



# Total productive maintenance: literature review and directions

Total productive  
maintenance

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709

## Abstract

**Purpose** – The purpose of this paper is to review the literature on Total Productive Maintenance (TPM) and to present an overview of TPM implementation practices adopted by the manufacturing organizations. It also seeks to highlight appropriate enablers and success factors for eliminating barriers in successful TPM implementation.

**Design/methodology/approach** – The paper systematically categorizes the published literature and then analyzes and reviews it methodically.

**Findings** – The paper reveals the important issues in Total Productive Maintenance ranging from maintenance techniques, framework of TPM, overall equipment effectiveness (OEE), TPM implementation practices, barriers and success factors in TPM implementation, etc. The contributions of strategic TPM programmes towards improving manufacturing competencies of the organizations have also been highlighted here.

**Practical implications** – The literature on classification of Total Productive Maintenance has so far been very limited. The paper reviews a large number of papers in this field and presents the overview of various TPM implementation practices demonstrated by manufacturing organizations globally. It also highlights the approaches suggested by various researchers and practitioners and critically evaluates the reasons behind failure of TPM programmes in the organizations. Further, the enablers and success factors for TPM implementation have also been highlighted for ensuring smooth and effective TPM implementation in the organizations.

**Originality/value** – The paper contains a comprehensive listing of publications on the field in question and their classification according to various attributes. It will be useful to researchers, maintenance professionals and others concerned with maintenance to understand the significance of TPM.

**Keywords** Preventive maintenance, Productive maintenance, Reliability management, Critical success factors

**Paper type** Research paper

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## 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 behaviour (Ahuja *et al.*, 2006). In today's highly dynamic and rapidly changing environment, the global competition among organizations has led to higher demands on the manufacturing organizations (Miyake and Enkawa, 1999). The global marketplace has witnessed an increased pressure from customers and competitors in manufacturing as well as service sector (Basu, 2001; George, 2002).

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 (Raouf, 1994). 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 (R&D) (Gotoh, 1991; Hipkin and Cock, 2000). In today's fast-changing marketplace, slow, steady improvements in manufacturing operations do not guarantee sustained profitability or survival of an organization (Oke, 2005). Thus the organizations need to improve at a faster rate than their competitors, if they are to become 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 (Yamashina, 1995). 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 (Gomes *et al.*, 2006). 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 (Ben-Daya and Duffuaa, 1995; Pintelon *et al.*, 2006). 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 (Tajiri and Gotoh, 1992). 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 (Wireman, 1990b). Thus the inadequacies of the maintenance practices in the past, have adversely affected the organizational competitiveness thereby reducing the throughput 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.

### **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 (Al-Hassan *et al.*, 2000). The maintenance processes can be streamlined to eliminate waste and produce breakthrough performance in areas valued by customers (Hammer and Champy, 1993).

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

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(Pintelon and Gelders, 1992; Foster and VanTran, 1990). In financial terms, maintenance can represent 20 to 40 per cent of the value added to a product as it moves through the plant (Hora, 1987; Eti *et al.*, 2006). 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 (Dunn, 1988), whereas in refineries, the maintenance and operations departments are often the largest and each may comprise about 30 per cent of total staffing (Dekker, 1996). 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 (Cross, 1988). With sobering 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 (Yoshida *et al.*, 1990). Thus the effectiveness of maintenance function significantly contributes towards the performance of equipment, production and products (Macaulay, 1988; Teresko, 1992).

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 (Riis *et al.*, 1997). 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 (Kutucuoglu *et al.*, 2001). Its importance is rather increasing in the growing advanced manufacturing technology application stages (Maggard and Rhyne, 1992). Therefore, equipment maintenance is an indispensable function in a manufacturing enterprise (Ahmed *et al.*, 2005). The recent competitive trends and ever increasing business pressures have been putting maintenance function under the spotlight as never before (Garg and Deshmukh, 2006). 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 (Kumar *et al.*, 2004). Thus achieving excellence in maintenance issues has to be treated as a strategic issue for manufacturing organizations to create world-class-manufacturers (Brah and Chong, 2004).

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 (Moubray, 2003). Strategic investments in the maintenance function can lead to improved performance of manufacturing system and enhance the competitive market position of the organization (Coetzee, 1999; Jonsson and Lesshammar, 1999). This has provided the impetus 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), over the traditional fire fighting reactive maintenance approaches (Sharma *et al.*, 2005).

The changing needs of the physical assets and equipments over time have been putting tremendous pressures on the maintenance management to adapt proactively

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 (Pun *et al.*, 2002). To that end, the effectiveness of maintenance needs to be improved (Murthy, 2002).

### **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. A more recent view of maintenance is defined by Gits (1992) as: "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 (Priel, 1974). 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 (Pintelon and Gelders, 1992). 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 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 (Murray *et al.*, 1996). When perceived in this wider context, the maintenance function is also known as physical asset management.

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 (Wireman, 1990a). This maintenance strategy was primarily

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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 (Telang, 1998).

- *Preventive maintenance (PM)*: This concept was introduced in 1951, which is a kind of physical check up 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 (Herbaty, 1990). During this phase, the maintenance function is established and time based maintenance (TBM) activities are generally accepted (Pai, 1997). 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 (Telang, 1998).
- *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 (Vanzile and Otis, 1992). The diagnostic techniques are deployed to measure the physical condition of the equipment such as temperature, noise, vibration, lubrication and corrosion (Brook, 1998). 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 (Herbaty, 1990).
- *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) (Steinbacher and Steinbacher, 1993). The primary difference between corrective and preventive maintenance is that a problem must exist before corrective actions are taken (Higgins *et al.*, 1995). 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 (Steinbacher and Steinbacher, 1993). 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 (Shirose, 1992). 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 (Dekker, 1996). 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 (Samanta *et al.*, 2001). The steps include selecting plant areas that are significant, determining key functions and performance standards, determining possible function failures, determining likely failure modes and their effects, selecting feasible and effective maintenance tactics, scheduling and implementing selected tactics, and optimizing tactics and programs (Moubay, 1997). The various tools employed for affecting maintenance improvement include 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 (Wakaru, 1988; Bhadury, 1988).
- *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

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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 (Hannan and Keyport, 1991; Singer, 1999).

The capability of CMMS to manage maintenance information contributes to improved communication and decision-making capabilities within the maintenance function (Higgins *et al.*, 1995). 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 (Dunn and Johnson, 1991).

- *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 (Bhadury, 2000).

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. This method further tunes up existing processes and equipment by reducing mistakes and accidents. TPM is a world class manufacturing (WCM) initiative that seeks to optimize the effectiveness of manufacturing equipment (Shirose, 1995). 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.

### **Detailed literature review of total productive maintenance**

The literature has revealed that the manufacturing organizations worldwide are facing many challenges to achieve successful operation in today's competitive environment. Modern manufacturing requires that to be successful, organizations must be supported by both effective and efficient maintenance practices and procedures. Over the past two decades, manufacturing organizations have used different approaches to improve maintenance effectiveness (Roup, 1999). 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 (Moore, 1997).

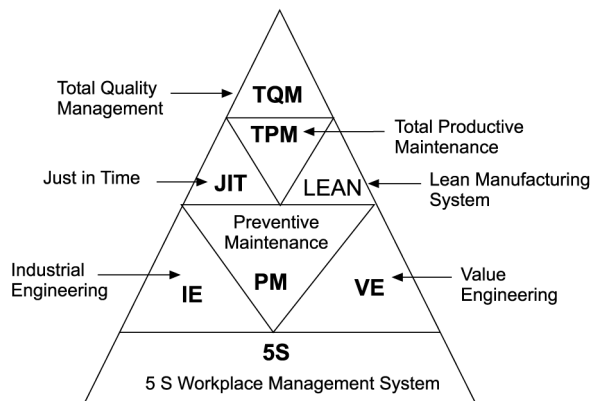
TPM is considered to be Japan's answer to US style productive maintenance (Wal and Lynn, 2002). TPM has been widely recognized as a strategic weapon for improving

manufacturing performance by enhancing the effectiveness of production facilities (Dwyer, 1999; Dossenbach, 2006). TPM has been accepted as the most promising strategy for improving maintenance performance in order to succeed in a highly demanding market arena (Nakajima, 1988). 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 (Ahuja *et al.*, 2004). TPM is a highly influential technique that is in the core of “operations management” and deserves immediate attention by organizations across the globe (Voss, 1995, 2005).

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 (Sekine and Arai, 1998). 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. Figure 1 shows the relationships between TPM and Lean Manufacturing building blocks. 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 is a production-driven improvement methodology that is designed to optimize equipment reliability and ensure efficient management of plant assets (Robinson and Ginder, 1995). TPM is a change philosophy, which has contributed significantly towards realization of significant improvements in the manufacturing organizations in the West and Japan (Maggard and Rhyne, 1992). TPM has been depicted as a manufacturing strategy comprising of following steps (Nakajima, 1989; Bamber *et al.*, 1999; Suzuki, 1992):

- 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;



**Figure 1.**  
Relationship between  
TPM and lean  
manufacturing  
philosophies



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- involving all staff members from top management to shop-floor workers; and
  - promoting improved maintenance through small-group autonomous activities.

Nakajima (1989), 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 (Conway and Perry, 1999, Bhadury, 2000). 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 (Cooke, 2000). Willmott (1994) portrays TPM as 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 realize 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 (Chowdhury, 1995). TPM is a system (culture) that takes advantage of the abilities and skills of all individuals in an organization (Patterson *et al.* 1995). An effective TPM implementation program provides for a philosophy based upon the empowerment and encouragement of personnel from all areas in the organization (Davis and Willmott, 1999).

