for realizing competitiveness in the global marketplace.
- Regulating inventory levels and production lead-times for realizing optimal equipment available time or up-time.
- To obviate problems faced by organizations in form of external factors like tough competition, globalization, increase in raw material costs and energy cost.
- Obviating problems faced by organizations in form of internal factors like low productivity, high customer complaints, high defect rates, non-adherence to delivery time, increase in wages and salaries, lack of knowledge, skill of workers and high production system losses.
- Ensuring more effective use of human resources, supporting personal growth and garnering of human resource competencies through adequate training and multi-skilling.
- To liquidate the unsolved tasks (breakdown, setup time and defects).
- To make the job simpler and safer.
- To work smarter and not harder (improve employee skill).

Moreover, strategic TPM implementation can also facilitate achieving the various organizational manufacturing priorities and goals as depicted:

5.1 Need for TPM in manufacturing

Productivity (P)	• Reduced unplanned stoppages and breakdown improving equipment availability and productivity • Provide customization with additional capacity, quick change-over and design of product
Quality (Q)	• Reduce quality problems from unstable production • Reduced in field failures through improved quality • Provide customization with additional capacity, quick change-over and design of product
Cost (C)	• Life cycle costing

	• Efficient maintenance procedures • Supports volume and mix flexibility • Reduced quality and stoppage-related waste
Delivery (D)	• Support of JIT efforts with dependable equipment Improves efficiency of delivery, speed. and reliability • Improved line availability of skilled workers
Safety (S)	• Improved workplace environment • Realizing zero accidents at workplace • Eliminates hazardous situations
Morale (M)	• Significant improvement in kaizen and suggestions • Increase employees' knowledge of the process and product • Improved problem-solving ability • Increase in worker skills and knowledge Employee involvement and empowerment

In addition, TPM implementation in an organization can also led 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. 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 realization of organizational goals and objectives. Ideally, TPM provides a framework for addressing the organizational objectives. The other benefits include favorable 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.

6 TPM IMPLEMENTATION STAGES

1. **Stage A- Preparatory stage –**

Step1- Announcement by management to all about TPM introduction in the organization: Proper understanding, commitment and active involvement of the top management in needed for this step. Senior management should have awareness programes, after which announcement is made. Decision the implement TPM is published in the in-house magazine, displayed on the notice boards and a letter informing the same is send to suppliers and customers.

Step 2- Initial education and propaganda for TPM: Training is to be done based on the need. Some need intensive training and some just awareness training based on the knowledge of employees in maintenance.

Step 3- Setting up TPM and departmental committees: TPM includes improvement, autonomous maintenance, quality maintenance etc., as part of it. When committees are set up it should take care of all those needs.

Step 4- Establishing the TPM working system and target: Each area/work station is benchmarked and target is fixed up for achievement.

Step 5- A master plan for institutionalizing: Next step is implementation leading to institutionalizing wherein TPM becomes an organizational culture. Achieving PM award is the proof of reaching a satisfactory level.

2. **Stage B- Introduction stage-** A small get-together, which includes our suppliers and customer's participation, is conducted. Suppliers as they should know that we want quality supply from them. People from related companies and affiliated companies who can be our customers, sisters concern etc. are also invited. Some may learn from us and some can help us and customers will get the message from us that we care for quality output, cost and keeping to delivery schedules.

3. **Stage C-TPM implementation-** In these stage eight activities are carried which are called eight pillars in the development of TPM activity. Of

these four activities are for establishing the system for production efficiency, one for initial control system of new products and equipment, one for improving the efficiency of administration and are for control of safety, sanitation as working environment.

4. **Stage D-Institutionalizing stage–** By now the TPM implementation activities would have reached maturity stage. Now is the time to apply for preventive maintenance award.

6.1 TPM Implementation Plan

The following is the brief description of each of the TPM implementation activities:

1. **Master plan:** The TPM team, along with manufacturing and maintenance management, and union representatives determines the scope/focus of the TPM program. The selected equipment and their implementation sequence are determined at this point. Baseline performance data is collected and the program's goals are established.

2. **Autonomous maintenance:** The TPM team is trained in the methods and tools of TPM and visual controls. The equipment operators assume responsibility for cleaning and inspecting their equipment and performing basic maintenance tasks. The maintenance staff trains the operators on how to perform the routine maintenance, and all are involved in developing safety procedures. The equipment operators start collecting data to determine equipment performance.

3. **Planned maintenance:** The maintenance staff collects and analyzes data to determine usage/need based maintenance requirements. A system for tracking equipment performance metrics and maintenance activities is created (if one is not currently available). Also, the maintenance schedules are integrated into the production schedule to avoid schedule conflicts.

4. **Maintenance reduction:** The data that has collected and the lessons learned from TPM implementation are shared with equipment suppliers. This 'design for maintenance' knowledge is incorporated into the next generation of equipment designs. The maintenance staff also develops plans and schedules for performing periodic equipment analysis. This data from analysis is also fed into the maintenance database to develop accurate estimates of equipment performance and repair requirements. These estimates are used to develop spare parts inventory policies and proactive replacement schedules.

5. **Holding the gains:** The new TPM practices are incorporated into the organization's standard operating procedures. These new methods and data collection activities should be integrated with the other elements of the production system to avoid redundant or conflicting requirements.

The new equipment management methods should also be continuously improved to simplify the tasks and minimize the effort required to sustain the TPM program.

7 Breakdown Maintenance

Majority of the API/pharmaceutical manufacturing companies in India rely on breakdown maintenance, which is a costly proposition. API manufacturing plants, some of which are automated high technology plants using highly advanced machinery with complex & precise designs, pose difficulties in maintenance. Down-time cost of these plants is enormous. Since machinery, and its arrangement is engineered for continuous production, stoppage / malfunctioning / breakdown of a single machine, like boiler, can cause stoppage of the whole plant, leading to heavy production loss, reducing revenue and profitability. This is true in most API manufacturing units / chemical process industries.

7.1 Tangible losses:

- **Down time cost**- Down time cost refers to the loss due to non-absorption of overheads for the period of the machine is under breakdown. Idle wages paid to workmen Idle wages paid to the direct work-men for the period when the machine is under repairs.
- **Loss of materials**- unexpected breakdowns usually result in loss of materials that are under processing, which are either to be scrapped or reworked/reprocessed.
- **Cost of repairs**- unexpected breakdowns usually cost more to repair. It happens partly due to damage done to the adjacent components and partly due to emergency action.
- **Opportunity cost**- Opportunity cost is nothing but fore-gone profits, due to inability of the company to produce during unexpected breakdown of the machine/equipment.

