EVALUATION OF CONTRIBUTIONS OF TOTAL PRODUCTIVE MAINTENANCE TOWARDS MANUFACTURING PERFORMANCE ENHANCEMENT

A THESIS

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CERTIFICATE

This is to certify that the work which is being presented in this dissertation entitled as **'Evaluation of contributions of Total Productive Maintenance towards Manufacturing Performance Enhancement'** submitted by **Mr. Vivek Sharma** in partial fulfillment of the requirement for the award of degree of **MASTER OF ENGINEERING** in **Production and Industrial Engineering** in the Mechanical Engineering Department, **THAPAR UNIVERSITY, PATIALA** is an authentic record of candidate's own work carried by him under the supervision and guidance of **Mr. Tarun Nanda, Sr. Lecturer, Mechanical Engineering Department, Thapar University, Patiala**. The matter embodied in this seminar report has not been submitted anywhere else for the award of any other degree.

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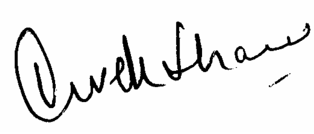

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ABSTRACT

The fierce pace in manufacturing technologies in the recent times accompanied with short product life-cycle, high time-to-market pressure, vulnerable JIT and lean manufacturing strategies have made it critical for manufacturing companies to adapt the proactive corporate and management strategies as well as production philosophies and processes. In the recent times, manufacturing industry has experienced unprecedented changes related to management perspectives, production and process technologies, drastic changes in customer expectations, supplier attitudes, competitive behavior besides demanding quality requirements due to global competition. These changes have greatly influenced the fundamental shift in the way organizations envision, manage and conduct their business. This calls for making drastic changes in the company's business environment to adapt to the rapidly changing market situation for gaining significant strategic competitive advantage.

The world-class competitiveness at every level calls for on-time delivery of the best quality product at the lowest possible cost. The manufacturing organizations over the period of time have tried many proactive strategies to solve the precarious situation faced due to rapid obsolescence of technologies and stiff competition, except the most important one – Machine's health. It has been well established that though health of the machine is a vital factor for achieving reliability in a manufacturing system, but unfortunately it has been highly neglected and oversimplified by the industrial entrepreneurs. The role that effective maintenance plays in cost effective manufacturing has received a greater attention with the concepts like asset management and life cycle costing of the productions assets and units gaining importance in the recent times.

Total Productive Maintenance is the latest plant management tool directed at the maximization of equipment effectiveness that results in increased productivity and reduction in costs in any industrial establishment. Leading Indian industries find TPM as an effective tool in their quest for cost effective manufacturing. The underlying reason is the premium focus of TPM strategy on equipment performance that is the main spring for delivering high yield of productivity, quality, production output, safety and morale. This study looks at both the need for and actual implementation of TPM in the Indian manufacturing industry in the quest to attain world-class competitiveness and sustainability efforts. The need for implementation of TPM in Indian industries has been brought out through the presentation of TPM benefits at a bearing manufacturing company. The various aspects of TPM implementation have also been illustrated with the help of a case study.

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LIST OF ABBREVIATIONS

BDM	Breakdown Maintenance
CBM	Condition based maintenance
CII	Confederation of Indian industries
CM	Corrective maintenance
CMMS	Computerized maintenance management systems
EOQ	Economic order quantity
FBM	Frequency based maintenance
FMEA	Failure mode and effect analysis
JH	Jishu hozen
JIT	Just in time
MIS	Management information systems
MOR	Machine operation ratio
MRP	Material requirement planning
MTBF	Mean time between functional failure
OEE	Overall equipment effectiveness
OR	Operation research
PLCS	Programmable logic controllers
PM	Preventive maintenance
QM	Quality maintenance
RAM	Reliability and maintainability
RCM	Reliability centered maintenance
TBM	Time based maintenance
TPM	Total Productive Maintenance
TQM	Total quality management
VBM	Vibration based maintenance
WIP	Work in progress

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CHAPTER 1
INTRODUCTION

Maintenance has traditionally been considered as a support, non-productive and non-value adding function of a business. Maintenance function has typically been regarded as a necessary evil and an operating expense to be minimized and not treated as an investment in increasing process reliability in many organizations (Patterson et al., 1996). Managing equipment performance has not been a top priority until the recent years in manufacturing enterprises. 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 (Elangovan et al., 2007). Thus, inadequacies of maintenance practices in the past have adversely affected the organizational competitiveness by reducing 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 and unreliable delivery performance (Ashayeri, 2007). 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 (Karuppuswamy et al., 2007).

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). Maintenance has now become a strategic tool to increase competitiveness rather than simply an overhead expense that must be controlled (Waeyenbergh and Pintelon, 2002). The equipment technology and development capabilities have become major factors that demonstrate the strength of an organization and set it apart from others (Braglia et al., 2006; Schuman and Brent, 2005). A world class maintenance department enhances the organization’s ability to provide their product or service (Kutucuoglu et al., 2002; Mishra et al., 2007). The recent competitive trends and ever increasing business pressures have been putting maintenance function under the spotlight as never before (Garg and Deshmukh, 2006). The maintenance processes can be streamlined to eliminate waste and produce breakthrough performance in areas valued by customers (Lewis, 2006). The ever increasing demands on the manufacturing organizations have contributed to complete overhaul of maintenance practices in manufacturing enterprises (Ahuja and Khamba, 2008). The manufacturing sector has globally witnessed drastic changes in the latter part of the 20th century. These changes have left their unmistakable marks on the different facets of the manufacturing organization (Gomes 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 contemporary dynamic environment has become highly challenging and the manufacturing organizations are finding it extremely difficult to manage competition and consumer expectations. The global marketplace has witnessed an increased pressure from customers and competitors for greater value from their purchase whether based on quality, faster delivery and lower cost in manufacturing as well as service sector (Basu, 2001; George, 2002). The recent competitive trends have been triggering the top management of the manufacturing enterprises to look upon the performance of each and every business function including manufacturing or maintenance for achieving competitive advantage (Ben-Daya and Duffuaa, 1995; Pintelon et al., 2006). It has been realized and well accepted by manufacturing organizations that the equipment maintenance and reliability are important strategies that can considerably influence the organization's ability to compete effectively (Madu, 2000). Thus, an effective maintenance programme can make significant contributions towards enhancing production efficiency, plant availability, reliability and organizational profitability (Coetzee, 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 firefighting reactive maintenance approaches (Sharma et al., 2005). 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 dynamic environment (Ahuja et al., 2004).

1.1 Importance of maintenance

Modern industrial societies are characterized by their dependence on technology to produce goods and services. Every business (mining, processing, manufacturing, and service-oriented businesses such as transport, health, utilities, communications, etc.) need equipment to deliver its outputs. Equipment is an asset that is critical for business success in the fiercely competitive global economy. Rapid changes in technology have resulted in improvements to equipment so that the output, productivity and efficiency have increased dramatically. But the equipment is getting more complex and more expensive. Businesses incur heavy losses when their equipment is not in full operational mode. For example, in open cut mining, the loss in revenue resulting from a typical dragline being out of action is $0.5-1.0 million per day. In the case of airline operations, the loss in revenue from a 747 plane being out of action is roughly $0.5million per day. Equipment degrades with age and usage and ultimately becomes non operational.

The rate of degradation depends on many factors. These include the decisions made during the design and manufacturing stages, the operating environment, the usage intensity, the operator skills, etc. The degradation can be controlled through good operating practices and proper preventive maintenance (PM) actions. When a failure occurs, the failed equipment can be restored to an operational state through proper corrective maintenance (CM) actions. Depending on the nature of the failure (which can vary from minor to catastrophic) the cost of rectification can be large and still larger is the cost of any consequential damage. An illustrative example is the failure of the electricity distribution network in New Zealand that resulted in their biggest city, Auckland, being blacked out for several weeks.