TPM is about communication. It mandates that operators, maintenance people and engineers collectively collaborate and understand each other’s language (Witt, 2006). 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 (Rhyne, 1990; Labib, 1999; Sun *et al.*, 2003). According to Chaneski (2002), TPM is a maintenance management programme 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 (Maggard *et al.*, 1989; Schonberger, 1996; Ollila and Malmipuro, 1999; Cua *et al.*, 2001). Lawrence (1999) describes TPM as the general movement on the part of businesses to try to do more with fewer resources. According to Besterfield *et al.* (1999), TPM helps to maintain the current plant and equipment at its highest productive level through the cooperation of all functional areas of an organization.

### **Need for TPM in contemporary manufacturing scenario**

TPM harnesses the participation of all the employees to improve production equipment’s availability, performance, quality, reliability, and safety. TPM endeavours 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 in Table I.

		Total productive maintenance
Manufacturing priorities	TPM considerations	
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	<b>719</b>
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 <i>kaizen</i> and suggestions Increase employees' knowledge of the process and product Improved problem-solving ability Increase in worker skills and knowledge Employee involvement and empowerment	

**Table I.**  
Organizational manufacturing priorities and goals realized through TPM

In addition, TPM implementation in an 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. 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 (Dossenbach, 2006). 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 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.

### 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, 1988; Willmott, 1994; Noon *et al.*, 2000). Nakajima

suggests that equipments should be operated at 100 percent capacity 100 percent of the time (Nakajima, 1988). 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.

The main goal of an effective TPM program effort is to bring critical maintenance skilled trades and production workers together (Labib, 1999). Total employee involvement, autonomous maintenance by operators, small group activities to improve equipment reliability, maintainability and productivity, and continuous improvement (kaizen) are the principles embraced by TPM. A TPM program typically enlarges the responsibility of production employees from merely operating machines to such areas as detecting machine failures, performing basic maintenance, and keeping work areas clean and organized. Swanson (2001) describes the four key components of TPM as worker training, operator involvement, teams and preventive maintenance. As TPM is a common element to the lean drive, it requires not only flexible equipment, but also flexible employees involved in the production process (Sahin, 2000). The practices of TPM help eliminate waste arising from an unorganized work area, unplanned downtime, and machine performance variability.

Like the concept of TQM, TPM is focused on improving all the big picture indicators of manufacturing success (Marcus, 2004). TPM is very much about safety, asset utilization, expanding capacity without investment in new equipment or people and, of course, continuing to lower the cost of equipment maintenance and improve machine uptime. TPM implementation requires a long-term commitment to achieve the benefits of improved equipment effectiveness through training, management support, and teamwork.

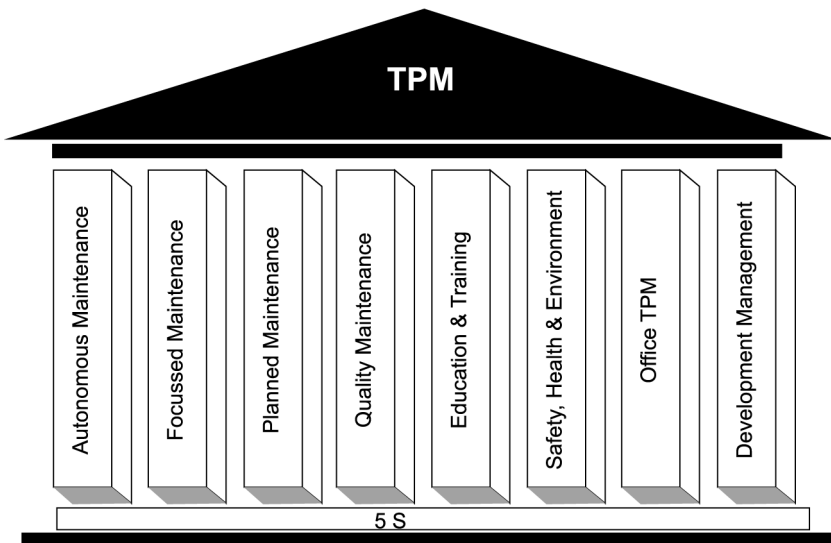
McKone *et al.* (2001) identify training, early equipment design, early product design, focused improvement teams, support group activities, and autonomous and planned maintenance as the six major activities in TPM implementation. In measuring TPM implementation, Maier *et al.* (1998) consider preventive maintenance, teamwork shop floor employee competencies, measurement and information availability work environment, work documentation, and extent of operator involvement in maintenance activities as factors reflecting TPM implementation.

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 (Sangameshwaran and Jagannathan, 2002). 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 (Ireland and Dale, 2001; Shamsuddin *et al.*, 2005; Rodrigues and Hatakeyama, 2006). The JIPM eight pillar TPM implementation plan is depicted in Figure 2. Table II depicts detailed maintenance and organizational improvement initiatives and activities associated with the respective TPM pillars.

There are a variety of tools that are traditionally used for quality improvement. It provides an easy way of deploying activities through its TPM promotion organization involving 100 per cent of employees on a continuous basis. TPM uses the following tools to analyze and solve the equipment and process related problems: Pareto Analysis, Statistical Process Control (SPC – Control Charts, etc.) Problem Solving Techniques (Brainstorming, Cause-Effect Diagrams and 5-M Approach) Team Based Problem Solving, Poka-Yoke Systems, Autonomous Maintenance, Continuous Improvement, 5S, Setup Time Reduction, Waste Minimization, Bottleneck Analysis, Recognition and Reward Program and Simulation (Jostes and Helms, 1994). Figure 3 shows the framework for TPM implementation and depicts the tools used in the TPM implementation program with potential benefits accrued and targets sought, while Table III depicts the key activities to be holistically deployed for effective 5S implementation at the workplace.

TPM provides a comprehensive, life cycle approach, to equipment management that minimizes equipment failures, production defects, and accidents. It involves everyone in the organization, from top-level management to production mechanics, and production support groups to outside suppliers. The objective is to continuously improve the availability and prevent the degradation of equipment to achieve maximum effectiveness (Ravishankar *et al.*, 1992). These objectives require strong management support as well as continuous use of work teams and small group activities to achieve incremental improvements.



**Figure 2.** Eight pillars approach for TPM implementation (suggested by JIPM)

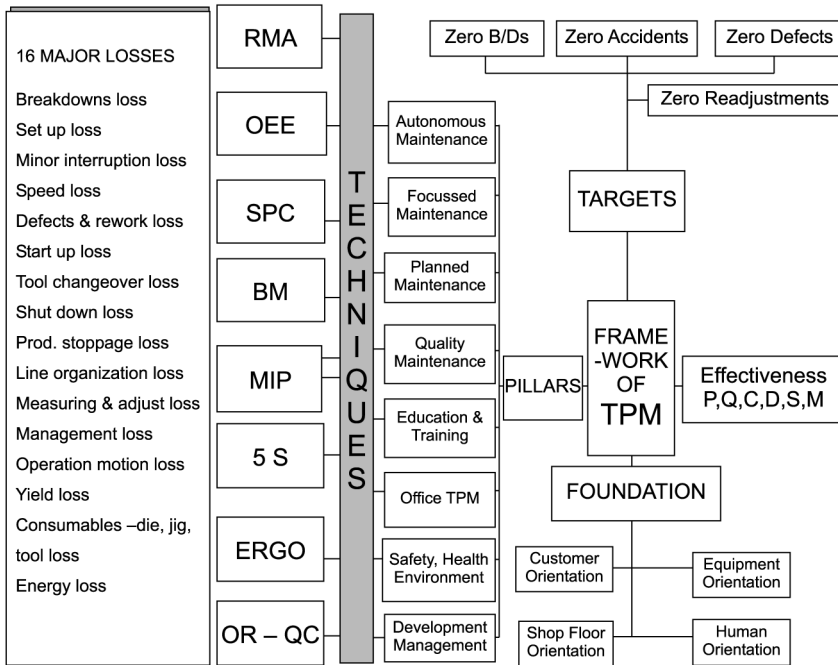
	Fostering operator skills
Autonomous maintenance	Fostering operator ownership Perform cleaning – lubricating – tightening – adjustment – inspection – readjustment on production equipment
Focused improvement	Systematic identification and elimination of 16 losses Working out loss structure and loss mitigation through structured why-why, FMEA analysis Achieve improved system efficiency Improved OEE on production systems
Planned maintenance	Planning efficient and effective PM, PdM and TBM systems over equipment life cycle Establishing PM check sheets Improving MTBF, MTTR
Quality maintenance	Achieving zero defects Tracking and addressing equipment problems and root causes Setting 3M (machine/man/material) conditions
Education and training	Imparting technological, quality control, interpersonal skills Multi-skilling of employees Aligning employees to organizational goals Periodic skill evaluation and updating
Safety, health and environment	Ensure safe working environment Provide appropriate work environment Eliminate incidents of injuries and accidents Provide standard operating procedures
Office TPM	Improve synergy between various business functions Remove procedural hassles Focus on addressing cost-related issues Apply 5S in office and working areas
Development management	Minimal problems and running in time on new equipment Utilize learning from existing systems to new systems Maintenance improvement initiatives

**Table II.**  
Issues addressed by  
various TPM pillar  
initiatives

### Overall equipment effectiveness

TPM initiatives in production help in streamlining the manufacturing and other business functions, and garnering sustained profits (Ahuja and Khamba, 2007). 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 (Gosavi, 2006). 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 (COO).