- **Effect on other machines/equipment-** The broken-down machine, at times, may render other machines/equipment, which are dependent on deceased ma-chine, idle. The cost of idle time of such machines/equipment requires to be considered towards cost of breakdown. For example, if a boiler breaks down in an API manufacturing unit, the entire plant operations, especially production operations, shut down, leading to stoppage of all reactors that in turn leads to loss of productivity.

- **Expediting cost-** Eventual breakdowns are not anticipated. The disturbed schedules cause queuing of the batches, which leads to overtime to expedite the work.

- **Accident cost-** Accident cost implies the compensation payable to the employee for injury caused by the eventual breakdown. In-jury to the workmen may be caused either directly from the breakdown or indirectly from the confusion and hurried actions required to repair the machine/equipment. The accident cost for certain equipment like pressure vessels, electric hoists &cranes, temperature control devices, elevators etc. can be especially high. However, this may not happen always for all types of machine breakdowns

- **Added set up cost** - Breakdown of a machine is normally accompanied by added machine set-up due to:

1. Re-setting of job on the broken-down machine after it has been repaired
2. Change of job(s) on the machine(s)effected by the broken-down machine.

- **Increase in WIP investmen**t- Breakdown of the machine usually in-creases manufacturing cycle time, since works are held up near the broken-down machines, which increases investment in WIP (work in progress) inventory.

- **Overtime wages paid to the maintenance personnel-** Since the machine has broken-down in normal production, it is very likely it will be required very urgently. Overtime payment will have to be paid to maintenance personnel to get the machine back into operation at the earliest.

- **Premium paid on the spare parts-** If a spare part is required and is not readily available, it will have to be purchased from the market at higher (premium) price due to emergency.

7.2 INTANGIBLE LOSSES

- **Reduced life of the equipment-** Frequent breakdowns tend to reduce the life of equipment, thus necessitating premature replacement of the equipment, which not only entails capital investment, but also affects depreciation structure.

- **Broken promises-** Eventual breakdowns of equipment usually cause failure in delivery commitments to customers. And frequent failures in delivery commitments, in turn, lead to customer dissatisfaction, or at times even cancellation of orders, or loss of customer(s).

- **Lowered morale-** A plant plagued by frequent break-downs of machines leads to delay of planned batches. This, in turn, leads to stressed supervisors shouting at subordinates, production control personnel following up supervisory staff to expedite production, refusal of the supervisors to sanction leave to lower cadre personnel etc. All this culminates in lowering the morale of employees.

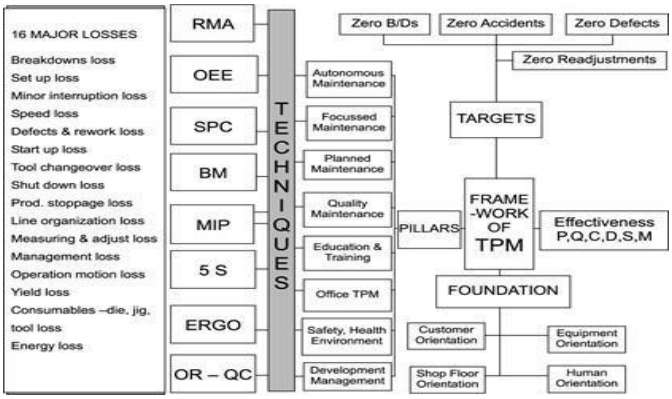
- **Higher spares inventory investment-** In case of frequent breakdowns, there won't be fixed pattern of consumption of spares. In order to shorten downtime period, companies tend to stock large number of spares in the store. Such inventory usually consists of parts, which do not move for a long time. This leads to unnecessary inventory investment.

- **Cost of standby equipment-** Many companies install standby equipment to ensure continuous production in the event of a breakdown. Such investments lock up scarce capital. This is not a good idea, if planned maintenance is carried out as per the predetermined schedules.

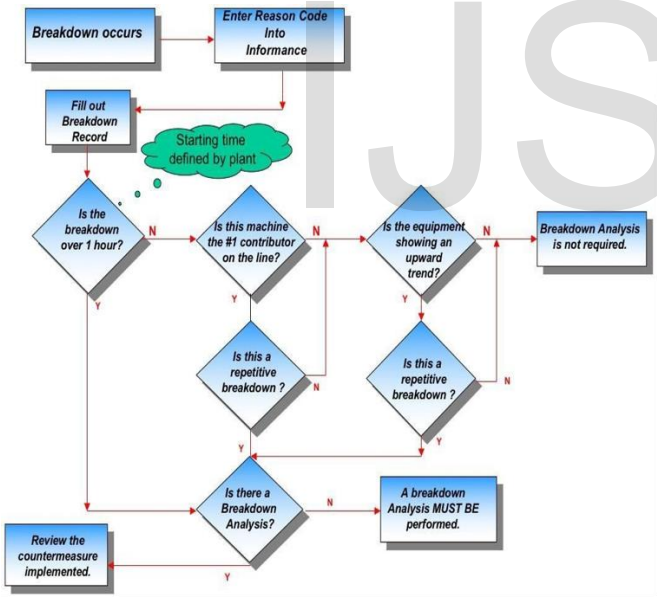
8 FRAMEWORK OF TOTAL PRODUCTIVE MAINTENANCE

TPM seeks to maximize equipment effectiveness throughout the lifetime of the equipment. It strives to maintain the equipment in optimum condition in order to prevent unexpected breakdown, speed losses, and quality defects occurring from process activities. There are three ultimate goals of TPM: zero defects, zero accident, and zero breakdowns. Nakajima suggests that equipment should be operated at 100 percent capacity for 100 percent of the time. Benchmarking on overall equipment effectiveness (OEE), productivity (P), quality (Q), cost (C), delivery (D), safety (S) and morale (M) etc. 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. TPM has been envisioned as a comprehensive manufacturing strategy to improve equipment

productivity. The strategy elements include cross-functional teams to eliminate barriers to machine uptime, rigorous preventive maintenance programs, improved maintenance operations management efficiency, equipment maintenance training to the lowest level, and information systems to support the development of imported equipment with lower cost and higher reliability.



BREAKDOWN FLOWCHART



9 Zero Defects

This strategy has the goal to decrease and mitigate failures within manufacturing processes and 'to do things right in the first time', in other words to eliminate defected parts during production. But the idea of Zero-Defect Manufacturing (ZDM) is not new, it was first mentioned during the cold war within the US army regarding their defective weapon system. ZDM is a disruptive concept that is able to entirely reshape the manufacturing ideology.

The Zero-Defect Manufacturing can be implemented in two different approaches. The product- oriented ZDM and the process-oriented ZDM. The difference is that a product-oriented ZDM studies the defects on the actual parts and tries to find a solution while on the other hand the process-oriented ZDM studies the defects of the manufacturing equipment, and based on that can evaluate whether the manufactured products are good or not. The latter one lays within the predictive maintenance concept.