The annual cost of maintenance (corrective and predictive) as a fraction of the total operating budget varies across industry sectors. In the mining industry it can be as high as 40-50 per cent (which translates into $0.5 billion per year for a big mining firm) and in the transport industry it can vary from 20-30 per cent. These are the direct costs of actions to keep the equipment in a fully operational state. As mentioned earlier, the indirect costs resulting from delay in delivery, customer dissatisfaction leading to loss of goodwill and customers is much higher. This means that maintenance is an important element of a modern business and must be managed effectively.

1.2 Challenges for maintenance function in contemporary manufacturing scenario

During the last two decades, many organizations have made investments in strategic lean manufacturing tools like Just-in-Time (JIT) and Total Quality Management (TQM) in an effort to enhance organizational capabilities (Cua et al., 2006). The nature of production technologies has changed tremendously because of implementation of advanced manufacturing technologies and Just-in-Time manufacturing. The benefits from these programs have often been limited because of unreliable or inflexible equipment (Tajiri and Gotoch, 1992). Maintenance is responsible for controlling the cost of manpower, material, tools and overhead (Foster and VanTran, 1990; Pintelon and Gelders, 1992). Equipment maintenance represents a significant component of the operating cost in transportation, utilities, mining and manufacturing industries. The quality and reliability of products may also be severely affected by effectiveness of maintenance function. Equipment that is not properly maintained may experience excessive variation and lead to production of out-of-specification products that end up as scrap, material losses and rework. Maintenance effectiveness is readily apparent in the performance of production equipment. The inefficiencies in equipment management have a greater impact on a company's output and profit. Maintenance also impacts the ability of production system to produce products according to the planned schedules.

Maintenance is of ever-increasing importance to industry as technology becomes more sophisticated, spiraling inflation strains capital investment and energy problems adversely affect profits. The success of organizational objectives relies heavily on effectiveness of managing the maintenance function. The maintenance function may also be a source of competitive advantage thereby achieving a sustainable edge over competitors. Effective maintenance extends equipment life, improves equipment availability and retains equipment in appropriate condition. The challenges faced by maintenance function have been briefly discussed below:

Emerging trends of operation strategies: The conventional wisdom embracing the concept of 'economy of scale' is losing followers. An increasing number of organizations have switched to 'lean manufacturing', 'just-in-time production' and 'six-sigma programs'. These trends highlight a shift of emphasis from volume to quick response, elimination of waste and defect prevention. With the elimination of buffers in such demanding environments, breakdowns, speed loss and erratic process yields will create immediate problems for the timely supply of products and services to customers. Obviously, installing the right equipment and facilities, optimizing the maintenance of these assets and effective deployment of manpower to perform the maintenance activities are crucial factors to support these emerging trends of operation strategies.

Toughening societal expectations: There is widespread acceptance of the need to protect the environment and safeguard people's safety and health. In the developed countries, a wide range of regulations has been enacted to control industrial pollution and prevent accidents in the workplace. Scrap, defects, and inefficient use of materials and energy are sources of pollution. They are often the result of operating plant and facilities under less than optimal conditions. Machine breakdowns interrupt production. In chemical production processes, a common cause of pollution is the waste material produced during the start-up period after production interruptions. Apart from producing waste material, catastrophic failures of operating plant and machinery are also the major cause of industrial accidents and health hazards. Keeping facilities in optimal conditions and preventing failures are an effective means to meet the ever more demanding societal challenge of pollution control and accident prevention. These are parts of the core functions of maintenance.

Technological changes: Technology has always been a major driver of change in diverse fields. It has been changing at a breathtaking rate in recent decades, with no signs of slowing down in the foreseeable future. Maintenance is no exception in being under the influence of rapid technological changes. Non-destructive testing, transducers, vibration measurement, thermography, ferrography and spectroscopy make it possible to perform non-intrusive inspection. By applying these technologies, the condition of equipment can be monitored continuously or intermittently while it is in operation. This gave birth to condition based maintenance, an alternative to the classical, time-driven approach of preventive maintenance (Tsang, 1995). Power electronics, programmable logic controllers (PLCs), computer controls, transponders and telecommunications systems are increasingly being introduced to substitute electro-mechanical systems.

They offer the benefits of improved reliability, flexibility, compactness, light weight or low cost. Fly-by-wire technology, utilizing software controlled electronic systems, has become a design standard for the current generation of aircraft. Flexible manufacturing cells and computer-integrated manufacturing systems are gaining acceptance in the manufacturing industry. Contact less smartcards (CSC) are being introduced in public transport services as a convenient means of fare collection. In the electric utility industry, automation systems are being installed to identify and deal with faults in the transmission and distribution network remotely

The deployment of these new technologies is instrumental to enhancing system availability, improving cost effectiveness of operations and delivering better or innovative services to customers. The move presents new challenges to maintenance. New knowledge has to be acquired to specify and design the new systems, taking advantage of these emerging technologies. New capability has to be developed to commission, operate and maintain such new systems. During the phase-in period, interfacing old and new plant and equipment is another challenge to be handled by maintenance.

Changes in the people and organizational systems: The doctrine that focuses primarily on efficiency in industrial management worked well to produce exemplary performance in past eras of stable business environments. Companies were busy producing standard goods and services to satisfy the insatiable demand of their customers, and these companies were protected from the onslaught of outside competition through regulation or imposition of trade barriers in their home market. Product life cycle was long due to slow technological change and tolerance of accommodating customers who would take what was available on the market. On the human dimension, people perceived work merely as a means to earning a living. All these have changed in today's turbulent environment. People at work – the individuals who make things happen in organizations – have undergone significant transformation.

1.3 Evolution of maintenance management

The approach to maintenance has changed dramatically over the last century (Blischke and Murthy, 2000). Up to about 1940, maintenance was considered an unavoidable cost and the only maintenance was CM. Whenever an equipment failure occurred, a specialized maintenance workforce was called on to return the system to operation. Maintenance was neither incorporated into the design of the system, nor was the impact of maintenance on system and business performance duly recognized. The evolution of operations research (OR) from its origin and applications during the Second World War to its subsequent use in industry led to the widespread use of PM. Since the 1950s, OR models for maintenance have appeared at an ever-increasing pace. These can be found in many books (for example, Gertsbakh, 1997; Niebel, 1885) and the many review papers on the topic (McCall, 1965; Pierskalla and Voelker, 1976; Monahan, 1982; Jardine and Buzzacot, 1985; Sherif and Smith, 1986; Thomas, 1986; Gits, 1986; Valdez-Flores and Feldman, 1989; Pintelton and Gelders, 1992; Scarf, 1997; Cho and Parlar, 1991; Dekker et al., 1997). These models deal with the effect of different maintenance policies and optimal selection of the parameters of the policies. The impact of maintenance actions on the business performance is not addressed. In the 1970s, a more integrated approach to maintenance evolved in both the government and private sectors. New costly defence acquisitions by the US government required a life cycle costing approach, with maintenance cost being a significant component. The close linkage between reliability (R) and maintainability (M) was recognized. The term 'R&M' became more widely used in defence-related systems. This concept was also adopted by manufacturers and operators of civilian aircraft through the methodology of reliability centred maintenance (RCM) in the USA. In the RCM approach (Moubray, 1991), maintenance is carried out at the component level and the maintenance effort for a component is a function of the reliability of the component and the consequence of its failure under normal operation. The approach uses failure mode effects analysis (FMEA) and to a large extent is qualitative. At the same time, the Japanese evolved the concept of total productive maintenance (TPM) in the context of manufacturing (Tajiri and Gotoh, 1992). Here, maintenance is viewed in terms of its impact on the manufacturing through its effect on equipment availability, production rate and output quality. Ben-Daya et al. (2000) has presented various aspects on maintenance and summarizes the latest results and the current status. Both RCM and TPM view maintenance in the broader business context and take into account the link between component failures and their impact on the business performance. However, they assume a nominal operating condition and the optimal maintenance strategy is designed for this condition. As such they do not model the load on the equipment and its effect on the degradation process. In real life, the load (causing mechanical, electrical, heat stresses on the components) depends on the production rate and this in turn depends on the demand pattern. For example, in the case of a dragline used in open cut coalmines higher market price for the coal can lead to operating the dragline with a bigger bucket. This might lead to gains in the short run but the increased degradation of the equipment due to the higher load can lead to lower availability and higher maintenance cost in the long run. The operating load and maintenance strategies need to be optimized jointly since the load degrades the equipment and maintenance actions control this degradation. This optimization needs to be done from the overall business perspective. Neither RCM nor TPM deal with this issue. Both RCM and TPM deal with short- to medium-term operational issues (focusing on the equipment or asset) as opposed to the medium- to long-term strategic issues (focusing on the business as a whole). For example, in the case of a business dealing with water distribution and sewerage processing, the asset is the pipe network. The long-term strategies for maintenance are different from the short-term strategies. The short-term strategies need good predictive models to assess the condition of different elements of the network and their residual lives under different maintenance strategies. This requires good understanding of the mechanism of degradation and building models based on this and the field data. In other words, the science aspect becomes dominant. The long-term strategies need to take into account the socio-political , demographic trends and the capital needed.