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 (Ravishankar *et al.*, 1992; Gupta *et al.*, 2001, Juric *et al.*, 2006). The evaluation of TPM efficiency can facilitate significantly enhanced organizational capabilities across a



**Figure 3.**  
Framework of TPM  
Implementation

Japanese nomenclature	English 5S	English 5C	Features
<i>Seiri</i>	Sort	Clear	Sort out unnecessary items from the workplace and discard them
<i>Seiton</i>	Set in order	Configure	Arrange necessary items in good order so that they can be easily picked up for use
<i>Seisio</i>	Shine	Clean and check	Clean the workplace completely to make it free from dust, dirt and clutter
<i>Seiketsu</i>	Standardize	Conformity	Maintain high standard of house keeping and workplace organization
<i>Shitsuke</i>	Sustain	Custom and practice	Train and motivate people to follow good housekeeping disciplines autonomously

**Table III.**  
Key activities for  
effective 5S  
implementation at the  
workplace

variety of dimensions (Wang, 2006). 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 (Jeong and Phillips, 2001). The overall goal of TPM is to raise the overall equipment effectiveness (Shirose, 1989; Huang *et al.*, 2002; Juric *et al.*, 2006). OEE is calculated by obtaining the product of

availability of the equipment, performance efficiency of the process and rate of quality products (Dal *et al.*, 2000; Ljungberg, 1998):

$$OEE = \text{Availability (A)} \times \text{Performance efficiency (P)} \times \text{Rate of quality (Q)}$$

where:

$$\text{Availability (A)} = \frac{\text{Loading time} - \text{Downtime}}{\text{Loading time}} \times 100$$

$$\text{Performance efficiency (P)} = \frac{\text{Processed amount}}{\text{Operating time/theoretical cycle time}} \times 100$$

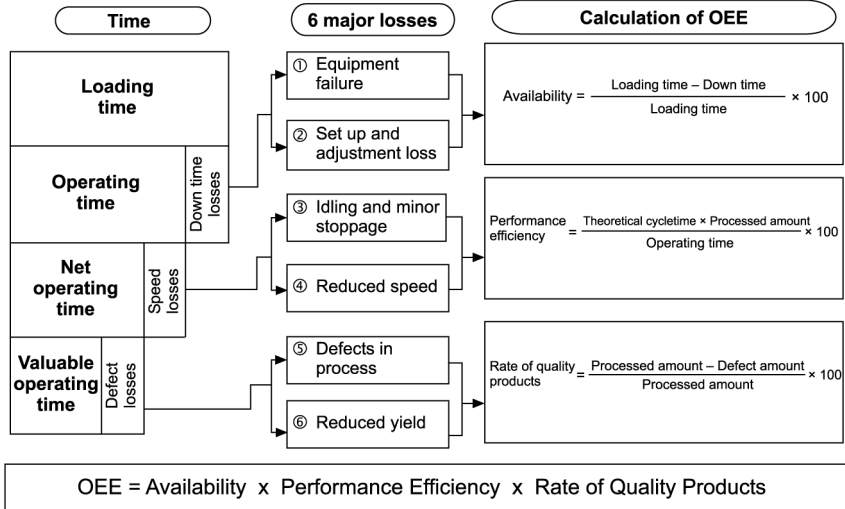
$$\text{Rate of quality (R)} = \frac{\text{Processed amount} - \text{Defect amount}}{\text{Processed amount}} \times 100$$

This metric has become widely accepted as a quantitative tool essential for measurement of productivity in manufacturing operations (Samuel *et al.*, 2002). The OEE measure is central to the formulation and execution of a TPM improvement strategy (Ljungberg, 1998). TPM has the standards of 90 per cent availability, 95 per cent performance efficiency and 99 per cent rate of quality (Levitt, 1996). An overall 85 per cent benchmark OEE is considered as world-class performance (Blanchard, 1997; McKone *et al.*, 1999). OEE measure provides a strong impetus for introducing a pilot and subsequently company wide TPM program.

A key objective of TPM is to eliminate or minimize of all losses related to manufacturing system to improve overall production effectiveness. In the initial stages, TPM initiatives focus upon addressing six major losses, which are considered significant in lowering the efficiency of the production system (Gupta *et al.*, 2001). 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 endeavours 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 in Figure 4 (McKellen, 2005). Using OEE metrics and establishing a disciplined reporting system help an organization to focus on the parameters critical to its success.

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 (Holmgren, 2005). 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 (Hansen, 2002). Overall Plant Efficiency is also referred to as Total Effectiveness Equipment Performance (TEEP). The terms OPE or TEEP are used to evaluate how well the organization's assets are used relative to the total calendar time. OPE/TEEP are the metrics that indicate opportunities that might exist between

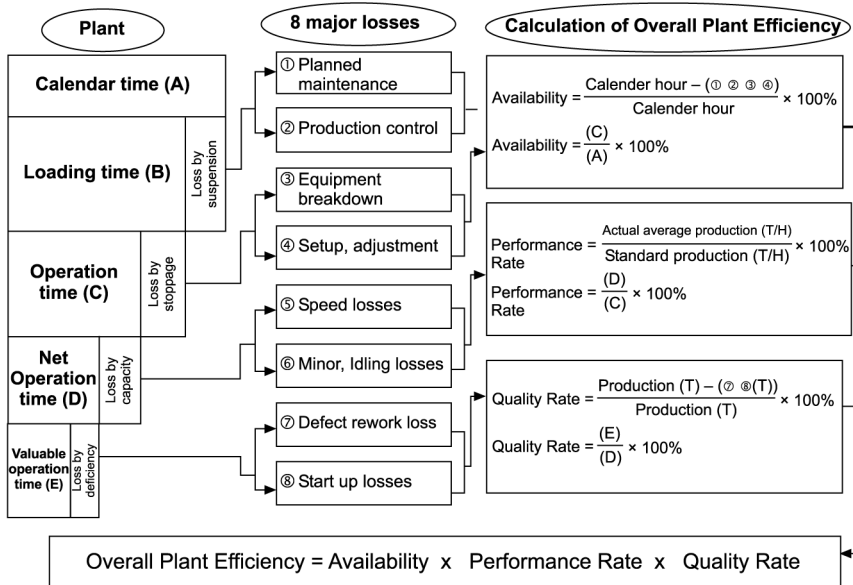




**Figure 4.** Calculation of OEE based on six major production losses

current operations and world-class levels. The calculation of OPE by considering the impact of the eight major losses on the production system is indicated in Figure 5.

In the quest to achieve world class manufacturing, the organizations world over, are now, relying upon exhaustive analysis of the manufacturing systems in order to ascertain the inefficiencies associated with the enterprises. It has been observed that other than equipment related losses, losses affecting human performance and energy/yield inefficiencies also need to be accounted appropriately for achieving



**Figure 5.** Calculation of Overall Production Effectiveness (OPE) based on eight major production losses

world-class performance. In all 16 losses are identified and strategies developed for reducing the impact of the losses, or eliminating the losses from the manufacturing systems. For the purpose, 16 major losses have been identified to be impeding the manufacturing performance and efficiency. These losses have been categorized into four categories, which include seven major losses impeding equipment efficiency (failure losses, setup/adjustment losses, reduced speed losses, idling/minor stoppage losses, defect/rework losses, start-up losses, and tool changeover losses), losses that impede machine loading time (planned shutdown losses), five major losses that impede human performance (distribution/logistic losses, line organization losses, measurement/adjustment losses, management losses, and motion related losses) and three major losses that impede effective use of production resources (yield losses, consumable – jig/tool/die losses, and energy losses) (Shirose, 1996). The brief description of various losses in context of manufacturing organizations, have been elaborated in Table IV.

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 (Wang, 2006). 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.

### **An overview of TPM implementation practices**

Lycke (2000) points out that TPM is a highly structured approach and careful, thorough planning and preparation are keys to successful company-wide implementation of TPM and so is senior management's understanding and belief in the concept. One of the most significant elements of TPM implementation process is that, it is a consistent and repeatable methodology for continuous improvement. A driving consideration for TPM is the fact that successful TPM implementation takes from three to five years, with an average of three and a half years from introduction to achievement of TPM Prize winning results (Society of Manufacturing Engineers, 1995; Wang and Lee, 2001). TPM is a long-term process, not a quick fix for today's manufacturing problems (Horner, 1996).

The organizations across the world have been struggling since long to evolve the best possible strategy for successful implementation of TPM. However, the TPM experts and practitioners around the world have now acknowledged problems regarding a cookbook-style TPM in the organizations due to factors like highly variable skills associated with the workforce under different situations, age differences of the workgroups, varied complexities of the production systems and equipments, altogether different organization cultures, objectives, policies and environments and the differences in prevailing status of maintenance competencies (Wireman, 2004).

*Seven major losses that impede overall equipment efficiency*

- |   |                                |   |
|---|--------------------------------|---|
| 1 | Breakdown/failure loss         | Losses due to failure. Types of failure include sporadic function-stopping failures and function-reducing failures in which the function of the equipment drops below normal levels                         |
| 2 | Set-up and adjustment loss     | Stoppage losses that accompany set-up changeovers. These losses are caused by changes in operating condition. Equipment changeovers require a period of shutdown so that the tools can be exchanged         |
| 3 | Reduced speed loss             | Losses due to actual operating speed falling below the designed speed of the equipment  |
| 4 | Idling and minor stoppage loss | Losses that occur when the equipment temporarily stops or idles due to sensor actuation or jamming of the work. The equipment will operate normally through simple measures (removal of work and resetting) |
| 5 | Defect and rework loss         | Volume/time losses due to defect and rework (disposal defects), financial losses due to product downgrading, and time losses required to repair defective products to turn them into excellent products     |
| 6 | Start-up loss                  | When starting production, the losses that arise until equipment start-up, running-in and production-processing conditions stabilize   |
| 7 | Tool changeover loss           | Stoppage losses caused by changing the cutting blades due to breakage or caused by changing the cutting blades when the service life of the grinding stone, cutter or bite has been reached                 |

*Losses that impede equipment loading time*

- |   |                       |  |
|---|-----------------------|--|
| 8 | Planned shutdown loss | Losses that arise from planned equipment stoppages at the production planning level in order to perform periodic inspection and statutory inspection |
|---|-----------------------|--|