The reasons why the ZDM thinking is attractive for companies are manifold. First, it can considerably reduce the costs of the company's resources related to the treatment of defective products. The ZDM process relies essentially on the fact that no useless element is present within a process. Useless element refers to anything that does not bring any added value to the product, e.g., defective machines and tools, inefficient employees, etc. Significant reduction of scrap production and therefore money expenditure can be realized with ZDM. Beyond that, the overall production chain should be continuously improved. Any possibility of system enhancement must also be meticulously and extensively assessed. In that way, product manufacturing is getting closer and closer to perfection. This approach can also be motivated by increasing safety and customers' satisfaction, which might strengthen customer loyalty and soar the financial benefits of the company.

This concept had been implemented only partially due to numerous technological limitations that were prohibiting its implementation. Currently, with the evolution of Industry 4.0, ZDM concept is easier to be implemented due to the availability of the required amount of data for techniques such as machine learning to work properly but still a lot of effort is needed for better integration and coordination of the capabilities of each technology. Furthermore, the equipment that is required for such data recording used to be very expensive and companies were not investing on that. However, the landscape has changed now with computer power and data storage rising, while sensors price dropping significantly together with the new technologies that make the concept of ZDM possible. ZDM will be the new standard for companies towards more eco-friendly and more efficient production lines with zero defects.

10. Overall equipment effectiveness

TPM initiatives in production help in streamlining the manufacturing and other business functions, and garnering sustained profits. The strategic outcome of TPM implementations is the reduced occurrence of unexpected machine breakdowns that disrupt production and lead to losses, which can exceed millions of dollars annually. Overall equipment effectiveness (OEE) methodology incorporates metrics from all equipment manufacturing states guidelines into a measurement system that helps manufacturing and operations teams improve equipment performance and, therefore, reduce equipment cost of ownership.

TPM initiatives are focused upon addressing major losses, and wastes associated with the production systems by affecting continuous and systematic evaluations of production system, thereby affecting significant improvements in production facilities. The evaluation of TPM efficiency can

facilitate significantly enhanced organizational capabilities across a variety of dimensions. TPM employs OEE as a quantitative metric for measuring the performance of a productive system. OEE is the core metric for measuring the success of TPM implementation program. The overall goal of TPM is to raise the overall equipment effectiveness. OEE is calculated by obtaining the product of availability of the equipment, performance efficiency of the process and rate of quality products:

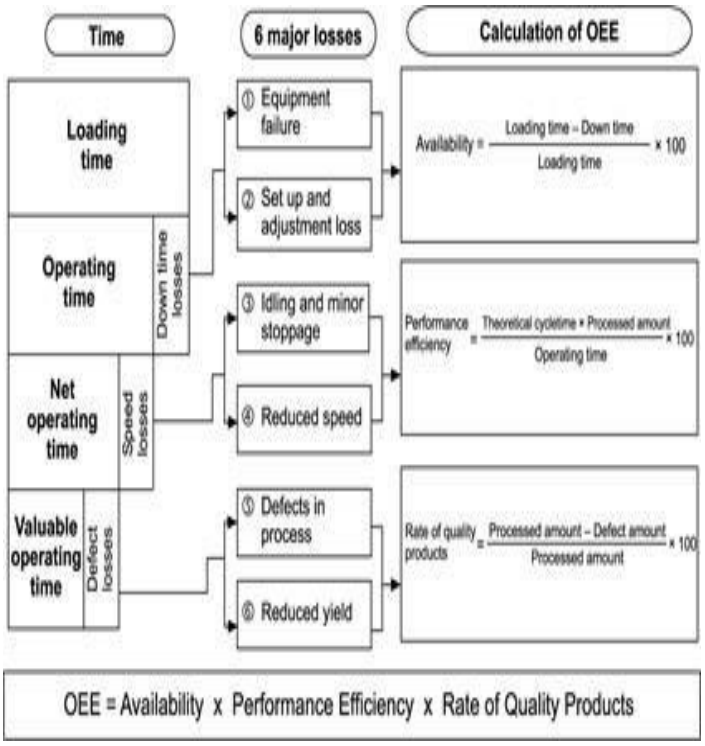
OEE = Availability (A) × Performance efficiency (P) × Rate of quality (Q)

Where:

Availability (A) = ((Loading time – Downtime) / Loading time) × 100

Performance efficiency (P) = ((Processed amount) / Operating time/theoretical cycle time) × 100

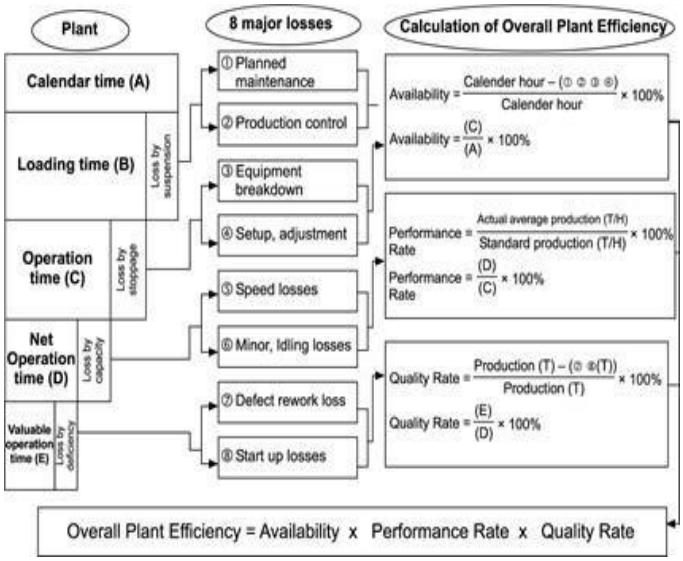
Rate of quality (R) = ((Processed amount - Defect amount) / Processed amount) × 100



This metric has become widely accepted as a quantitative tool essential for measurement of productivity in manufacturing operations. The OEE measure is central to the formulation and execution of a TPM improvement strategy. TPM has the standards of 90 per cent availability, 95 per cent performance efficiency and 99 per cent rate of quality. An overall 85 per cent benchmark OEE is considered as world-class performance.