1.4 Types of maintenance

There are three major maintenance management approaches commonly used in power plants (Kelly, 1989; Davies, 1990; British Standards Institution, 1993; Gits, 1994; Niebel, 1996; Pintelon and Gelders, 1992):

1. Reactive or breakdown maintenance (BDM)
2. Preventive maintenance
3. Periodic maintenance or time-based maintenance (TBM);
4. Predictive or condition-based maintenance (CBM)
5. Corrective maintenance
6. Maintenance prevention
7. Reliability centered maintenance
8. Computerized Maintenance Management system
9. Total productive maintenance (TPM)

Reactive or breakdown maintenance (BDM)

Failure-driven maintenance (FDM), which is also named as run-to-failure maintenance (Moubray, 1997), is a reactive maintenance approach to run the equipment until failure. Under FDM, equipment receives no ongoing health care or only minimal routine maintenance, i.e. lubricating, calibrating and refurbishing. In this only routine servicing is performed on the item until it fails. This can be justified when the impact of failure is inconsequential or the investment in preventive measures exceeds the expected benefits of improved reliability or higher availability

In this type of maintenance, no care is taken for the machine, until equipment fails. Repair is then undertaken. This type of maintenance could be used when the equipment failure does not significantly affect the operation or production or generate any significant loss other than repair cost. However, an important aspect is that the failure of a component from a big machine may be injurious to the operator. Hence breakdown maintenance should be avoided.

In reactive maintenance, which is also known as frequency-based or breakdown maintenance (FBM), repairs are done to bring the equipment back from failure stage to operational stage. It results in fluctuation in production, higher down time and increase in the scrap and rework rate. Thus, the ultimate effect is increase in overall maintenance costs. No action is taken to detect the onset or how to prevent frequent failures, which accounts for usually high maintenance related costs. In a situation where customer demand exceeds supply and profit margins are large, breakdown maintenance (BDM) is a feasible approach. As the main objective of BDM is to keep the process running in order to maximize the availability. Traditionally, this type of strategy was mainly practiced as an action-oriented or fire-fighting approach that solves production problems. However, today stiff global competition and small profit margins had forced the maintenance managers to think and adapt cost effective and reliable maintenance strategies (Pintelon and Gelders, 1992; Sheu and Krajewski, 1994).

Preventive maintenance

It is a daily maintenance (cleaning, inspection, oiling and re-tightening), design to retain the healthy condition of equipment and prevent failure through the prevention of deterioration, periodic inspection or equipment condition diagnosis, to measure deterioration. It is further divided into periodic maintenance and predictive maintenance. Just like human life is extended by preventive medicine, the equipment service life can be prolonged by doing preventive maintenance. The main objective of carrying out preventive maintenance (PM) is to reduce the frequent and sudden sporadic failures by performing repairs, replacement, overhauling, lubrication, cleaning and inspection (Gits, 1992) at a specific predetermined interval of time say weekly, monthly, bi-monthly, half-yearly or annually regardless of the condition of the equipment/component.

Thus, PM reduces the probability of equipment breakdown by proper planning of interval (age-based or calendar time), for carrying out PM tasks (Dekker, 1996). For successful implementation of PM and assessment of the time for action a decision support system is required

Periodic maintenance (Time based maintenance - TBM)

Time-based maintenance (TBM), which is also known as periodic preventive maintenance, assumes that the estimated failure behavior of the equipment, i.e. the mean time between functional failure (MTBF) has statistically or experientially been known during equipment and machinery degrading within normal usage (Gertsbakh, 1977). Time based maintenance consists of periodically inspecting, servicing and cleaning equipment and replacing parts to prevent sudden failure and process problems. E.g. Replacement of coolant or oil every 15 days.

Predictive or condition-based maintenance (CBM)

This is a method in which the service life of important part is predicted based on inspection or diagnosis, in order to use the parts to the limit of their service life. Compared to periodic maintenance, predictive maintenance is condition-based maintenance. It manages trend values, by measuring and analyzing data about deterioration and employs a surveillance system, designed to monitor conditions through an on-line system. E.g. Replacement of coolant or oil, if there is a change in colour. Change in colour indicates the deteriorating condition of the oil. As this is a condition-based maintenance, the oil or coolant is replaced. it aims at carrying out corrective maintenance works when a unit or component has reached a pre-determined condition before failure or breakdown. With the extensive use of CBM, more planned corrective maintenance works can be performed

Predictive or CBM strategy reduces the probability of sudden sporadic failures with the aid of diagnostics and timely intervention. Vibration-based maintenance (VBM) involves periodic (VBMp) and continuous (VBMc) collection and interpretation of data, which is based on deterministic and probabilistic models. Thus, it provides useful information for diagnoses and prognoses. For instance, diagnostic equipments are used to measure the physical conditions such as temperature, vibration, noise, corrosion, etc. about the root cause(s) and failure mechanisms.

Corrective maintenance

This is a strategy, introduced in 1957, in which the concept to prevent equipment failures is further expanded to be applied to improvement of equipment so that equipment failures can be eliminated (improving the reliability) and 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 to improve equipment reliability, maintainability, safety, and design weaknesses (material, shapes). It improves equipment and its components so that preventive maintenance can be carried out reliably. Equipment with design weakness must be redesigned to improve reliability or improving maintainability. This happens at the equipment user level. E.g. Installing a guard, to prevent the burrs falling in the coolant tank.

Maintenance prevention

Introduced in 1960's, this is an activity wherein the equipment are 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 strategically aim at ensuring reliable equipment, easy to care for and user friendly, so that operators can easily manage, adjust and run it (Shirose, 1992). This program indicates the design of new equipment. Weakness of current machines is sufficiently studied (on site information leading to failure prevention, easier maintenance and prevents of defects, safety and ease of manufacturing). The observations and the study made are shared with the equipment manufacturer and necessary changes are made in the design of new machine.