*Five major losses that impede worker efficiency*

- |    |                                 |  |
|----|---------------------------------|--|
| 9  | Distribution/logistic loss      | Losses occurring due to inability to automate, e.g. automated loading/unloading leading to manpower reduction not implemented                                    |
| 10 | Line organization loss          | These are waiting time losses involving multi-process and multi-stand operators and line-balance losses in conveyor work   |
| 11 | Measurement and adjustment loss | Work losses from frequent measurement and adjustment in order to prevent the occurrence and outflow of quality defects   |
| 12 | Management loss                 | Waiting losses that are caused by management, such as waiting for materials, waiting for tools, waiting for instructions, waiting for repair of breakdowns, etc. |
| 13 | Motion-related loss             | Losses due to violation of motion economy, losses that occur as a result of skill differences and walking losses attributable to an inefficient layout           |

*Three major losses that impede efficient use of production resources*

- |    |                                   |  |
|----|-----------------------------------|--|
| 14 | Yield loss                        | Material losses due to differences in the weight of the input materials and the weight of the quality products   |
| 15 | Consumables (jig, tool, die) loss | Financial losses (expenses incurred in production, regrinding, reinitriding, etc.) which occur with production or repairs of dies, jigs and tools due to aging beyond service life or breakage |
| 16 | Energy loss                       | Losses due to ineffective utilization of input energy (electricity, gas, fuel oil, etc.) in processing   |

**Table IV.**  
Sixteen major losses impeding manufacturing performance

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Although “there is no single right method for implementation of a TPM program” (Wireman, 1990b) and there has been “a complexity and divergence of TPM programs adopted throughout industry” (Bamber *et al.*, 1999) it is clear that a structured implementation process is an identified success factor and a key element of TPM programs. “For world-class competitors, minimal performance requirements include repetitive and predictable year-over-year actual per-unit cost reductions, ever-reducing variation, improved product quality, and extraordinary customer service. Winning requires an institutionalized management proof process that is sustainable despite changes in leadership, strategy, and business conditions – a corporate culture dedicated to manufacturing excellence” (Elliott, 2001). In order to introduce the principles and practice application of TPM, an implementation method is necessary.

There have been many approaches suggested by different practitioners and researchers for implementing TPM in the different organizations having varying environments for garnering manufacturing competencies to accomplish the organizational goals and objectives. It has been observed that many organizations follow a strict JIPM-TPM implementation process, by strategically employing the eight pillars approach towards TPM implementation (Wakaru, 1988; Ireland and Dale, 2001). The eight pillars involved for achieving goals of TPM include autonomous maintenance; focused maintenance; planned maintenance; quality maintenance; education and training; safety, health and environment; office TPM and Development Management (Nakajima, 1988). The Nakajima model of TPM implementation has already been depicted in Figure 2.

Nakajima has also outlined 12 steps involved in developing and implementing a TPM program in four stages (Nakajima, 1988; Shirose, 1996). These 12 steps support the basic developmental activities, which constitute the minimal requirements for the development of TPM. The various steps involved in the TPM implementation methodology have been depicted in Table V.

Hartmann has outlined another TPM implementation process that simplifies the Nakajima implementation model (Hartmann, 1992).

*Phase I* – Improving equipment to its highest required level of performance and availability (focused improvement):

- determine existing equipment performance and availability – current OEE;
- determine equipment condition;
- determine current maintenance performed on equipment;
- analyze equipment losses;
- develop and rank equipment improvement needs and opportunities;
- develop setup and changeover improvement needs and opportunities;
- execute improvement opportunities as planned and scheduled activity; and
- check results and continue with improvement as required.

*Phase II* – Maintaining equipment at its highest required level of performance and availability (autonomous maintenance, planned maintenance, quality maintenance):

- develop planned maintenance, cleaning, lubrication requirements for each machine;
- develop planned maintenance, cleaning, and lubrication procedures;

Phase of implementation	TPM implementation steps	Activities involved	Total productive maintenance
Stage preparation	Declaration by top management decision to introduce TPM	Declare in TPM in-house seminar	729
	Launch education and campaign to introduce TPM	Carried in organization magazine Managers: trained in seminar/camp at each level General employees: seminar meetings using slides Committees and sub-committees	
	Create organizations to promote TPM	Committees and sub-committees	
Preliminary implementation	Establish basic TPM policies and goals	Benchmarks and targets evolved Prediction of effects	
	Formulate master plan for TPM development	Develop step-by-step TPM implementation plan Framework of strategies to be adopted over time	
	Hold TPM kick-off	Invite suppliers, related companies, affiliated companies	
TPM implementation	Establishment of a system for improving the efficiency of production system	Pursuit of improvement of efficiency in production department	
	Improve effectiveness of each piece of equipment	Project team activities and small group activities (SGA) at production centers	
	Develop an autonomous maintenance (AM) program	Step system, diagnosis, qualification certification	
	Develop a scheduled maintenance program for the maintenance department	Improvement maintenance, periodic maintenance, predictive maintenance	
	Conduct training to improve operation and maintenance skills	Group education of leaders and training members	
	Develop initial equipment management program level	Development of easy to manufacture products and easy to operate production equipment	
Stabilization	Establish quality maintenance organization	Setting conditions without defectives, and its maintenance and control	
	Establish systems to improve efficiency of administration and other indirect departments	Support for production, improving efficiency of related sectors	
	Establish systems to control safety, health and environment	Creation of systems for zero accidents and zero pollution cases	
	Perfect TPM implementation and raise TPM	Sustaining maintenance improvement efforts Challenging higher targets Applying for PM awards	

Source: Nakajima (1988)

**Table V.**  
Twelve-step TPM implementation methodology

- develop inspection procedures for each machine;
- develop planned maintenance, lubrication, cleaning and inspection systems, including all forms and controls;
- develop planned maintenance manuals;

- execute planned maintenance, cleaning and lubrication as planned and scheduled activities; and
- check results and apply corrections to system as required.

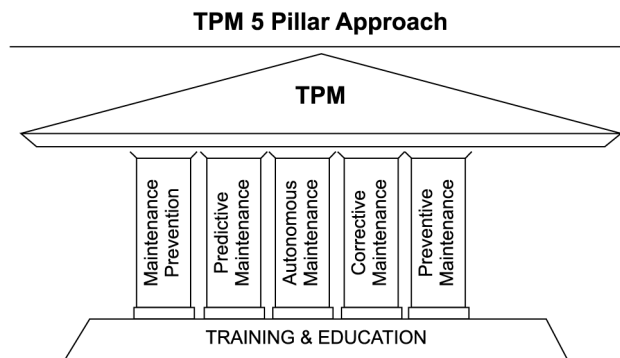
*Phase III* – Establishing procedures to purchase new equipment and developing new processes with a defined level of high performance and low life cycle cost (maintenance prevention, quality maintenance):

- develop engineering specifications;
- get feedback from production operations based on current equipment experience;
- get feedback from maintenance operations based on current equipment experience;
- eliminate past problems in new equipment and process technology design;
- design in diagnostic capabilities with new equipment and processes;
- start training on new equipment and processes early (prior to deployment); and
- accept and deploy new equipment and processes only if they meet or exceed engineering specifications.

Naguib (1993) has proposed a five-phase roadmap to implementation which includes: an awareness program to obtain management commitment and support; a restructuring of the manufacturing organization to integrate maintenance in production modules; planning maps to cover TPM activities related to equipment effectiveness, the maintenance management system, and workplace and workforce improvements; an implementation process based on the work of cross-functional, multi-skilled, self-directed teams; and an assessment process to “close loop” the implementation process and define directions for continuous improvements.

Another simplified Western approach involving “Five Pillar Model” proposed by Steinbacher and Steinbacher (1993) is presented in Figure 6. TPM implementation process, at the highest level requires initialization, implementation, and institutionalization. In this model, “Training and Education” are an integral element of all other pillars rather than stand-alone pillar as in the Nakajima model.

TPM focuses on equipment that is easy to operate, requires minimum maintenance work, and is capable of reliable, low cost, and high quality operation. For existing equipment, Willmott (1994) has presented a three-phase, nine-step TPM improvement



**Figure 6.**  
Steinbacher and  
Steinbacher model of TPM  
implementation

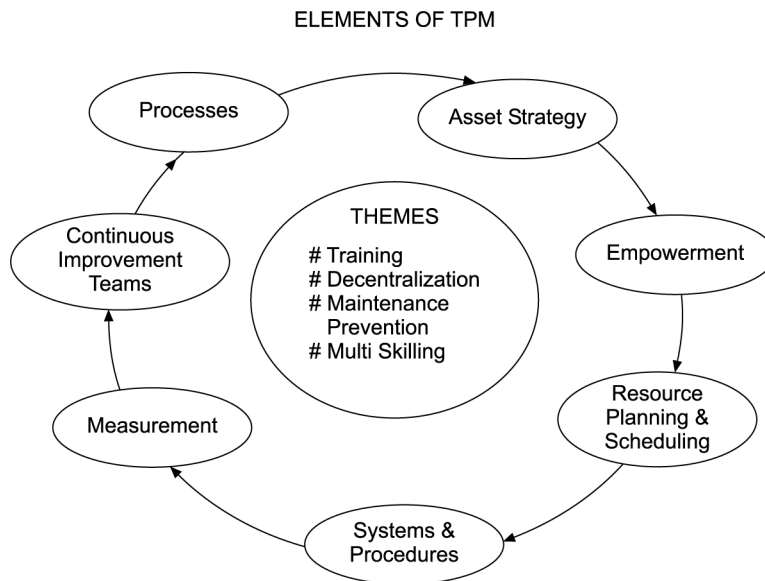
plan that involves Condition cycle (criticality assessment, condition appraisal, refurbishment and future asset care), Measurement cycle (evaluating OEE, equipment history, improvement cycle, assessment of six losses, problem solving, and best practice routines).

Suzuki (1994) has also emphasized on the contribution of TPM to business excellence, and the eight fundamental TPM development activities that includes leadership and administration; people management and focused improvement; policy and strategy and early management, autonomous maintenance (AM); process and planned maintenance; people satisfaction and training and education; customer satisfaction and quality maintenance; and impact on society and safety and environment management.