TPM initiatives focus upon addressing six major losses, which are considered significant in lowering the efficiency of the production system. The six major losses include equipment failure/breakdown losses, setup and adjustment losses, idling and minor stoppage losses, defect and rework losses, and start-up losses. TPM endeavors to increase efficiency by rooting out losses that sap efficiency. The calculation of OEE by considering the impact of the six major losses on the production system is indicated:

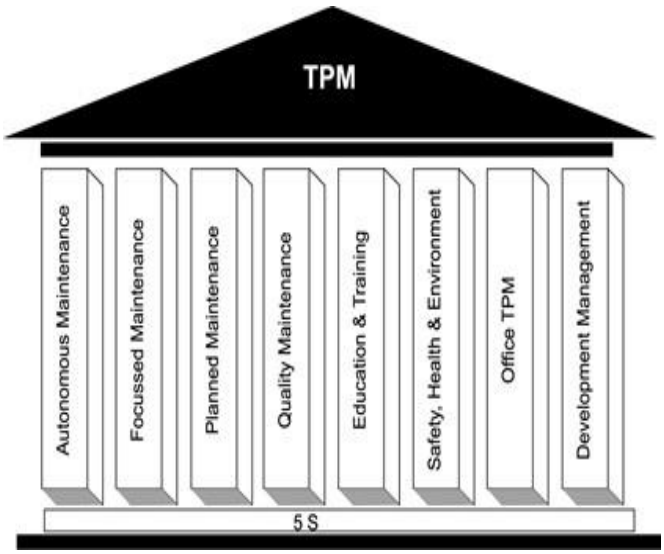
However, with time, many manufacturing organizations have started focusing upon all the losses including the planned downtime for scheduled maintenance activities, as well as focusing upon the unplanned downtime and losses for affecting ultimate improvements in the production system. While OEE measures the effectiveness of planned production schedules, Overall Plant Efficiency (OPE), measures the overall equipment effectiveness relative to every minute of the clock, or calendar time. The calculation of OPE by considering the impact of the eight major losses on the production system is indicated:



The OEE metric offers a starting-point for developing quantitative variables for relating maintenance measurement to corporate strategy. OEE can be used as an indicator of the reliability of the production system. Analyzing OEE categories can reveal the greatest limits to success. Forming cross-functional teams to solve the root causes/problems can drive the greatest improvements and generate real bottom-line earnings. A comparison between the expected and current OEE measures can provide the much-needed impetus for the manufacturing organizations to improve the maintenance policy and affect continuous improvements in the manufacturing systems. OEE offers a measurement tool to evaluate equipment corrective action methods and ensure permanent productivity improvement. OEE is a productivity improvement process that starts with management awareness of total productive manufacturing and their commitment to focus the factory work force on training in teamwork and cross-functional equipment problem solving.

11. TPM Pillars

The basic practices of TPM are often called the pillars or elements of TPM. The entire edifice of TPM is built and stands, on eight pillars. TPM paves way for excellent planning, organizing, monitoring and controlling practices through its unique eight-pillar methodology. TPM initiatives, as suggested and promoted by Japan Institute of Plant Maintenance (JIPM), involve an eight-pillar implementation plan that results in substantial increase in labor productivity through controlled maintenance, reduction in maintenance costs, and reduced production stoppages and downtimes. The core TPM initiatives classified into eight TPM pillars or activities for accomplishing the manufacturing performance improvements include Autonomous Maintenance; Focused Maintenance; Planned Maintenance; Quality Maintenance; Education and Training; Office TPM; Development Management; and Safety, Health and Environment. The JIPM eight pillar TPM implementation plan is depicted in figure:



Pillar 1-5S:

TPM starts with 5S. It is a systematic process of housekeeping to achieve a serene environment in the work place involving the employees with a commitment to sincerely implement and practice housekeeping. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. Making problems visible is the first step of improvement. 5S is a foundation program before the implementation of TPM. If this 5S is not taken up seriously, then it leads to 5D (delays, defects, dissatisfied customers, declining profits, and demoralized employees).

This 5S implementation has to be carried out in phased manner. First the current situation of the workplace has to be studied by conducting a 5S audit. This audit uses check sheets to evaluate the current situation. This check sheet consists of various parameters to be rated say on a 5-point basis for each 'S'. The ratings give the current situation. The each of the above-mentioned 5S is implemented and audit is conducted at regular intervals to monitor the progress and evaluate the success of implementation. After the completion of implementation of 5S random audits could be conducted using company check sheets to ensure that it is observed in true spirits by everyone in the work place. Table depicts the key activities to be holistically deployed for effective 5S implementation at the workplace.

Japanese nomenclature (English 5S/5C): Features
Seiri (Sort/Clear): Sort out unnecessary items from the workplace and discard them

Seiton (Set in order/Configure): Arrange necessary items in good order so that they can be easily picked up for use
Seisio (Shine/Clean and check): Clean the workplace completely to make it free from dust, dirt and clutter
Seiketsu (Standardize/Conformity): Maintain high standard of housekeeping and workplace organization
Shitsuke (Sustain/Custom and practice): Train and motivate people to follow good housekeeping disciplines autonomously

Pillar 2- Autonomous maintenance (AM):

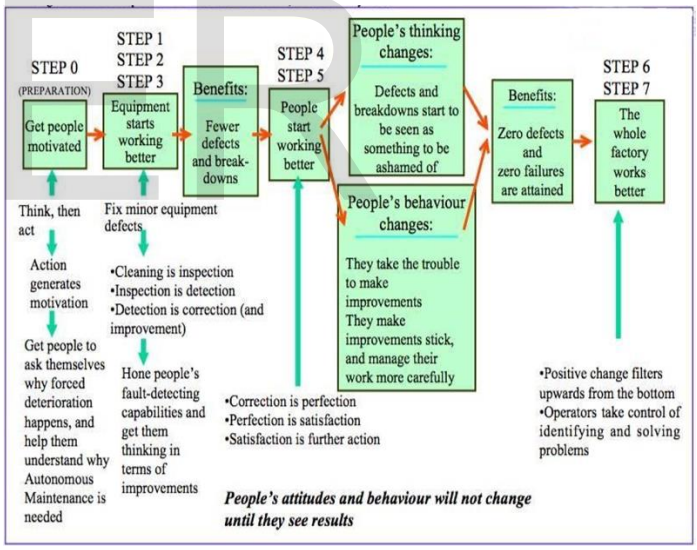
This pillar is geared towards developing operators to be able to take care of small maintenance tasks, thus freeing up the skilled maintenance people to spend time on more value-added activity and technical repairs. The operators are responsible for upkeep of their equipment to prevent it from deteriorating. By use of this pillar, the aim is to maintain the machine in new condition. The activities involved are very simple nature. This includes cleaning, lubricating, visual inspection, tightening of loosened bolts etc.
AM policy are-uninterrupted operation of equipment, flexible operators to operate and maintain other equipment, and eliminating the defects at source through active employee participation.
Steps in AM are preparation of employees, initial cleanup of machines, take counter measures, fix tentative AM (JISHU HOZEN) standards, general inspection, autonomous inspection, and standardization.