Reliability-centered maintenance (RCM)

It provides a structure for determining the maintenance requirement of any physical asset in its operating context, with the primary objective of preserving system function cost effectively (Moubray, 1997; Smith, 1993). Identification of system functions and functional failures, as well as failure mode and effects analysis, are important elements in RCM. Performing these analyses on assets for the first time is labour intensive and time consuming. It requires the involvement of the operators and the maintainers. There are two reasons for such requirement. First, it draws on the operators' intimate knowledge about the asset concerned. The involvement motivates the operators to use their resourcefulness to develop innovative ways of performing the PM tasks. Second, the collaboration nurtures a team working spirit between operations and maintenance, replacing the adversarial relationship which commonly exists between the two parties. It is also part of the buy-in process – being an active collaborating party of the decision process, operations will be more ready to implement the maintenance tasks they have to perform as determined from the RCM exercise

Moubray (2000) defined RCM as a systematic approach used to optimize preventive and predictive maintenance programs to increase equipment efficiency (uptime, performance and quality) while targeting on minimizing the maintenance cost. In RCM methodology the focus is on maintaining system function rather than restoring equipment to an ideal condition. Earlier RCM methodology was restricted to the airline and nuclear industries. But today it offers tremendous opportunities in areas such as fossil power plants, oil-refineries, and other process industries.

Computerized Maintenance Management System (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, expedite dispatch of breakdown calls and manage the overall maintenance workload. CMMS can be deployed 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). Now a days computers form an essential part of maintenance function. Generally they are used to store the data about the machines, failure history, maintenance schedules and spare parts management. In specialized industries, computers are used in on-line condition monitoring and even to trouble shoot. Specialized software systems are available for limited applications; however, large business houses rely on ERP packages such as SAP as they provide an integrated system that aligns with the rest of the business operations

Total productive maintenance (TPM)

TPM defined by Nakajima (1988) includes a company wide approach to plant, equipment or asset care that involves the active participation of all from top management to workers on the floor to enhance equipment effectiveness by eliminating the six big losses such as downtime losses, set-up and adjustments losses; speed losses; reduced speed; defect losses and reduced yield. In TPM the practice of PM is combined with the concept of total quality through employee involvement (TQEI) (autonomous maintenance groups). Operators maintain their own machines by practicing 5S principles. They compile and interpret maintenance and operating data of their machines that helps to identify signs of deterioration, if any. Routine daily maintenance checks, minor adjustments, lubrication, and minor part changes are the activities performed by the operators. TPM seeks to improve the overall equipment effectiveness (OEE), which is an important indicator, used to measure TPM.

1.5 The Key Objectives of TPM

- Maximize productive capacity by cost effectively maximizing overall workplace effectiveness through the identification and elimination or minimization of all losses - 4Ms: Man (People), Machine (Equipment), Methods (Processes), Materials (including Energy) .
- Minimize overall costs by creating a sense of 'ownership' among all employees so they become committed to caring for their workplace and practicing 'prevention at source'.
- Improve workplace conditions and culture by establishing everyone's involvement in formal continuous improvement through Area Based Teams and Cross-functional Teams so as to unleash the full potential of the employees.
- 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.
- Tapping significant cost reduction opportunity regarding maintenance related expenses.
- Minimizing investments in new technologies and accruing maximized 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 market-place.

1.6 The Key Principles of TPM

The TPM objectives are achieved through all leaders (Site Manager to Team Leader) adopting the Key Principles that underpin TPM to guide their daily decision-making:

Holistic Measurement: We need to look at both the whole picture of equipment performance (OEE = A x R x Q) rather than just one element such as downtime or availability along with the whole picture of workplace performance through the measures of Safety and Environment, Asset Performance, Quality, Customer Satisfaction, Supplier Performance, Human Resource Performance and Financial Performance to ensure a holistic perspective of overall performance

Workplace Ownership: We need to create an environment involving properly led and supported Area Based Teams where all employees have ownership to their work area and equipment, along with the decisions involving them, so as to address 'Lack of Understanding or Desire to Care', which is the root cause of failure and poor performance. Purpose Driven and Learning Area Based Teams create ownership while allowing flexibility through base skills and expertise through mastery skills

Formal Continuous Improvement: We need to create an environment where all employees participate at least 10% of their normal work time in formal improvement activities through both Area Based Teams and Cross-functional Teams so as to unleash the full potential of the employees

1.7 Need for Total Productive Maintenance

Today, a 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 method has the potential to meet the current demands. Nevertheless, it alone cannot solve all the current needs of manufacturing organizations but has the potential to transcend into other major dimensions. TPM's mission is directed toward elimination of equipment and plant maintenance. One of the imperatives for that is to apply a total participatory equipment maintenance technique by K(knowledge)-workers in teams. TPM management brings everyone, from equipment designer to operators, together to work under autonomous and small group environment (Bamber et al., 1999). According to Besterfield et al. (1999) "TPM is keeping the current plant and equipment at its highest productive level through the cooperation of all areas of an organization". TPM is a partnership between maintenance and production organizations to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability, and improve the company's over state of maintenance (Rhyne, 1990).

Proper maintenance is one of them, which protects the firm's investment (Heizer and Render, 2001), prolongs equipment life and can lead to substantial savings in capital investment (Noori and Radford, 1995). In order to make a manufacturing system efficient, effective, and environmentally sound and fair to the human society, TPM can be combined with EOM concept and Japanese 5Ss housekeeping rules. Eco-efficiency in general includes .any measure or initiative undertaken by any production system that results both in reduced environmental impact and increased efficiency and resulting in cost savings for the company concerned (APEC, 1998).

The Japanese advocacy on good management is titled as the 5S rewarding principles. The five keys, popularly known as 5S's, come from the first five letters of the five Japanese terms, namely Seiri, Seiton, Seiso, Seiketsu, and Shitsuke. In English, they are, respectively, organization, neatness, cleaning, standardization, and discipline. The 5Ss, if properly conceived and followed, could be revolutionary toward greater productivity and quality in any manufacturing and service industry. The combination of TPM, EOM and 5S appear to be appreciable for obtaining a 'total' productive environment. There are some proofs that companies could have promoted their competitiveness through the applications of total productive maintenance and 5S housekeeping functions (Nakajima, 1988; Hirano, 1997; Willmott, 1994). Therefore, TPM system should be internally strong to integrate different departments where a set of working principles can be developed for improvement of the organization's performances, the major is equipment improvement.

Production systems have undergone major changes in recent years. Market forces are demanding more emphasis on customization, quick delivery and superb quality (Raouf and Ben-Daya, 1995). In response to these requirements, manufacturers are opting for using more high-tech equipment as well as adopting non-traditional production management techniques such as just-in-time (JIT) production and material requirements planning (MRP) that focus on minimizing set-up time and reducing inventory level. The success of these efforts relies on maintenance to optimize equipment capability and availability. The traditional approach to maintenance is no longer adequate as maintenance costs in such situations are as high as 15 to 40 per cent of total production costs (Wireman, 1990).

TPM, which is built on the preventive maintenance concept imported from the USA, was initiated in Japan in 1969 (Hall, 1990). It is a people-oriented approach that has been proved to be effective for optimizing equipment effectiveness and eliminating breakdowns. It mobilizes the machine operators to play an active role in maintenance work by cultivating in these front-line workers a sense of ownership of the facilities they operate (Campbell, 1995), and enlarging their job responsibilities to include routine inspection, cleaning, lubrication and minor repair of their machines. Traditionally, these duties fall outside the responsibilities of the machine operator.

Thus, TPM involves a restructuring of work relating to equipment maintenance. Being relieved of such routine tasks, the expertise in the maintenance unit can now be deployed to focus on more specialized activities such as major repairs, overhauls, tracking and improvement of equipment performance, and replacement or acquisition of physical assets. Instead of having to continuously fire-fight and attend to numerous minor chores, it can now devote its resources to address strategic issues such as formulation of maintenance strategies, establishment of maintenance management information systems, tracking and introduction of new maintenance technologies, training and development of production and maintenance workers.