Pirsig (1996) emphasizes upon seven unique broad elements and four main themes in any TPM implementation program. The key themes in the TPM implementation program include training, decentralization, maintenance prevention and multi-skilling, while the broad elements include asset strategy, empowerment, resource planning and scheduling, systems and procedures, measurement, continuous improvement and processes. The inter-relation between TPM themes and broad elements has been depicted in Figure 7.

Carannante *et al.* (1996) have proposed developed the eight-step approach to the implementation of TPM involving system, measurement, autonomous maintenance, housekeeping, continuous improvement, culture, training, and plant design.

Bamber *et al.* (1999) have suggested a six-step TPM implementation approach to help companies that require a renewed emphasis or vitality to an already implemented but floundering TPM program, and emphasize upon creating a steering organization; understanding the current situation; understanding the restraining forces and the driving forces with production associates; developing and implementing plan



**Figure 7.**  
Pirsig model of TPM implementation

including milestones and measures of performance; implementation of the TPM plan; review the implementation of the plan; and amend activities or milestones as necessary.

Productivity Inc. has proposed a TPM rollout plan that incorporates and expands on the Nakajima TPM implementation process (Productivity, Inc., 1999). This model, as shown in Figure 8, depicts various activities to be performed during different stages of TPM implementation with respect to time frame.

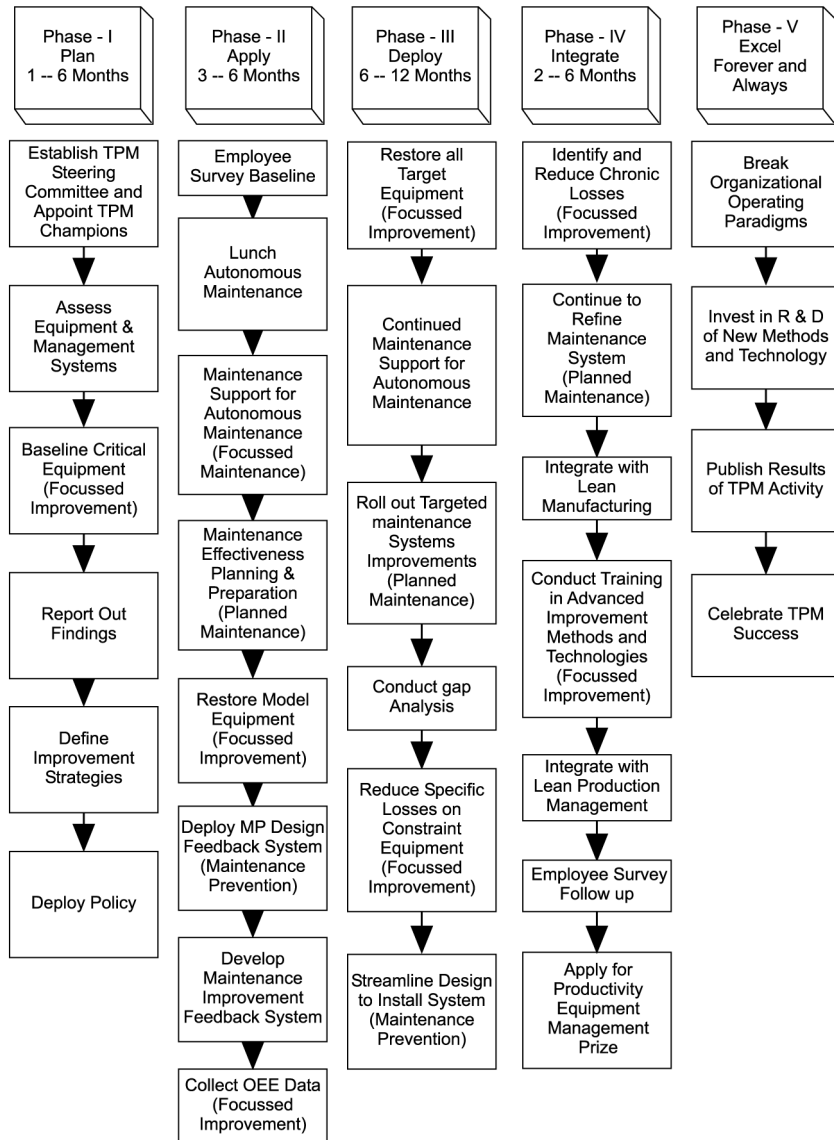


Figure 8. Productivity inc. model of TPM implementation



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Leflar (2001) has presented a five-step plan to guide the TPM implementation and calls for holistically following five steps including restoring equipment to new condition (ensure that equipment is clean and free of humanly detectable minor defects, create cleaning and inspection standards to keep machines in this condition, and create visual controls to rapidly identify variation from this condition), identifying complete maintenance plans (create PM checklists, establish schedules for PM execution, create PM procedures, specify equipment inspection procedures, identify and standardize equipment replacement parts, create equipment parts logs, and implement equipment quality checks), implementing maintenance plans with precision (complete all PM's on time, complete 100 per cent of PM checklist items, execute PM checklists without variation, and continually advance the knowledge and skill of the factory personnel), preventing recurring machine failures (implement failure analysis to prevent recurring failure, establish continuous PM evaluation and improvement – make PM's easier, faster, better), and improving machine productivity (lubrication analysis, calibration and adjustment analysis, quality maintenance analysis, machine part analysis, condition-of-use and life analysis, productivity analysis, extended condition monitoring, continuous condition monitoring, and maintenance cost analysis).

Thus it has been observed through the literature review that, although number of models and methodologies have been suggested by practitioners and researchers for the Western World, the organizations world-wide are faced with a stiff challenge of working out right sequence of initiatives for effectively deploying TPM practices successfully, in the most effective manner.

### **Stumbling-blocks in TPM implementation**

It has been reported in the literature that TPM implementation is not an easy task by any means. The number of companies successfully implemented TPM program is considered relatively small. While there are several success stories and research on TPM, there are also documented cases of failure in the implementation of TPM programs in different situations. TPM demands not only commitments, but also structure and direction. Some of the prominent problems in TPM implementation include cultural resistance to change, partial implementation of TPM, overly optimistic expectations, lack of a well-defined routine for attaining the objectives of implementation (equipment effectiveness), lack of training and education, lack of organizational communication, and implementation of TPM to conform to societal norms rather than for its instrumentality to achieve world class manufacturing (Crawford *et al.*, 1988; Becker, 1993).

The failure of organizations to successfully institutionalize effective TPM implementation program is due to lack of a support system to facilitate learning and transform learning into effective diffusion of the practices of TPM. The failure of the organizations to successfully harness the true potential of TPM can also be attributed to confusion over what exactly constitutes TPM, lack of management consensus, underestimating the importance of knowledge, inconsistent and unclear expectations, neglecting the basics, and TPM implementation within an existing organization structure that does not provide the necessary support. These problems reflect the lack of a clear understanding of what are the fundamental and complementary manufacturing practices. It has been observed that companies that have experienced failure in the TPM implementation programs have often neglected the development of

basic practices continuous improvement, total employee involvement, cross functional teams, that support the implementation of TPM techniques.

Another significant contributor for failure of TPM implementation program is the organization's inability to obviate resistance to change. The resistance to change takes a number of forms, that is, reluctance of individuals to change roles (Riis *et al.*, 1997; Cooke, 2000), inability to create dissatisfaction with the present situation (reason to change) (Maggard and Rhyne, 1992; Ireland and Dale, 2001) and inability to change organizational roles and culture (Patterson *et al.*, 1995; Lawrence, 1999).

Many researchers have tried to explain why failures and undesirable effects occur.

Crawford *et al.* (1988) have pointed out several problems faced by organizations towards successfully implementation lean manufacturing initiatives including TPM involved cultural resistance of change, lack of training and education, lack of organizational communication, use of inappropriate performance measurement, and poor quality.

Bakerjan (1994) has stated that many organizations that attempt to implement TPM initiatives experience difficulties and are not able to achieve the anticipated benefits. The failure of an organization to successfully implement a TPM program has been attributed to the various obstacles including lack of management support and understanding, lack of sufficient training, failure to allow sufficient time for the evolution.

Hayes and Pisano (1994) have believed that while programs such as TQM, JIT, and TPM have proliferated the manufacturing sector, management seems content with investing in these programs without a full sense of their implementation requirements and their impact on overall manufacturing performance. The crux of the problems that many companies have experienced with improvement programs is that most companies focus on the mechanics of the programs rather than on their substance, the skills and capabilities that enable an improvement program to achieve its desired results.

McAdam and Duffner (1996) have described that many issues arise when trying to implement TPM in a union environment. Workers fear that the only drive is to improve production efficiency, reduce labour, and increase employee workload. Many operators do not want additional responsibility and are happy with the situation the way it is. In addition the skilled trades enjoy feeling indispensable and think that the autonomous maintenance activity threatens their job security.

Davis (1997) has outlined various reasons for TPM failure within UK manufacturing organizations including lack of commitment of top management, deployment of inexperienced consultants, lack of structure, failure to implement change on the shop floor, lack of education and training for employees, lack of employee involvement, and poor structure to support the TPM initiatives.

Fredendall *et al.* (1997) have suggested that potential barrier that often affect TPM implementation is the inability of the organizations to coordinate its human resource practices, management policies and technology. Together, these problems reflect the lack of a system that supports the implementation of world-class manufacturing programs such as TQM, JIT and TPM.

Lawrence (1999) has stated that many TPM programs fail because the organizations are unable to change their culture. Thus, a comprehensive TPM implementation methodology is indispensable.

Cooke (2000) has attributed the failure of TPM implementation program to the inability of management to holistically implement the TPM practices at the workplace

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and highlights that serious deviations have been observed between officially laid out TPM policies and actual practices deployed at workplace.