The Basic Precepts of Autonomous Maintenance

The equipment has become increasingly sophisticated and complex, and the maintenance function has gradually become separated from the production function, with the result that production and maintenance departments have become isolated in their own camps, with one 'making' and the other 'fixing'. This approach makes equipment much less efficient than it could be, and the need to remedy this culture has led to the emergence of the discipline known as 'Autonomous
Maintenance', the basic precepts of which are listed below.

The basic precepts of Autonomous Maintenance:

1. The problems that stop equipment from working, or make it work less effectively, can be eliminated – in other words, zero-defect, zero-breakdown status can be attained – by changing the way everyone who works with the equipment, including the operators, thinks and behaves.
2. When the equipment works better, the people work better, and when people work better, the whole factory works better.
3. Autonomous Maintenance should be introduced step by step under the guidance of management, with each step implemented thoroughly. It should involve the whole workforce and empower each individual to fulfill his or her potential.



The Seven Autonomous Maintenance Steps

Autonomous Maintenance must be implemented following a management-led plan. A system for progressively upgrading production equipment and operators' capabilities should be put in place, and the Autonomous Maintenance program should be rolled out under this plan, with each step being reviewed by management before an authorization is given to proceed to the next.

1	Initial cleaning (Checking through cleaning)	Eliminate dust and dirt from main body of equipment, lubricate and tighten, expose and deal with equipment problems
2	Tackling contamination sources and hard-to-access areas	Reduce housekeeping time by eliminating or containing sources of dust, dirt or other contamination, and improving places that are hard to clean, lubricate, tighten or check
3	Provisional Autonomous Maintenance standards	Formulate provisional standards to enable cleaning, lubricating, tightening and checking to be sustained dependably with minimal time and effort (this will mean establishing time slots for routine and periodic maintenance)
4	General inspection	Train operators in inspection procedures using inspection manuals, enabling them to expose and correct equipment defects by performing comprehensive equipment inspections
5	Autonomous checking	Formulate definitive cleaning, lubrication and inspection standards that can be followed efficiently and dependably; draw up autonomous inspection checklists and put them into use
6	Standardisation	Develop a comprehensive housekeeping system by devising additional standards for items such the following: • Movement of materials around the shop floor • Data recording • Control of moulds, jigs, tools, etc. • Quality assurance data on the process
7	Full self-management	Roll out and implement company policies and objectives, and continually improve the equipment by keeping accurate MTBF and other maintenance records, analysing the data captured, and doing improvements as a routine part of the job

Stage 1

Steps 1 to 3 constitute Stage 1. This is where the basic equipment conditions are painstakingly achieved (mainly through cleaning and inspecting), and a system for sustaining these conditions is established.
Everyone should be helped to understand the process that is going to transform their equipment as they implement Autonomous Maintenance. During this process, everyone needs to get into the habit of working through difficulties, exercising creativity and ingenuity in solving problems, and thinking hard about what they are doing and why they are doing it. The work carried out at this stage will revolve around three activities: cleaning, lubricating, and tightening. These activities, through which basic equipment conditions are sustained, are the minimum prerequisites for preventing equipment deterioration and form the foundation on which all the other activities are built.

Stage 2

Steps 4 and 5 constitute Stage 2. At this stage, operators receive training in general equipment inspection skills and start performing these inspections for themselves. This enables them to move on from preventing deterioration to measuring deterioration.
Through this, the operators become truly equipment-competent, capable of performing routine checks using their five senses backed up by logic, and able and willing to make improvements on their own initiative. This is the stage at which the results really start to appear, and people's attitudes change. These new attitudes produce a new atmosphere, as operators start to take pride in the smooth running of their equipment, while defects and breakdowns are seen as letting the side down. This is a crucial part of creating a true system of self-management.

Stage 3

Stage 3 consists of Steps 6 and 7. This is the stage at which the finishing touches are put to the Autonomous Maintenance program by completing the process of standardization and self- management begun in the previous steps, and operators work towards perfecting their maintenance skills. These processes transform the operators and the workplace, and self-management kicks in as a result.

Pillar 3-Kaizen:

"Kai" means change, and "Zen" means good (for the better). Basically, kaizen is for small improvements, but carried out on a continual basis and involve all people in the organization. Kaizen is opposite to big spectacular innovations. Kaizen requires no or little investment. The principle behind is that "a very large number of small improvements are move effective in an organizational environment than a few improvements of large value". This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various kaizen tools. These activities are not limited to production areas and can be implemented in administrative areas as well.
Kaizen policy are practice concepts of zero losses in every sphere of activity, relentless pursuit to achieve cost reduction targets in all resources, relentless pursuit to improve overall plant equipment effectiveness, extensive use of PM analysis as a tool for eliminating losses, and focus of easy handling of operators. Kaizen target are achieved and sustain zero loses with respect to minor stops, measurement and adjustments, defects and unavoidable downtimes. It also aims to achieve 30% manufacturing cost reduction.
Tools used in kaizen are Why-Why analysis, Poka-Yoke (Poka-Yoke is Japanese term, which in

English means 'mistake proofing' or 'error prevention'), summary of losses, kaizen register, and kaizen summary sheet.
Six losses in the work place: The objective of TPM is maximization of equipment effectiveness. TPM aims at maximization of machine utilization and not merely machine availability maximization. As one of the pillars of TPM activities, kaizen pursues efficient equipment, operator and material and energy utilization that is extremes of productivity and aims at achieving substantial effects. Kaizen activities try to thoroughly eliminate losses. Six major losses that were identified are-equipment failure, set-up and adjustments, small stops, speed losses during production, and losses during warm-up (Nakajima, 1988).

Pillar 4-Planned maintenance (PM):

It is aimed to have trouble free machines and equipment producing defect free products for total customer satisfaction. This breaks maintenance down into four "families" or

groups, viz., preventive maintenance, breakdown maintenance, corrective maintenance, and maintenance prevention.
With PM we evolve our efforts from a reactive to a proactive method and use trained maintenance staff to help train the operators to better maintain their equipment. In PM policy are achieve and sustain availability of machines, optimum maintenance cost, reduces spares inventory, and improve reliability and maintainability of machines.
PM targets are zero equipment failure and break down, improve reliability and maintainability by 50 percent, reduce maintenance cost by 20 percent, and ensure availability of spares all the time. Six steps in planned maintenance are equipment evaluation and recoding present status; restore deterioration and improve weakness; building up information management system; prepare time- based information system; select equipment, parts and members and map out plan; prepare predictive maintenance system by introducing equipment diagnostic techniques; and evaluation of planned maintenance.