Total employee involvement, autonomous maintenance by operators, small group activities to improve equipment reliability, maintainability and productivity, and continuous improvement, or kaizen are the principles embraced by TPM. The extent to which these principles are applied in the TPM programmes of selected manufacturing organizations in the USA with a high quality reputation was studied by Chen (1994). The documented success stories of TPM implementation outside Japan happened almost exclusively in the West (Dunn, 1992; Maggard and Rhyne, 1992; Sanderson et al., 1993; Patterson et al., 1996). The benefits achieved through TPM as reported in these success cases include improved equipment availability, less emergency work and unplanned downtime, improved productivity of TPM tasks entrusted to operators, reduced work-in-process, faster response to customers, improved product quality, more team working and empowerment in the workforce.

CHAPTER 2
LITERATURE REVIEW ON TPM

Total Productive Maintenance is a unique Japanese philosophy, which has been developed based on 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. TPM 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. TPM initiative is targeted to enhance competitiveness of the enterprises and encompasses a powerful structured approach to change the mind-set of employees thereby making a visible change in work culture of the organizations (Heston, 2006). TPM seeks to engage all levels and functions in the organizations to maximize overall effectiveness of production facilities. Willmott (1994) portraits TPM as a relatively new and practical application of Total Quality Management (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 an important world class manufacturing programme introduced during the quality revolution. TPM is a highly influential technique that is in the core of 'operations management' and deserves immediate attention by organizations across the globe (Voss, 2005). TPM supports the other strategies most often associated with World Class Manufacturing: Just-in-Time (JIT) manufacturing, TQM and Employee Involvement (El) (Ollila and Malmipuro, 1999; Cua et al., 2001). While JIT and TQM programmes have been around for a while, the manufacturing organizations, of late, have been putting in enough confidence upon the latest strategic quality maintenance tool as TPM. Similar to TQM, TPM is focused on improving all the big picture indicators of manufacturing success (Marcus, 2004). TPM is considered to be an effective strategic improvement initiative for improving quality in maintenance engineering activities (Pramod et al., 2007). TPM addresses entire production system over the entire life cycle and builds a concrete, shop floor-based mechanism to prevent various losses and wastes (McCarthy, 2004; Sharma et al., 2006).

TPM has been depicted as a manufacturing strategy comprising of the following steps (Nakajima, 1989):

1. maximizing equipment effectiveness through optimization of equipment availability, performance, efficiency and product quality
2. establishing a preventive maintenance strategy for the entire life cycle of equipment
3. covering all departments such as planning, user and maintenance departments
4. involving all staff members from top management to shop-floor workers
5. promoting improved maintenance through small-group autonomous activities

TPM is a highly structured approach, and careful and efficient planning and preparation are keys to successful company-wide implementation of TPM. TPM embraces a series of methods that ensures every piece of equipment in a production process is always able to perform its required task. TPM has been widely recognized as a strategic weapon for improving manufacturing performance by enhancing the effectiveness of production facilities (Dossenbach, 2006; Dwyer, 1999). TPM initiatives in production help in streamlining manufacturing and other business functions, and garnering sustained profits (Ahuja and Khamba, 2007). TPM initiatives are targeted to enhance competitiveness of organizations and encompass a powerful structured approach to change the mindset of employees, thereby making a visible change in the work culture of an organization (Heston, 2006). TPM also links together all other maintenance and reliability programmes together for a new business strategy that focuses on results and changes the work culture along the way. Leblanc (1995) emphasizes upon various success factors, initiatives like predicting cost savings from TPM programme, integration of cross-functional teams and effective identification of root cause of equipment problems, for reaping benefits from TPM implementation. 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 areas of an organization. TPM endeavors to increase efficiency by rooting out losses that sap productive efficiency (Sarkar, 2007). TPM is a partnership between maintenance and production function organizations to improve product quality, reduce waste, reduce manufacturing cost, increase equipment availability and improve the company's state of maintenance. 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). Its purpose is to eliminate various minor and major production losses and wastes associated with the production systems, by affecting continuous and systematic evaluations of production system thereby affecting significant improvements in production facilities (Witt, 2006). The goal of TPM is to continually maintain, improve and maximize the condition and effectiveness of equipment through complete involvement of every employee, from top management to shop floor workers (Ireland and Dale, 2006). An effective TPM programme can facilitate enhanced organizational capabilities across a variety of dimensions (Wang, 2006). TPM implementation in an organization can ensure higher productivity, better quality, fewer breakdowns, lower costs, reliable deliveries, motivating working environments, enhanced safety and improved morale of the employees. The ultimate benefits that can be obtained by implementing TPM are enhanced productivity and profitability of the organization. TPM implementation programme provides for a philosophy based upon the empowerment and encouragement of personnel from all areas in the organization (Davis and Willmott, 1999). TPM is a relatively new and practical application of TQM and 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 diagnostics and equipment improvement projects. TPM is a people-oriented concept that starts by fully exploiting and harnessing the human intellectual capabilities which are normally hidden and unexploited in most organizations. The core TPM initiatives can be classified into eight TPM pillars or activities for accomplishing the manufacturing performance improvements including Autonomous Maintenance; Focused Maintenance; Planned Maintenance; Quality Maintenance; Education and Training; Safety, Health and Environment; Office TPM and Development Management (Ireland and Dale, 2001; Rodrigues and Hatakeyama, 2006).

TPM employs Overall Equipment Effectiveness (OEE) as a quantitative metric for measuring the performance of a productive system (Jeong and Phillips, 2001). 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; Gregory,2006).

TPM has the standards of 90% availability, 95% performance efficiency and 99% rate of quality parts (Levitt, 1996). An overall 85% benchmark OEE is considered as world class performance (Blanchard, 1997; McKone et al., 1999). OEE can be used as an indicator of the reliability of the production system. Another strategic outcome of TPM implementations is reduced occurrence of unexpected machine breakdowns that disrupt production and lead to losses which can exceed millions of dollars annually (Gosavi, 2006).Moreover, TPM implementation also helps to foster motivation in the workforce, through adequate empowerment, training and felicitations, thereby enhancing the employee participation towards realization of organizational goals and objectives. Ideally, TPM provides a framework for addressing the organizational objectives.

The other benefits include favorable changes in the attitude of the operators, achieving goals by working in teams, sharing knowledge and experience and workers getting a feeling of owning the production facilities (Ogaji et al., 2006). Indian manufacturing and process organizations look upon state-of-the-art proactive TPM strategies for improving equipment performance for delivering high yield of productivity, quality, production output, safety and morale. The case study of TPM implementation in Indian manufacturing industry has been brought out through the presentation of TPM achievements and benefits at the manufacturing division. The approach has been directed towards justification of TPM implementation for its support to competitive manufacturing in the context of Indian manufacturing industries.

2.1 Overall equipment effectiveness (OEE) as a metric for evaluating the progress of TPM

Total productive maintenance (TPM) is a people-intensive, preventive maintenance system for maximizing equipment effectiveness and which involves all departments and functions in the organization. The concept of TPM was originally suggested by Nakajima (1988) who proposed overall equipment effectiveness (OEE) as a metric for evaluating the progress of TPM, which is interpreted as the multiplication of availability, performance and quality.