Mora (2002) has stated that though in recent years, many companies have attempted to implement TPM programs, less than 10 per cent of companies succeed in implementing TPM. Implementing TPM requires the change of the organizational culture and change of existing behaviours of all employees, operators, engineers, maintenance technicians, and managers. The TPM implementing process has been fraught with roadblocks and pitfalls.

Rodrigues and Hatakeyama (2006) have suggested that factors contributing to the failure of TPM implementation program include increasing daily rhythm of production with the same team; lack of time for the autonomous maintenance; operators commanding more than one machine at the same time; work stress; TPM implementation in a quick way omitting some consolidation steps; lack of personal training (not only technical but management); lack of follow-up of the progress of the program and its evaluation; goals that are not achieved and are left without explanation; ignorance by the operators of the evolution of TPM program; non-truly commitment of the immediate bosses and superior staff; high leadership turn over, and cutting investments without clear criteria for operators and maintenance people.

The various obstacles hindering organization's quest for achieving excellence through TPM initiatives have been classified as organizational, cultural, behavioural, technological, operational, financial and departmental barriers (Ahuja and Khamba, 2008c). The obstacles affecting successful TPM implementation in manufacturing organizations include: organization's inability to bring about cultural transformations, attaining total employee involvement, holistically implementing change management initiatives; lack of commitment from top management and communication regarding TPM; lack of understanding of TPM concepts and principles; inadequacies of reward and recognition mechanisms; inadequacies of master plan in the absence of a focused approach; middle management's resistance towards offering empowerment and recognition of operators; inability to strictly adhere to laid out TPM practices and standards; occasional difficulties to succeed as cross functional teams (CFT); functional orientation and loyalty; inadequate efforts towards multi-skilling and periodic skill updating of employees; resistance to accept changes due to job insecurity and apprehension of loss of specialization; little emphasis to improve production capabilities beyond the design capabilities; inadequate initiatives to improve reliability of production systems; absence of mechanisms for investigating inefficiencies of production system (losses, wastes); poor flexibilities offered by production systems due to long set up and changeover times; little empowerment to operators to take equipment related or improvement decisions; resistance from production operators to perform basic autonomous maintenance tasks; emphasis on restoration of equipment conditions rather than prevention of failures; resource crunch; low synergy between maintenance and production departments; and firm divisions between maintenance and production department responsibilities.

Thus it can be asserted that, there are many factors that may contribute to the failure of the organizations to successfully implement TPM and reap the true potential of TPM. Thus TPM implementation requires a long-term commitment to achieve the benefits of improved equipment effectiveness. Training, management support, and teamwork are essential to a successful implementation. Thus, it becomes pertinent to

develop TPM support practices like committed leadership, vision, strategic planning, cross-functional training, employee involvement, cultural changes in the organizations, continuous improvement, and motivation, and evolving work related incentive mechanisms in the organizations to facilitate the TPM implementation programs to realize world class manufacturing attributes.

### **Success factors for TPM implementation**

TPM is a result of the corporate focus on making better use of available resources. TPM literature presents many success criteria for effective and systematic TPM implementation. In order to realize the true potential of TPM and ensure successful TPM implementation, TPM goals and objectives need to be fully integrated into the strategic and business plans of the organizations, because TPM affects the entire organization, and is not limited to production. The first course of action is to establish a strategic direction for TPM. The transition from a traditional maintenance program to TPM requires a significant shift in the way the production and maintenance functions operate. Rather than a set of instructions, TPM is a philosophy, the adoption of which requires a change of attitude by production and maintenance personnel. Swanson (1997) recommends four key components for successful implementation of TPM in an organization as: worker training, operator involvement, teams and preventive maintenance. There is an utmost need to foster initiatives facilitating smooth TPM implementation that include committed leadership, strategic planning, cross-functional training, and employee involvement. In order to capture the TPM program completely, it is pertinent to combine the TPM practices identified as pillars or elements of TPM with the TPM development activities. For TPM to be successful, the improvement processes must be recognized as benefiting both the organization and the workers (Robinson and Ginder, 1995). There is need to foster an environment for facilitating employees to smoothly implement the TPM techniques of autonomous and planned maintenance.

As can be expected, several of the factors that have led to the successful TPM programs are simply doing the opposite of the barriers. One key strategy, in effective implementation of TPM workgroups is, management's support the efforts to drive continuous improvement in the team environment. Building on trust through effective communication, worker participation in decisions, acceptance of ideas, and frequent feedback are catalysts that drive improvement through strategic TPM implementing programs. Team Leadership must provide consistent messages, and should include encouragement, facilitating and maintaining order, and help with decision-making. The role of the worker needs to change from one that supports the traditional craft mentality of maintaining specialized jobs, to one that allows greater flexibility. In addition, this new role necessitates removing age-old barriers in place since the inception of automated production (McAdam and Duffner, 1996). This effort requires an "active organization" (Yamashina, 2000). This requires competent leaders who are willing to invest in education and willing to empower the workforce. These developmental activities form a set of strategic and human resource oriented practices.

Bohoris *et al.* (1995) have emphasized upon affecting changes in the management structure, focusing on continuous production system improvements, managing synergic cooperation of production and maintenance, deployment of effective developed computerized maintenance management system (CMMS) and gradual

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implementation of TPM on a handful of machines at a given time as key contributors towards successful TPM implementation.

Groote (1995) has proposed a maintenance performance evaluation approach based on a quality audit and quantifiable maintenance performance indicators. He has suggested that the maintenance function effectiveness must be defined through relative economic and technical ratios, to permit the maintenance manager to follow the evolution of maintenance performance and to make decisions necessary for improved maintenance management.

Leblanc (1995) has recommended the postulates for realizing the true potential of TPM including evaluating cost savings from TPM can be predicted and measured, cross-functional teams integrated to enhance the value of TPM, and identification and mitigation of the root cause of equipment problems effectively.

Raouf and Ben-Daya (1995) have proposed a systematic approach to total maintenance management, comprising of three subsystems: maintenance management; maintenance operations; and equipment management. They have emphasized upon significance of conducting maintenance audits and benchmarking studies as an essential measure for improving maintenance productivity to achieve a level of world-class maintenance effectiveness and identifying the areas for focussing maintenance improvements initiatives.

Al-Najjar (1996) has emphasized upon the importance of total quality maintenance in achieving and maintaining high OEE by ensuring the availability of improved manufacturing processes, capable of producing quality products without interruption in JIT implementation. He has emphasized on development of an effective maintenance program to ensure availability of machinery and output quality, and presents a new concept of condition based maintenance and total quality maintenance. Najjar describes the extensive use of strategic tools like identification and elimination of quality deviations and failure causes at early stages, and extensive use of data feedback to accomplish continuous improvements and to assure high quality products. He has called for the extensive use of the improvement cycle, or Deming cycle (PDCA) to be adopted as one of the essential forces driving TQM and TPM programs to affect improvement in maintenance function.

Davis (1997) has suggested that the experience of TPM implementation in the UK has shown that the key factors for successful implementations are to approach TPM realistically; developing a practical plan and employing program and project management principles; accept that TPM will take a long time to spread across the organization and change existing maintenance culture; be determined to keep going, put in place, train and develop a network of TPM co-coordinators that will promote and support TPM activities every day; support TPM co-coordinators with time and resources, plus senior level back up; put in place relevant measures of performance and continually monitor and publicize benefits achieved in financial terms.

Fredendall *et al.* (1997) has emphasized that a TPM development program should typically emphasize among other things: the leadership role of top management in launching and implementing TPM; establishment of TPM policies, goals; master plan and communicating these to everyone in the organization; and building a system for training and employee involvement. The commitment of top management in preparing a suitable environment for TPM's introduction and in planning and coordinating for its implementation is considered crucial to TPM's success.

Jonsson (1997) has emphasized on improvement of the maintenance management components in the Swedish manufacturing organizations. He has described five linked components of maintenance management as: strategy, human aspects, support mechanisms, tools and techniques, and organization and advocates for formulating clear maintenance strategies that are linked to manufacturing and corporate strategies.

Hutchins (1998) has advocated for making considerable efforts for recognizing teams and enabling them to display their work for successful TPM implementation.

Bamber *et al.* (1999) has conducted a study aimed at discovering the factors affecting the successful implementation of TPM at a UK manufacturing small to medium-size enterprise (SME). They have outlined a generic model indicating factors affecting the successful implementation of TPM in the UK manufacturing small-to-medium size enterprises (SME) which include alignment to mission, the existing organization, the involvement of people, an implementation plan, knowledge and beliefs, time allocation for implementation, management commitment, the motivation of management and workforce, and measures of performance.

Davis and Willmott (1999) have recommended two significant enablers for successful implementation of TPM initiatives in the manufacturing organizations:

- (1) A structured approach which uses a number of tools and techniques to achieve highly effective plants and production equipment and to measure its effectiveness.
- (2) A philosophy, which is based upon the empowerment and encouragement of factory floor-based personnel from all areas.

Lawrence (1999) has suggested the use of mathematical modelling to bring about the cultural change necessary to make TPM work and suggest the use of linear programming, integer programming, other related OR techniques and measurement of MTTT-MTTR to optimize the maintenance management process and describes how such models might be used to promote the cultural change by making the potential benefits of TPM more tangible and objective to employees. He suggests that mathematical modelling may just be that extra boost that an organization's TPM effort needs to turn an unsuccessful effort into a successful one.

McKone *et al.* (1999) have considered short-term measures for facilitating TPM activities that are typically implemented in a plant. They have suggested autonomous maintenance related activities such as the use of teams, housekeeping, cross training, and operator involvement; and planned maintenance related activities such as disciplined planning of maintenance tasks, information tracking, and schedule compliance for successful implementation of TPM programs.

Prickett (1999) has described the role of designating and using OEE as a measure of TPM effectiveness towards identification of the major causes of losses in manufacturing effectiveness, and allowing the continuous monitoring of the most important factors, which influence system performance. He has emphasized upon the necessity of planned maintenance to preserve the machine conditions, while emphasizing upon the need for development of a wider maintenance management strategy and explains the work program to increase the OEE of machine tools and flexible manufacturing systems (FMS).