Pillar 5-Quality maintenance (QM):

It is aimed towards customer delight through highest quality through defect free manufacturing. Focus is on eliminating non-conformances in a systematic manner, much like focused improvement. We gain understanding of what parts of the equipment affect product quality and begin to eliminate current quality concerns, and then move to potential quality concerns. Transition is from reactive to proactive (quality control to quality assurance).
QM activities are to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to maintain perfect quality of products. The condition is checked and measure in time series to very that measure values are within standard values to prevent defects. The transition of measured values is watched to predict possibilities of defects occurring and to take counter measures beforehand.
In QM policy are defect free conditions and control of equipment, quality maintenance activities to support quality assurance, focus of prevention of defects at source, focus on Poka-Yoke (fool proof system), in-line detection and segregation of defects, and effective implementation of operator quality assurance. QM targets are achieved and sustain customer complaints at zero, reduce in-process defects by 50 percent, and reduce cost of quality by 50 percent.

Pillar 6-Training:

It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill. It is not sufficient know only "Know-How" by they should also learn "Know Why". By experience they gain, "Know-How" to overcome a problem what to be done. This they do train them on knowing "Know-why". The employees should be trained to achieve the four phases of skill. The goal is to create a factory full of experts. The different phase of skills is phase 1-do not know, phase 2-know the theory but cannot do, phase 3-can do but cannot teach, and phase 4-can do and also teach.
Training policies are focused on improvement of knowledge, skills and techniques, creating a training environment for self-learning based on felt needs, training curriculum including tools/assessment etc. conductive to employee revitalization, and training to remove employee fatigue and make, work enjoyable.
Training target are achieved and sustain downtime due to want men at zero on critical machines, achieve and sustain zero losses due to lack of knowledge/skills/techniques, and aim for 100 percent participation in suggestion scheme.
Steps in educating and training activities are setting policies and priorities and checking present status of education and training, establish of training system for operation and maintenance skill up gradation, training the employees for upgrading the operation and maintenance skills, preparation of training calendar, kick-off of the system for training, and evaluation of activities and study of future approach.

Pillar 7-Office TPM:

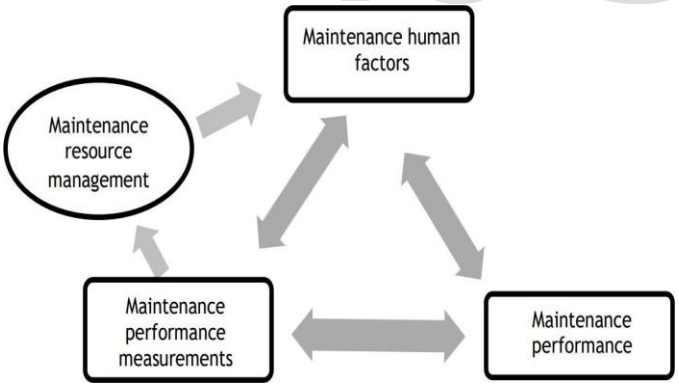
Office TPM should be started after activating four other pillars of TPM (AM, Kaizen, PM, and QM). Office TPM must be followed to improve productivity, efficiency in the administrative functions and identify and eliminate losses. This includes analyzing processes and procedures towards increased office automation.
Office TPM addresses twelve major losses, they are processing loss; cost loss including in areas such as procurement, accounts, marketing, sales leading to high inventories; communication loss; idle loss; set-up loss; accuracy loss; office equipment breakdown; communication channel breakdown, telephone and fax lines; time spent on retrieval of information; non availability of correct on line stock status; customer complaints due to logistics; and expenses on emergency dispatches/purchases.
Office TPM and its benefits are involvement of all people in support functions for focusing on better plant performance, better utilized work area, reduce repetitive work, reduced administrative costs, reduced inventory carrying cost, reduction in number of files, productivity of people in support functions, reduction in breakdown of office equipment, reduction of customer complaints due to logistics, reduction in expenses due to emergency dispatches/purchases, reduced manpower, and clean and pleasant work environment.

Pillar 8-Safety, health and environment:

In this area focus is on to create a safe workplace and a surrounding area that is not damaged by our process or procedures. This pillar will play an active role in each of the other pillars on a regular basis. Safety, health and environment target are zero accident, zero health damage, and zero fires. A committee is constituted for this pillar, which comprises representative of officers as well as workers. The committee is headed by senior vice president (technical). Utmost importance to safety is given in the plant. Manager (safety) looks after functions related to safety. To create awareness among employees, various competitions like safety slogans, quiz, drama, posters, etc.
related to safety can be organized at regular intervals.

12 Human Factor in Maintenance

The effectiveness of maintenance functions is influenced by the overall human factors of the maintenance staff. The influence of human factors is increasingly acknowledged by technical and organizational specialists, who recognize that achieving greater operating reliability can be achieved by identifying and correcting repeating sources of failure that are within the organization's control, and the system that contributed to the error.
A maintenance function's effectiveness depends on the competency, training, and motivation of its staff. This is validated by Simoes, Gomes and Yasin, who state that future research needs to be aimed at determining human factor performance measurements for maintenance performance effort.



Maintenance performance measurements are used to determine whether the maintenance function's performance is satisfactory. This is done using quantitative values within a measurement framework. Through different psychological factors and theories, maintenance performance measurement influences maintenance human factors, which leads to either a positive or a negative influence on maintenance performance. Maintenance resource management therefore plays a critical role in managing the link between maintenance human factors and maintenance performance measurements. Maintenance resource management is also required to ensure that maintenance human factors are addressed, to influence the maintenance function's performance positively
The purpose of maintenance performance measurements is to manage the maintenance function's performance by tracking the important maintenance elements. A general critique of human factors is that long-term cost availability and ergonomic points of view in a wide range of industries need investigating. Maintenance human factors is a multidisciplinary approach that focuses on human capabilities and limitations, with the human as the center point of the system.

12.1 Maintenance human factors measurement

The goal of measuring maintenance human factors is to provide a leading indicator to predict future human performance, and to act on that prediction to improve on human performance. Kantrowitz emphasizes that measuring maintenance human factors provides the opportunity not only to determine the performance of an individual, but also the performance of teams, and hence of the department or overall system as well. He also advocates not only measuring human factors, but also discussion and action as a result.
Kantrowitz states that it is critical that follow-up action on measurements is seldom done; that a single measure of a complex system is difficult to create (a statistical combination of multiple indicators is needed); those measurements are chosen on the basis of easy obtainability; that some measurements are chosen without the guidance of an adequate theory; and those human factors research needs to be highly generalizable.
Wang, Sun and Yang developed a quantitative and objective method to analyze and evaluate human factors in aviation maintenance processes. This method is mathematically taxing and is not easily implementable at shop floor level.
Maintenance human factors cannot be considered in isolation from human factors in other literature spheres. Several measurement criteria for human factors are found in the psychosomatic and medical literature, such as for stress, fatigue, and workload. Some measurements are either easily quantified using enterprise resource planning (ERP) systems, such as absenteeism, while others are difficult to obtain.