Based on his observations in Japan, Nakajima (1988) suggested the following six big time losses:

(1) Equipment failure

(2) Setup and adjustment

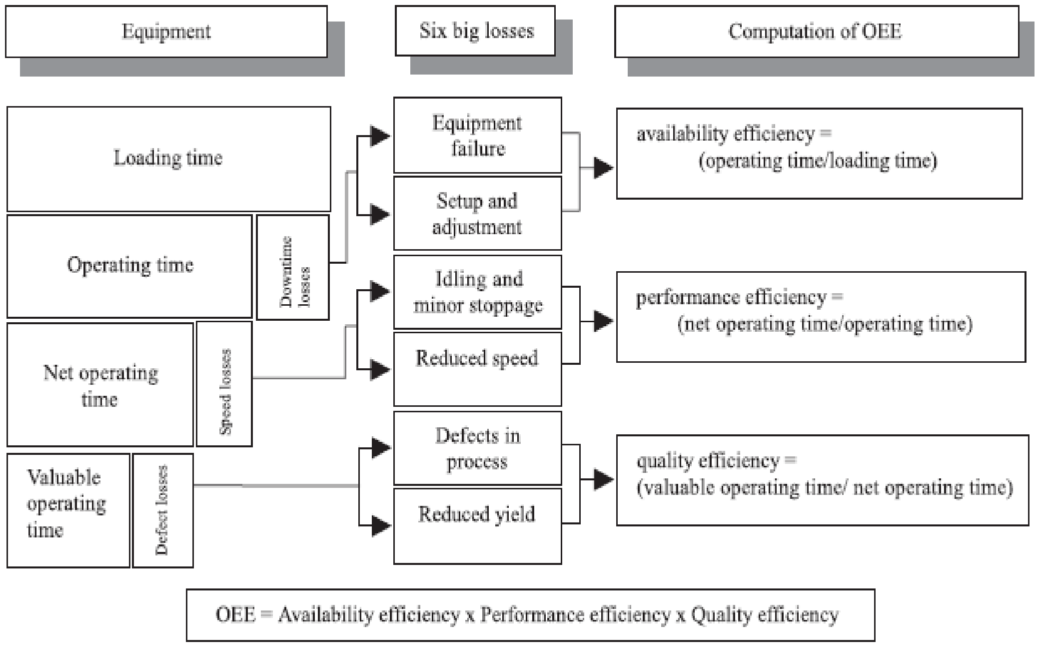
(3) Idling and minor stoppages

(4) Reduced speed

(5) Defects in process and

(6) Reduced yield.

According to Nakajima, (1) equipment failure and (2) setup and adjustment were categorized as downtime time loss, reducing availability; (3) idling and minor stoppage and (4) reduced speed were categorized as speed loss, thus reducing performance. Finally, (5) defects in process and (6) reduced yields were considered as defect loss generated from low quality. The procedure for computing OEE using six basic losses is shown in Figure 2.1.1.



Source: Nakajima (1988)

Figure 2.1.1 Computation of OEE with six major losses

2.1.1 Definition of sixteen major losses:

A	**Seven major losses that impede overall equipment efficiency**	
1	Failure losses (Breakdown)	Losses due to failures. Types of failures include sporadic function-stopping failures, and function-reduction failures in which the function of the equipment drops below normal levels.
2	Set up and adjustment losses	Stoppage losses that accompany set-up changeovers
3	Cutting blade change losses	Stoppage losses caused by changing the cutting blade due to breakage, or caused by changing the cutting blade when the service life of the grinding stone, cutter or bite has been reached.
4	Start-up losses	When starting production, the losses that arise until equipment start-up, running-in and production processing conditions stabilize.
5	Minor stoppage and idling losses	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 the work and resetting).
6	Speed losses	Losses due to actual operating speed falling below the designed speed of the equipment
7	Defect & rework loss	Defect and rework losses are defined as volume losses due to defects and rework (disposal defects) and time losses to repair defective products to turn them into excellent products
B	**Losses that impede equipment loading time**	
8	Shutdown (SD) losses	Losses that arise from planned equipment stoppages at the production planning level in order to perform periodic inspection and statutory inspection
C	**Five Major losses that impede workers efficiency**	
9	Management losses	Waiting losses that are caused by management, such as waiting for materials, waiting for a dolly, waiting for tools, waiting for instructions etc.
10	Motion losses	Losses due to violation of motion economy, losses that occur as a result of skill differences, and walking losses attributable to an inefficient layout.
11	Line organization losses	These are the waiting losses involving multi-process and multi-stand operators & line-balance losses in conveyor work
12	Distribution losses	Losses occurring due to inability to automate for example automated loading and unloading leading to manpower reduction not implemented
13	Measurement and adjustment losses	Work losses from frequent measurement and adjustment in order to prevent the occurrence and outflow of quality defects.
D	**Three major losses that impede efficient use of production subsidiary resources**	
14	Energy losses	Losses due to ineffective utilization of input energy (electric, gas, fuel oil, etc) in processing.
15	Die, jig and tool losses	Financial losses (expenses incurred in production, regarding renitriding, etc.) which occur with production or repairs of dies, jigs and tolls due to aging beyond services life or breakage
16	Yield losses	Material losses due to differences in the weight of the input materials and the weight of the quality products

Table 2.1.1 Definition of sixteen major losses

Chronic and sporadic disturbances in the manufacturing process result in different kinds of waste or losses. These can be defined as activities which absorb resources, but create no value. The objective of OEE is to identify these losses. It is a bottom-up approach where an integrated workforce strives to achieve overall equipment effectiveness by eliminating the six big losses (Nakajima, 1988):

Downtime losses

(1) Breakdown losses categorized as time losses when productivity is reduced, and quantity losses caused by defective products.

(2) Set-up and adjustment losses result from downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirements of another item.

Speed losses

(3) Idling and minor stoppage losses occur when production is interrupted by a temporary malfunction or when a machine is idling.

(4) Reduced speed losses refer to the difference between equipment design speed and actual operating speed.

Quality losses

(5) Quality defects and rework are losses in quality caused by malfunctioning production equipment.

(6) Start-up losses are yield losses that occur during the early stages of production, from machine start-up to stabilization.

The six big losses are measured in terms of overall equipment effectiveness (OEE), which is a function of availability (A), performance rate (P) and quality rate (Q). The exact definition of OEE differs between applications and authors.

Nakajima (1988) was the original author of OEE and De Groote (1995) is one of several later authors. The availability measures the total time that the system is not operating because of breakdown, set-up and adjustment, and other stoppages. It indicates the ratio of actual operating time to the planned time available. Planned production time (or loading time) is separated from theoretical production time and measures unplanned downtime in the equipment, i.e. by this definition unavailability would not include time for preventive maintenance. This definition gives rise to planning of preventive activities, such as preventive maintenance, but it might lead to too much maintenance of the equipment and too long set-up times. If planned downtime is included in the production time, the availability would be significantly lower, but the true availability would be shown. That would create motives for decreasing the planned downtime, e.g. through more efficient tools for set-up and more efficient planned maintenance.

The performance rate measures the ratio of actual operating speed of the equipment (i.e. the ideal speed minus speed losses, minor stoppages and idling) and the ideal speed (based on the equipment capacity as initially designed).

Nakajima (1988) measures a fixed amount of output, and in his definition (P) indicates the actual deviation in time from ideal cycle time. De Groote (1995), on the other hand, focuses on a fixed time and calculates the deviation in production from planned. Both definitions measure the actual amount of production, but in somewhat different ways.

The quality rate only takes into consideration the quality losses (number of items rejected due to quality defects) that happen close to the equipment, not the quality losses that appear downstream. This is a very introspective approach.

A wider definition of (Q) would be interesting, but would complicate the calculations and interpretations. It should be according to which process is to blame, and this is not always easy to identify.