Ben-Daya (2000) has described the nature of TPM and RCM processes and the relationship between the two. He has emphasized upon equipment management and

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employee empowerment and involvement as key strategies of TPM implementation program and adds that RCM is central to the development of an effective preventive maintenance management program. He has suggested that RCM offers a sound framework for optimizing the maintenance effort and getting the maximum out of the resources committed to the PM program.

Muthu *et al.* (2001) have claimed that the concepts of TPM fundamentally aim at applying TQM philosophy in maintenance engineering. They emphasize the need of incorporating quality system and its monitoring to enhance maintenance quality. They point out that QS 9000 standard is expected to be a future quality system model in enterprises and describe the design features of maintenance quality system model that has been developed based on QS 9000 standards.

Park and Han (2001) have emphasized upon two important issues that are critical to successful implementation of TPM. First, to implement TPM successfully, companies need to have established their strategy and their basis of competition, and must have undertaken thorough preparatory planning. Second, companies should be aware that the mere application of the operational aspects of TPM, with little regard for the underlying principles, will not ensure the full, long-term benefits of TPM. The long-term benefits of TPM are the result of considerable investment in human resource development and management. Thus TPM practitioners should build a supportive culture and environment with emphasis on human aspects for TPM implementation. Specifically, training for TPM and employee participation in maintenance-related decision making is critical to successful TPM adoption.

Ferrari *et al.* (2002) have suggested that personalization of products, mix variability and short time to market are forcing the manufacturing organizations to adopt the lean manufacturing practices based on flexibility of productive lines, reduction of storage and integration among various organizational functions. This brings to the focus the need for forging the effectiveness of the maintenance function in an organization to be able to contribute to the success of the factory. Ferrari aims to introduce a methodology for a soft and tenable application of the principles of TPM in Italian factories and focuses on TPM links with productive maintenance in order to suggest a method for TPM.

Alsyouf (2006) has developed a balanced scorecard framework to assess the contribution of support functions, such as maintenance, to strategic business objectives. He observed that it is possible to measure and identify the cause-and-effect relationship of using an effective maintenance strategy, and assess its impact on the company's competitive advantages and found that there is potential to ideally improve the company's return on investment (ROI) by 9 per cent. This figure represents a projected US \$8.4 million in lost profits, which are caused by planned inoperative time and overall equipment effectiveness (OEE) elements. Alsyouf asserts that at least 14 per cent of the ROI potential improvements are directly related to the maintenance function as lost profit, which is due to unplanned stoppages and bad quality caused by maintenance-related problems.

Parida and Kumar (2006) have identified various issues and challenges associated with development and implementation of a maintenance performance measurement (MPM) system. The study finds that for successful implementation of MPM all employees should be involved and all relevant issues need to be considered. Furthermore, the research advocates for measuring the total maintenance effectiveness

both internal and external effectiveness should be considered besides traditional OEE used by the organizations, as it only measures the internal effectiveness.

Rodrigues and Hatakeyama (2006) have recommended that success of a TPM program is closely connected to employee management. As it happens in all management process, it is necessary to create indicators for the evaluation of performance indicators of the program. In this context the indicators used to verify and control TPM are productivity, costs, supply, levels and circulation, quality can achieve zero defects, safety, almost total eliminating of violations, and morale, suggestions and participation of all employees in the small group meetings.

The success criteria for effective and efficient TPM implementation must include steps like following an established TPM implementation process, committing management to the TPM Process, integrating TPM with other continuous programs (Lean Manufacturing, Total Quality Management, Six-Sigma, etc.), linking TPM activity directly to corporate business goals and objectives, documenting learning gained during TPM activity, and staying the course because TPM implementation does not always proceed smoothly, patience and determination is required.

Thus organizations need to develop an understanding of the restraining and driving forces, and need to take constructive and proactive initiatives for overcoming and eliminating the limitations caused by the obstacles to successful TPM implementation program for reaping the true potential of TPM. Only steadfast adherence to the TPM vision and well chalked out master plans can effectively lead to success of TPM implementation program. Thus organizations need to accept with the true spirit that, TPM is implemented right the first time, even if it takes a little longer. The organizations must realize that short cuts or unrealistic schedules and unrealistically aggressive plans might result in failure, restarts and loss of motivation to consistently implement TPM over a long period of time. The key is to learn from mistakes and make subsequent efforts better.

### **Contributions of TPM towards improving manufacturing performance**

Manufacturing is considered to be an important element in a firm's endeavour to improve firm performance (Hayes and Wheelwright, 1984; Skinner, 1982). Superior manufacturing performance leads to competitiveness (Leachman *et al.*, 2005). TPM is a highly structured approach, which uses a number of tools and techniques to achieve highly effective plants and machinery. With competition in manufacturing industries rising relentlessly, TPM has proved to be the maintenance improvement philosophy preventing the failure of an organization (Eti *et al.*, 2006). Today, an effective Total Productive Maintenance strategy and programs are needed, which can cope with the dynamic needs and discover the hidden but unused or under utilized resources (human brainpower, man-hours, machine-hours). TPM methodology has the potential to meet the current demands. A well conceived TPM implementation program not only improve the equipment efficiency and effectiveness but also brings appreciable improvements in other areas of the manufacturing enterprise. A number of researchers and practitioners have evaluated the contributions of an effective TPM implementation program towards improving manufacturing performance.

Leblanc (1995) has emphasized upon various initiatives like predicting cost savings from TPM program, integration of cross-functional teams and effective identification root cause of equipment problems, for reaping benefits from TPM implementation. It



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has been reported that careful and efficient planning, preparation are keys to successful organization-wide implementation of TPM. Neely *et al.* (1995) see performance measurement as the process of quantifying action, and more specifically as “the process of quantifying the efficiency and effectiveness of actions”.

Maier *et al.* (1998) have investigated the impact of TPM initiatives on the production system and present the findings about the implementation of TPM and its benefits based on data gained from the research project “World Class Manufacturing”. They have emphasized upon various factors like: subjective measures (program flexibility, delivery speed, on-time delivery, volume flexibility, quality and average unit costs) and objective measures (cost efficiency, quality performance, fast delivery, on-time delivery, inventory turnover and flexibility) for assessing the contributions of TPM initiatives on plant performance. The analysis confirmed the significant impact of TPM implementation on the effectiveness of manufacturing system. They have concluded that TPM is not the only factor determining a plant performance and recommend that there is an emerging need to investigate the interrelations of TPM with other approaches to continuous improvement leading to a better explanation of manufacturing performance achievements.

McKone *et al.* (1999) have proposed a theoretical framework by testing the impact of the contextual issues affecting the maintenance system performance of firms through systematic TPM implementation. The study brings out clearly that TQM and TPM programs are closely related. The study also identifies the critical dimensions of TPM and their impact on manufacturing performance and demonstrates a strong relationship among TPM and the contextual factors. The research provides a better understanding of the relationships among TPM, JIT, TQM and EI for supporting the successful implementation of TPM.

As regards the contributions of TPM on manufacturing performance (MP), Miyake and Enkawa (1999) have studied the application of JIT, TQC and TPM paradigms to improve manufacturing systems performance. They have highlight that TPM has stood out as a vehicle, which has been very conducive to the realization of improvements at shop floor level (from elementary countermeasures to technologically complex projects), involving technical staff, foremen and workers.

Muthu *et al.* (2000) have proposed a model called “strategic maintenance quality engineering” (SMQE) to make the theory of TPM exhaustive and suggest that the scope of TPM could be enlarged and made more powerful by integrating it with the contemporary continuous quality improvement model called “statistical quality management” (SQM). The study reveals that the use of information technology (IT) for benchmarking SMQE would aid in improving strategic maintenance quality more effectively.

Kutucuoglu *et al.* (2001) have stated that equipment is the major contributor to the performance and profitability of manufacturing systems. They have classified the maintenance performance measures into five categories, namely, equipment related performance, task related performance, cost related performance, immediate customer impact related performance, and learning and growth related performance. The study looks at the role of performance measurement systems (PMS) in maintenance, with particular reference to developing a new PMS using the quality function deployment (QFD) technique. The framework substantially contributes to the area of maintenance management by incorporating the key features of a successful PMS, namely goal deployment, cross-functional structure and a balanced view of a system.

McKone *et al.* (2001) have investigated the relationship between TPM and manufacturing performance through structural equation modelling. TPM has a positive and significant relationship with low cost (as measured by higher inventory turns), high levels of quality (as measured by higher levels of conformance to specifications), and strong delivery performance (as measured by higher percentage of on-time deliveries and by faster speeds of delivery). The study derives a positive relationship between TPM and MP. The results show that there is a significant and positive indirect relationship between TPM and MP through JIT practices.

Sangameshwaran and Jagannathan (2002) have reported that the essence of TPM is business process improvement through working teams, cutting across organizational layers. The study reports that TPM has immensely helped Hindustan Lever Limited (HLL), India's largest FMCG company, by changing itself internally to give itself a long term competitive advantage in manufacturing. They further add that TPM is the only business initiative where returns have been eight and 12 times that of investments. It has been reported that TPM costs and benefits for various HLL plants over the three year period included: Silvassa PP Plant – Investment (Rs. 1.50 Crores) and Benefits (Rs. 21 Crores); Chhindwara Plant – Investment (Rs. 0.80 Crores) and Benefits (Rs. 2.40 Crores); Yavatmal Plant – Investment (Rs.0.60 Crores) and Benefits (Rs. 6.0 Crores); Orai Plant – Investment (Rs. 0.45 Crores) and Benefits (Rs. 6.0 Crores); and Rajpura Plant – Investment (Rs. 0.42 Crores) and Benefits (Rs. 6.20 Crores). This clearly demonstrates the true potential of TPM in the typical proactive Indian organization.