Indicators	Measurement
Stress	The perceived stress scale (PSS) Copenhagen psychosocial questionnaire (COPSOQ) Dundee stress state questionnaire (DSSQ) Stress diagnostic survey (SDS) Salivary cortisol levels
Fatigue	Multidimensional fatigue inventory (MFI) Fatigue severity scale (FSS) Nottingham health profile (NHP) Polio problem list (PPL) Dutch short fatigue questionnaire (SFQ).
Workload	NASA-TLX Trier inventory for the assessment of chronic stress (TICS) Instantaneous self-assessment (ISA) Impact on mental workload (AIM) Rating scale of mental effort (RSME) Galvanic skin response Parasympathetic/sympathetic ratio (LF/HF), heart rate, heart rate variability (HRV), diastolic pressure, systolic pressure, eye blink frequency, and eye blink duration Cortisol responses after wakening
Motivation / morale	Absenteeism
Communication	Roberts and O'Reilly 35-item questionnaire Communication satisfaction questionnaire (CSQ)
Teamwork	Team effectiveness questions NOTECHS (Non-technical skills evaluation system)
Distraction	Noise levels Peripheral displays

12.2 Maintenance manuals

A maintenance manual is a comprehensive document that provides all the details necessary about a physical plant as well as individual pieces of equipment to help the maintenance staff keep everything running smoothly.

For medium- and larger-size companies, a maintenance manual is even more critical because so many more people and processes are involved. First, inefficiency multiplies quickly as a company grows. Every time an employee needs to perform a new task, there might be mini-training happening over and over. Second, without a manual, you can lose the consistency of work.

Different employees can complete the same job in inconsistent ways. And, finally, a lack of documented procedures can result in workplace errors, accidents, or injuries that can cost the company a significant amount of money.

A comprehensive maintenance manual consists the following:

- **Overview**: This section provides a general overview of the physical plant being discussed as well as the components covered in the manual. It includes personnel information, organizational charts, company history, or other background information.
- **Physical building**: This section details important information about one specific facility. Ideally, this information is collected during the construction of the facility itself and contains floor plans, building materials, finish data, building code and specification information, and site survey.
- **Operating procedures**: A comprehensive, detailed explanation of all major operating procedures should be documented so that a new employee can learn quickly and a seasoned technician can double-check work.
- **Maintenance procedures**: The preventive and corrective maintenance programs should be explained thoroughly including schedules, procedures, responsibilities, trouble-shooting and test requirements.
- **Emergency procedures**: It's important to think through emergency situations before they happen because it can be difficult to remember details in the middle of a chaotic situation. This section outlines all the people, steps, agencies, and other organizations that need to be notified as well as a primer on how to handle crisis communications internally and externally.

12.3 Maintenance staffing methods

Staffing is the process of hiring eligible candidates in the organization or company for specific positions. In management, the meaning of staffing is an operation of recruiting the employees by evaluating their skills, knowledge and then offering them specific job roles accordingly.

Functions of Staffing

1. The first and foremost function of staffing is to obtain qualified personnel for different jobs position in the organization.
2. In staffing, the right person is recruited for the right jobs, therefore it leads to maximum productivity and higher performance.

3. It helps in promoting the optimum utilization of human resource through various aspects.
4. Job satisfaction and morale of the workers increases through the recruitment of the right person.
5. Staffing helps to ensure better utilization of human resources.
6. It ensures the continuity and growth of the organization, through development managers.

Variables that affect maintenance staffing level decisions:

1. **Scope of work -** The breadth and depth of job-performance requirements varies widely in today's industries from extremely-narrow, single-task, repetitive job tasks to broad, multi- skill job roles. Maintenance is rarely a narrowly focused job role, either geographically in the plant or intellectually in the skills and knowledge requirements.
2. **Individual competency -** The second big variable for maintenance headcount is the skill set of each person—individual competency. If all maintenance people had the same level of skills and knowledge, there could be an easy answer to the question of "optimum maintenance staffing levels."
3. **Equipment reliability -** Highly reliable plants and equipment can be managed with relatively fewer maintenance technicians than comparable highly reactive plants. If you have a very reliable plant and equipment, the maintenance workloads are usually very well defined in terms of scope, skills and duration due to planned, scheduled and preventive/predictive maintenance.
4. **Historical information -** Work orders capture a whole host of information about maintenance and repair work, including problems, causes, corrective action and labor hours worked by named technicians. Sadly, there is a huge void of decision-making information if the plant or facility does not use work orders or does not reinforce the need for accurate equipment and work history information. Staffing levels are arbitrary, repetitive problems are not identified, common causes are overlooked, improper actions and rework go unnoticed.
5. **Maintenance & Reliability trends -** Many business decision-makers do not have enough information to truly understand maintenance and the big maintenance staffing variables outlined here. Regrettably, for decades "maintenance" has been treated as an overhead expense line item and a "non-value-adding" activity in many business operations. Some business decision-makers also perceive maintenance technicians as "fixers" rather than "preventers" of equipment problems.

Importance of Staffing

1. Efficient Performance of Other Functions
2. Effective Use of Technology and Other Resources
3. Optimum Utilization of Human Resources
4. Development of Human Capital
5. The Motivation of Human Resources
6. Building Higher Morale

Characteristics of Staffing

1. **People-Centered-** Staffing can broadly view as people-centered function and therefore, it is relevant for all types of organization. It is concerned with categories of personnel from top to bottom of the organization.
2. **Responsibility of Manager-** Staffing is the basic function of management which involves that the manager is continuously engaged in performing the staffing function. They are actively associated with the recruitment, selection, training, and appraisal of his subordinates. Therefore, the activities are performed by the chief executive, departmental managers and foremen in relation to their subordinates.

3. **Human Skills-** Staffing function is mainly concerned with different types of training and development of human resource and therefore the managers should use human relation skill in providing guidance and training to the subordinates. If the staffing function is performed properly, then the human relations in the organization will be cordial and mutually performed in an organized manner.

4. **Continuous Function-** Staffing function is to be performed continuously which is equally important for a new and well-established organization. Since in a newly established organization, there has to be recruitment, selection, and training of personnel. As we compare that, the organization which is already a running organization, then at that place every manager is engaged in various staffing activities.

13 Maintenance Management Information Systems

The process of overseeing maintenance resources so that the organization does not experience downtime from broken equipment or waste money on inefficient maintenance procedures. Maintenance management software programs can assist with the process

- A maintenance information system is a necessary part of a good maintenance program.
- Such a system makes the maintenance program more effective and reduces its cost in the long run.
- A suitable system allows the maintenance manager to gather data to support maintenance decisions. It includes equipment failure data that may be fed back to designers or manufacturers, used for process hazard evaluation or sent to the purchasing department to support changes to specifications or to support the selection or avoidance of particular vendors or equipment types.
- The maintenance information system is also a valuable resource for the planning department to use when preparing job packages for future maintenance work.