	Nakajima (1988)	De Groote (1995)
Availability (A)	$\frac{\text{Loading time} - \text{downtime}}{\text{Loading time}}$	$\frac{\text{Planned production time} - \text{unplanned downtime}}{\text{Planned production time}}$
Performance (P)	$\frac{\text{Ideal cycle time} \times \text{output}}{\text{Operating time}}$	$\frac{\text{Actual amount of production}}{\text{Planned amount of production}}$
Quality (Q)	$\frac{\text{Input} - \text{volume of quality defects}}{\text{Input}}$	$\frac{\text{Actual amount of production} - \text{non-accepted amount}}{\text{Actual amount}}$
OEE	(A) × (P) × (Q)	(A) × (P) × (Q)

Figure 2.1.3 Comparison of results of OEE

Owing to different definitions of OEE and other varying circumstances between companies, it is difficult to identify optimum OEE figures and to compare OEE between firms or shops. Some authors have tried to do it though; e.g. Nakajima (Raouf, 1994) asserted that under ideal conditions firms should have A > 0.90, P > 0.95 and Q > 0.99. These figures would result in an OEE > 0.84 for world-class firms and Nakajima considers this figure to be a good benchmark for a typical manufacturing capability. Kotze (1993), on the other hand, argues that an OEE less than 0.50 is more realistic. This figure corresponds to the summary of different OEE measurements presented by Ericsson (1997), where OEE varies between 0.30 and 0.80. These disparate figures indicate the difficulties of comparing OEE between processes. The benefits arising from TPM can be classified in six categories including Productivity (P), Quality (Q), Cost (C), Delivery (D), Safety (S) and Morale (M) (Nakajima, 1988).

Both nonscheduled time and scheduled maintenance time are included to avoid overestimation of OEE. Scheduled maintenance time seems to have trade-off relation with unscheduled maintenance time. Hence, increasing scheduled maintenance time to a certain extent decreases the unscheduled maintenance time. In general, the data collection for unscheduled maintenance time requires considerable time and cost.

As the product life cycle shortens, the time required R&D has a tendency to increase. Because of the high cost in purchasing the dedicated equipment for R&D and engineering usage, most companies use the same equipment for production, research and engineering. Hence, these times should be considered in OEE. Mileham et al. (1997) reported that the effect of setup and adjustment time on OEE increases significantly in multi-product manufacturing environments.

However, too rigid emphasis on OEE might unduly influence a business toward mass manufacturing. Hence, a proper compromise is necessary between OEE and setup and adjustment.

Suehiro (1992) has shown that idle and minor stoppage time is 20-30 percent of OEE in most automated lines, and Leachman (1995) observed that both WIP starvation time and idle time without operator were the most significant components of the idle and minor stoppage. The concepts for speed loss and quality loss correspond to the speed loss and defect loss, respectively, in Nakajima's concept.

OEE attempts to separate direct time losses from the relative time loss by classifying all time losses into three categories: total time loss, speed loss, and quality loss. All time losses corresponding to items nonscheduled time through idle time without operator are categorized as the total time loss because these are the direct production time losses which are used to compute the time efficiency. The procedure for computing OEE is shown in Figure 2.1.2 below

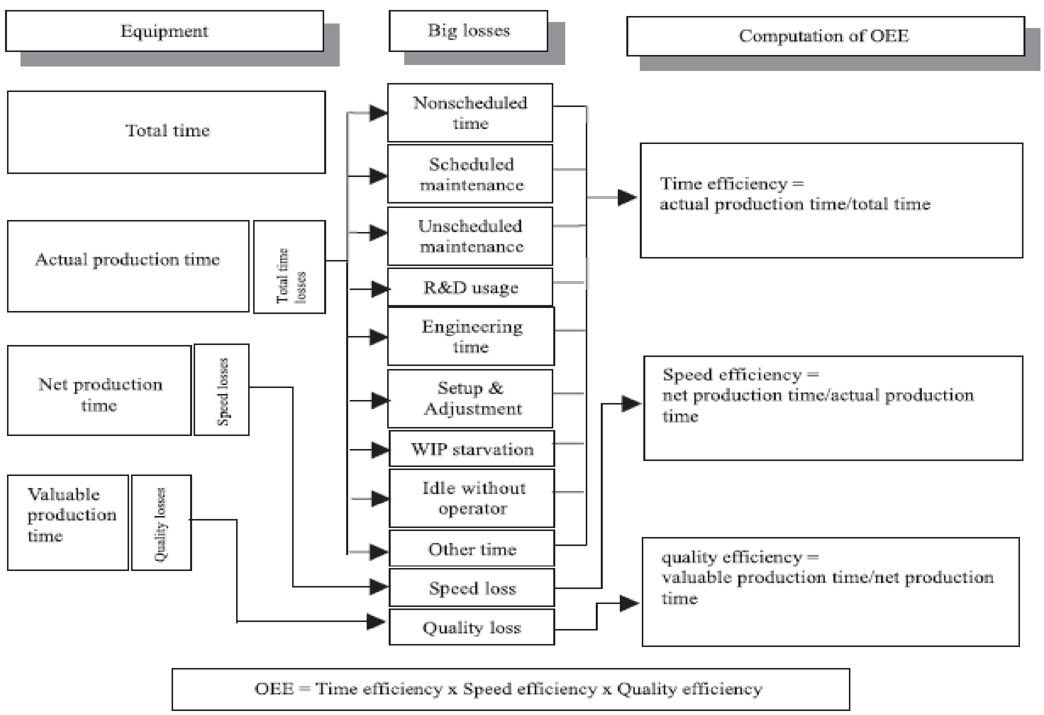


Figure 2.1.2 Computation of OEE with eight production losses

OEE is computed by multiplying time efficiency, speed efficiency and quality efficiency. The production facilities related losses can be roughly [(Tajiri and Gotoh (1992), Ljungberg (1997) and Nord et al. (1997)] divided into the two categories, chronic and sporadic, depending on how often they occur. Chronic disturbances are usually small, hidden and complicated because they are the result of several concurrent causes. Sporadic disturbances are more obvious since they occur quickly and as large deviations from the normal state. They occur irregularly and their dramatic effects are often considered to lead to serious problems, but instead there are chronic disturbances that result in the low utilization of equipment and large costs because they occur repeatedly (Nord et al., 1997). Chronic disturbances are more difficult to identify since they can be seen as the normal state. Identification of chronic disturbances is only possible through comparison of performance with the theoretical capacity of the equipment

2.2 Pillars of TPM

TPM seeks to maximize equipment effectiveness throughout the lifetime of equipment. It strives to maintain equipment in optimum condition in order to prevent unexpected breakdowns, speed losses and quality defects occurring from process activities. There are three ultimate goals of TPM: zero defects, zero accident and zero breakdowns. TPM has been envisioned as a comprehensive manufacturing strategy to improve equipment productivity. TPM implementation requires a long-term commitment to achieve the benefits of improved OEE through training, management support and teamwork. 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 (Sangameshwran and Jagannathan, 2002a). TPM paves way for excellent planning, organizing, monitoring and controlling practices through its unique eight pillar methodology involving autonomous maintenance; focused improvement; planned maintenance; quality maintenance; education and training; safety, health and environment; office TPM and development management (Ireland and Dale, 2001; Rodrigues and Hatakeyama, 2006). Figure – 2.2.1 shows maintenance and organizational improvement initiatives associated with the respective TPM pillars. TPM initiatives as suggested 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 setup and downtimes.