Eti *et al.* (2006) have explored the ways in which Nigerian manufacturing industries can implement TPM as a strategy and culture for improving its performance, and suggest self-auditing and benchmarking against world-class industries with similar product lines as desirable prerequisites before TPM implementation. They further report that Nigerian industry need to possess a culture dealing more effectively with rapid changes to inculcate a competitive outlook in their manufacturing environments.

Seth and Tripathi (2005) have investigated the strategic implications of TQM and TPM in an Indian manufacturing set-up. They have examined the relationship between factors influencing the implementation of TQM and TPM initiatives with business performance, for the following three approaches in an Indian context: TQM alone; TPM alone; both TQM and TPM together and have also extracted significant factors for the above three approaches. The research identifies critical significant factors like leadership, process management and strategic planning, equipment management and focus on customer satisfaction, for the effective adaptation of TQM and TPM programs in the Indian manufacturing environment.

Thun (2006) has described the dynamic implications of TPM by working out interrelations between various pillars of TPM to analyze the fundamental structures and identifies the most appropriate strategy for the implementation of TPM considering the interplay of different pillars of this maintenance approach. The research focuses upon analyzing the reasons behind failures of successful TPM implementation and identifies interrelations between the pillars of TPM. The focus of the research conducted is the analysis of fundamental structures and the identification of a strategy for the implementation of TPM.

Ahuja and Khamba (2008a) have investigated the significant contributions of TPM implementation success factors like top management leadership and involvement, traditional maintenance practices and holistic TPM implementation initiatives,

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towards affecting improvements in manufacturing performance in the Indian industry. The inter-relationships between various TPM implementation success factors with the manufacturing performance improvement parameters have been evaluated, to efficiently manage the TPM implementation program to realize organizational objectives of growth and sustainability. The study establishes that focused TPM implementation over a reasonable time period can strategically contribute towards realization of significant manufacturing performance enhancements. The study reveals that the TPM initiatives are far more influential in affecting manufacturing performance improvements, as compared to traditional maintenance practices. This validates the extremely high potential of TPM initiatives in realizing overall organizational competencies.

### **Contributions of TPM towards realizing core competencies**

A core competency is something that a firm can do well and that meets three conditions specified by Prahalad and Hamel (1990): it provides customer benefits, it is hard for competitors to imitate and it can be leveraged widely to many products and markets (Fernandes *et al.*, 2005). A core competency can take various forms, including technical/subject matter know how, a reliable process and close relationships with customers and suppliers (Mascarenhas *et al.*, 1998). It may also include product development or culture such as employee dedication.

In TPM, maintenance is recognized as a valuable resource and a role making business more profitable and competitive. The Japanese were the first to realize the importance of improved equipment maintenance for gaining the competitive market edge. Many world-class manufacturers are presenting dramatic improvements in product quality and operating effectiveness resulting from TPM. TPM links effectively to many other initiatives, including zero defects, lean manufacturing, total quality management (TQM), continuous process improvement, and productivity. TPM methods and tools are being applied in the manufacturing and service organizations as part of continuous improvement efforts to achieve manufacturing competitiveness. The acceptance of TPM by American global leader companies such as Procter and Gamble, Dupont, Eastman Chemical, Ford, AT&T, and Texas Instruments indicates that TPM is fast becoming a tool for competitiveness. TPM is also the most comprehensive maintenance management system because not only does it consider maintenance and equipment design, but it also includes the operational issues of the equipment. This three-prong approach to maintenance makes it a valuable tool for improving productivity.

Competitive pressures and changing production management paradigms have increased the importance of reliable and consistent production equipment (Ahuja and Khamba, 2008b). Productivity is a key strategy for manufacturing companies to stay competitive in a continuously growing global market. Increased availability of production equipment is crucial for competitiveness and to achieve increased availability, a good maintenance strategy is mandatory. The good maintenance program is achieved by having few corrective maintenance tasks performed, while the preventive maintenance is kept to a minimum. Total Productive Maintenance is one possible way of achieving this. Strategic TPM deployment helps to drive maintenance investments to improve equipment productivity and to help companies sustain their competitive advantage. Moreover, it is also important to consider the strategic implications of TPM. TPM plays a significant role in achieving the key manufacturing priorities like cost, quality, delivery,

flexibility, and service. By supporting effective structural and infrastructural decisions, TPM plays an important role in achieving each of the competitive priorities. TPM is considered to be an important management philosophy, which supports the organizations in their efforts to obtain satisfied customers.

It has been confirmed by extensive research that preventive and company-wide integrated maintenance is important for organizations seeking process control and flexibility, and critical for high performance in high-tech organizations. Maintenance contributes to the competitive strength and performance when carried out in the operational stage of a system's life cycle. Proactive and integrated maintenance should also be considered in the early design phase. By integrating maintenance into manufacturing, that is, integrating long-term visions, plans and goals for maintenance, and maintenance activities into manufacturing, seems to be important for overall success of the organizations. Integration of maintenance knowledge into cross-functional design teams, the OEE measure into the overall manufacturing performance measurement system, and maintenance planning into manufacturing planning and control system are other aspects that contribute towards improved manufacturing competencies in the organizations.

The holistic deployment of an effective TPM implementation program can help the organizations to realize core competencies for sustainability efforts to meet global competition. An efficient TPM implementation program in today's highly dynamic and irrepressible competitive global marketplace could render the firms, a consistent enhancement of core competencies like competitive and market related core competencies; strategic core competencies; technological core competencies; organizational core competencies; operational core competencies; and human resource core competencies. Strategic TPM initiatives have helped the struggling organizations across the globe to effectively compete in increasingly turbulent and technologically complex markets. The cases of organizations having successfully implemented performance improvement initiatives based upon TPM are proliferating steadily all over the world. Thus, an effective TPM implementation program has huge potential to deliver improvements in the manufacturing performance and can ensure the survival and growth of an organization by harnessing various core competencies related to organization.

Sharp *et al.* (1997) have discussed the contributions of implementing TPM into the maintenance function by bringing out dramatic transformation in the organization's performance thus demonstrating that TPM is not restricted to manufacturing and service functions. The approach included reorganizing the maintenance department, implementing maintenance tools, techniques and introducing CMMS. The study reveals significant improvements like realizing savings in excess of \$200,000 with opportunity costs in excess of \$1,000,000, manufacturing output enhancement by over 50 per cent which has improved the competitiveness of the company and improved their ability to meet customer demands.

Park and Han (2001) in their study have explored the impact of TPM on the competitiveness of the organization. They observe that TPM initiatives can be effectively integrated with other manufacturing management programs to optimize improved performance, and ultimately competitiveness (Currie and Seddon, 1992; David, 1995; Jostes and Helms, 1994). Typically, it is integrated within an overall initiative that includes Total Quality Management (TQM), Cellular Manufacturing (CM), and Just in Time (McCarthy, 1995). They report that TPM is instrumental in improving OEE of the production facilities and creates capabilities in the organization that lead to a competitive

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advantage in one or more dimensions – cost, quality, delivery, and flexibility. TPM enhances the competitive advantages of improved quality, improved delivery, and increased flexibility without excessive maintenance investments.

Shamsuddin *et al.*, 2005 have emphasized that in order to make a manufacturing system efficient, effective, environmentally sound and fair to the human society, TPM can be combined with ecology oriented manufacturing (EOM) concept and Japanese 5Ss housekeeping rules. The combination of TPM, EOM and 5S appear to be appreciable for obtaining a “total” productive environment. There are enough proofs that companies have promoted their competitiveness through the applications of total productive maintenance and 5S housekeeping functions (Nakajima, 1988; Willmott, 1994).

### **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 (Tripathi, 2005). 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 labour costs (Bohoris *et al.*, 1995).

The literature documents dramatic tangible operational improvements resulting from successful TPM implementation programs. Companies 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 (Suzuki, 1994). 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. The ultimate benefits obtained by implementing TPM are increased profitability and improved productivity. After successful TPM implementation, some cases show that companies achieved 15-30 per cent reduction in maintenance cost, while others revealed a 90 per cent reduction in process defects and 40-50 per cent increase in labour productivity (Nakajima, 1988). Also, some Japanese companies that have applied major TPM programs have seen a general increase in equipment productivity of 40-50 per cent (Willmott, 1994). Chowdhury (1995) reports that organizations with TPM culture have experienced benefits to the extent of 80 per cent reduction in defect rate, 90 per cent reduction in routine breakdowns and 50 per cent increase in production output.

Ahuja and Khamba (2007) 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

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 suggestions: 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 (McKone *et al.*, 1999). 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 (Windle, 1993). Koelsch (1993) has reported that companies that adopt TPM are seeking 50 per cent reductions in breakdown labour 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 labour productivity, and 60 per cent reductions in costs per maintenance unit. Tennessee Eastman expanded its capacity by 8 per cent and estimated savings of \$11 million per year from TPM. Nissan Motor reduced the number of breakdowns by 80 per cent, cut inventory by 55 per cent, reduced defects by 85 per cent, and decreased work hours by 50 per cent within the first three years of TPM implementation (Suzuki, 1992). Nippondenso decreased the percentage of maintenance time spent on breakdowns from 57.6 to 15.3 per cent after two years (Teresko, 1992). Moreover, successful TPM implementation programs have contributed towards realization of intangible benefits such as continuous improvement of workforce skills and knowledge, clarification of the roles and responsibilities for employees, a system for continuously maintaining and controlling equipment and manual work, an enhanced quality of work life, an improved participation rate, and reduced absenteeism caused by stress, and more open communication within and among workplaces (Suzuki, 1994; Carannante, 1995). Greater job satisfaction can translate into higher productivity and quality, and ultimately contributes to lower manufacturing costs (Hamrick, 1994). Companies need to consider the human aspect of TPM in combination with the technical and financial impacts.

### **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

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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.

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

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