Maintenance information system provides:

- An easily retrievable historical record for each major piece of equipment or group of similar equipment.
- Equipment inspection and service schedules that specify the inspection and service scope and standards.
- A persistent follow-up or tracking system to ensure that proper inspection and maintenance service are being performed according to schedule.
- Programs to analyze the effectiveness and cost of inspection and maintenance procedure.

Computerized maintenance management information system

- Also known as computerized maintenance management information system (CMMIS).
- Software package that maintains a computer database of information about an organization's maintenance operations.
- Information is intended to help maintenance workers do their jobs more effectively (and to help management make informed decisions (for example, calculating the cost of machine breakdown repair versus preventive maintenance for each machine, possibly leading to better allocation of resources).
- CMMS data may also be used to verify regulatory compliance

14 Benefits of TPM implementation

TPM is a world-class approach, which involves everyone in the organization, working to increase equipment effectiveness. TPM implementation in an organization can ensure 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 organizations. TPM aims to increase the availability of existing equipment in a given situation, reducing in that way the need for further capital investment. Instrumental to its success is the investment in human resources, which further results in better hardware utilization, higher product quality and reduced labor costs.
Ahuja and Khamba, have conducted a case study in the Indian Manufacturing Industry and revealed that there has been significant improvement in overall equipment effectiveness of all the production facilities as a result of TPM initiatives. The benefits realized through effective TPM implementation program included OEE improvement: 14-45 per cent, inventory reduction: 45-58 per cent, improvement in plant Total productive maintenance output: 22-41 per cent, reduction in customer rejections: 50-75 per cent, reduction in accidents: 90-98 per cent, reduction in maintenance cost: 18-45 per cent, reduction in defects and rework: 65-80 per cent, reduction in breakdowns: 65-78 per cent, reduction in energy costs: 8-27 per cent, increase in employee sug-

gestions: 32-65 per cent and total savings resulting from effective implementation of kaizen themes as a result of significantly enhanced participation across the organization: Rs. 80 million. The outstanding results of TPM implementation have led many firms facing competitive pressures to adopt TPM. Several Japanese companies with rich experience in implementing TPM programs have realized significant improvements including: a 50 per cent rise in equipment availability and a 90 per cent decline in process defects, 75 per cent decline in customer complaints, 30 per cent decline in maintenance costs and 50 per cent reduction in maintenance inventories. Koelsch, has reported that companies that adopt TPM are seeking 50 per cent reductions in breakdown labor rates, 70 per cent reductions in lost production, 50-90 per cent reductions in setups, 25-40 per cent increases in capacity, 50 per cent increases in labor productivity, and 60 per cent reductions in costs per maintenance unit.

14.1 Future directions for TPM

After successful institutionalization of TPM programs in the organizations, concerted efforts must be made to ensure sustained TPM deployment in the manufacturing organizations, as manufacturing improvements are only possible through persistent deployment of world class TPM initiatives. The goal of the organization at this stage, after successful deployment of TPM, has to continue the TPM Program into the incremental process improvement phase, using a Continuous Quality Improvement (CQI) approach. It is extremely important for an organization to consistently move forward after attaining TPM Excellence award for sustaining the levels attained and to reach higher levels of achievements. The changes introduced into the organization by TPM activities must be anchored thereby becoming an established part of everybody's daily routine. TPM has to be regarded as a "change process", rather than a "project" otherwise the competencies gained by the organization might fade away after the project is completed.

Once the crucial achievements through strategically implemented and institutionalized TPM programs have been realized, the TPM team should continue to work progressively to look for ways to improve upon their success. The organization must consistently send a strong message to employees that openness, trust, teamwork, continuous improvement and learning are the core values of the company. To sustain continuous improvement, a positive attitude throughout the organization must be evident. The manufacturing organizations must prepare for, implement and sustain improvement and their competencies cover a broad range of issues including: Innovative Thinking (structured problem solving, creative problem solving, visioning sessions, concurrent design, rapid product/service design); Developing Teams and Individuals (change agent development, cultural assessment and alignment, change management, flexible working, performance coaching, emotional intelligence, multi-function teams, project based team building); Effective Leadership (strategic planning, operational planning, policy deployment, strategic negotiation, strategic procurement, future state planning, leadership potential, performance coaching); Access to Knowledge and Expertise (lean service, lean manufacturing, risk management, process redesign, six sigma, project and program management, concurrent design, supply chain management, strategic procurement, outsourcing, knowledge management) and specific skills (value stream analysis, process analysis, 5S/visual management, SMED, Jidoka, SPC, DMAIC, Kanban, DFMA, FMEA/FMECA) for attaining long term core competencies and market leadership. Similarly, the manufacturing performance can also be evaluated by simultaneous implementation of TPM and other related lean manufacturing initiatives like JIT, TQM, QFD, TEI and CI etc. for enhancing overall manufacturing competencies.

Further, the TPM audit process and TPM Gap Analysis must be put into place for evaluating the evolution of permanent changes taking place in the organization. The appropriate auditing and monitoring system should be developed to improve TPM results continuously. This TPM audit process brings structure and metrics to TPM implementation and allows the steering team to place focused effort to move the implementation forward. Thus sustained TPM programs have the capability to achieve "world class organization" and assuming leadership roles in the competitive environments.

15 Conclusions

The literature highlights the contributions of various TPM implementation initiatives for accruing strategic benefits for meeting the challenges posed by global competition. TPM has emerged as a key competitive strategy for business organizations in the global marketplace. An effective TPM implementation program can focus on addressing the organization's maintenance related problems, with a view to optimize equipment performance. TPM has become a new management paradigm in all types of organizations. In recent years, many organizations have demonstrated that significant improvements in business can be achieved through TPM. TPM concepts and philosophy can be effectively employed to realize fundamental improvements of manufacturing performance in the organization, thereby leading the organizations successfully in the highly competitive environment. TPM can prove to be an effective global strategy for rendering firms a consistent enhancement of performance in terms of achieving strategic core competencies. Thus, in the highly competitive scenario, TPM might prove to be one amongst the best of the proactive strategic initiatives that can lead the organizations to scale new levels of achievements and could really make the difference between success and failure of the organizations. The study validates the relevance of strategic TPM initiatives into the manufacturing strategy for realization of organizational objectives in the successful organizations. The study clearly reveals that the successful TPM implementation program can facilitate the manufacturing organiza-

tion's quest for achieving enhanced manufacturing performance leading to competitive advantage.

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