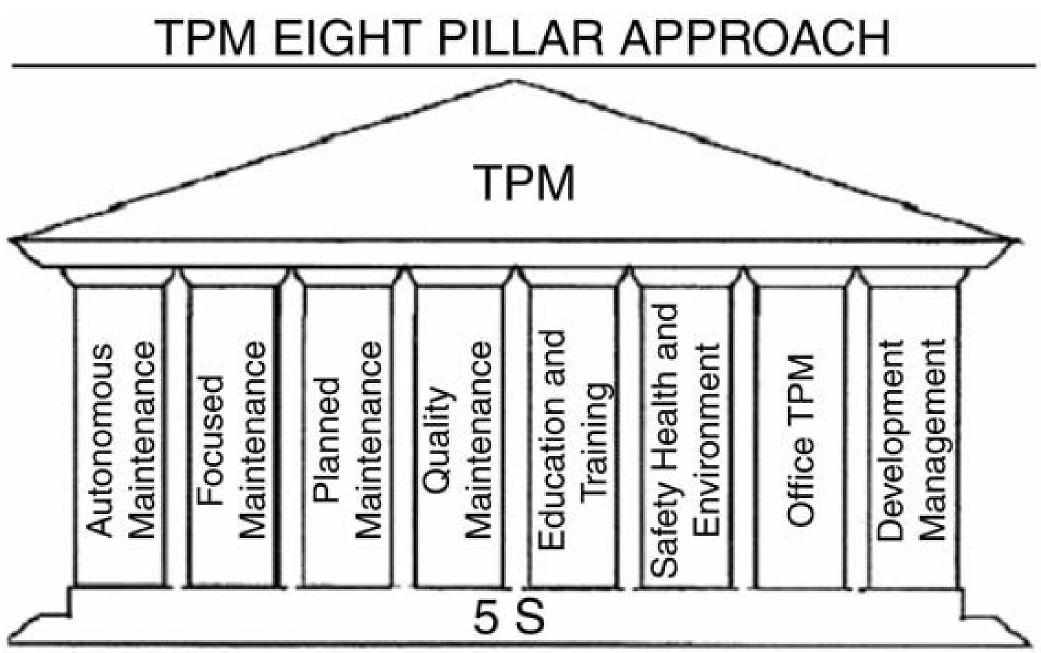


Figure 2.2.1 Pillars of TPM

2.2.1 PILLAR 0 - 5S

TPM starts with 5S. It is a systematic process of housekeeping to achieve a serene environment in the work place involving the employees with a commitment to sincerely implement and practice house keeping. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. Making problems visible is the first step of improvement. 5s is a foundation program before the implementation of TPM, hence in Figure 2.1.1, 5s has been positioned in the base. If this 5S is not taken up seriously, then it leads to 5D. They are Delays, Defects, Dissatisfied customers, declining profits and Demoralized employees. Following are the pillars of 5S

Japanese Term	**English Translation**	**Equivalent 'S' term**
Seiri	Organization	Sort
Seiton	Tidiness	Systematize
Seiso	Cleaning	Sweep
Seiketsu	Standardization	Standardize
Shitsuke	Discipline	Self - Discipline

Table 2.2.1 Japanese definition of 5S

SEIRI - Sort out

This means sorting and organizing the items as critical, important, frequently used items, useless, or items that are not need as of now. Unwanted items can be salvaged. Critical items should be kept for use nearby and items that are not be used in near future, should be stored in some place. For this step, the worth of the item should be decided based on utility and not cost. As a result of this step, the search time is reduced.

Priority	**Frequency of Use**	**How to use**
Low	Less than once per year, Once per month	Throw away, Store away from the workplace
Average	At least 2/6 months, Once per month, Once per week	Store together but offline
High	Once Per Day	Locate at the workplace

Table 2.2.2 Prioritization of items

SEITON - Organize:

The concept here is that 'Each items has a place, and only one place'. The items should be placed back after usage at the same place. To identify items easily, name plates and coloured tags has to be used. Vertical racks can be used for this purpose, and heavy items occupy the bottom position in the racks.

SEISO - Shine the workplace

This involves cleaning the work place free of burrs, grease, oil, waste, scrap etc. No loosely hanging wires or oil leakage from machines.

SEIKETSU - Standardization

Employees have to discuss together and decide on standards for keeping the work place / Machines / pathways neat and clean. These standards are implemented for whole organization and are tested / inspected randomly.

SHITSUKE - Self discipline

Considering 5S as a way of life and bring about self-discipline among the employees of the organization. This includes wearing badges, following work procedures, punctuality, dedication to the organization etc.

This 5S implementation has to be carried out in phased manner. First the current situation of the workplace has to be studied by conducting a 5S audit. This audit uses check sheets to evaluate the current situation. This check sheet consists of various parameters to be rated say on a 5-point basis for each 'S'.

The ratings give the current situation. The each of the above-mentioned 5S is implemented and audit is conducted at regular intervals to monitor the progress and evaluate the success of implementation. After the completion of implementation of 5S random audits could be conducted using these check sheets to ensure that it is observed in true spirits by every one in the work place. A sample check sheet is shown below. The check sheet shown below takes a general industry into consideration. It may vary from even from one plant to another, and more exhaustive.

The 5S model lists prerequisites for any improvement program. As waste is potential gain, so eliminating waste is a gain. The 5S philosophy focuses on effective work place organization, simplification of the work environment, and reduction of waste while improving quality and safety. The letters in the five S model stand for the five first letters of the following Japanese words (Willmott, 1994).

The 5S model has been diagrammatically represented in Figure 2.2.2 below on next page

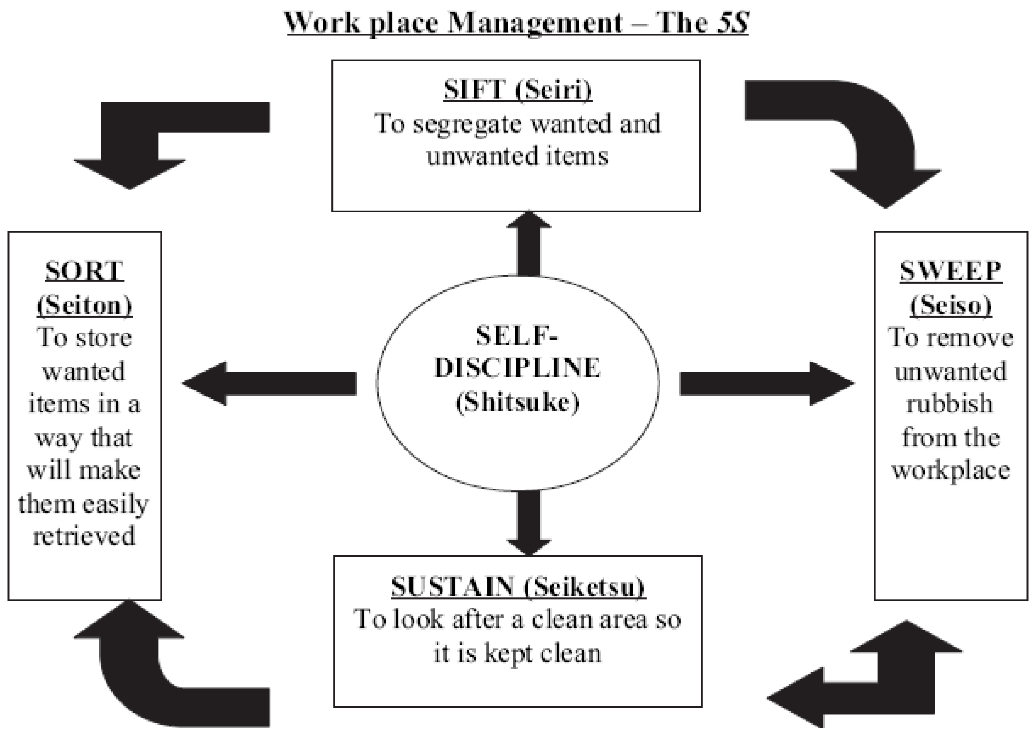


Figure 2.2.2 The principle of 5S

2.2.2 PILLAR 1- JISHU HOZEN (Autonomous maintenance):

Jishu Hozen, which means autonomous or self-maintenance, promotes development of production operators to be able to take care of small maintenance tasks, such as cleaning, inspecting, and lubricating their equipment, thus freeing the maintenance associates to spend time on more value-added activities and technical repairs. The operators are responsible for upkeep of their equipment to prevent it from deteriorating. Jishu Hozen (JH) has been shown to reduce oil consumption by 50% and process time by 50%. The goals of Jishu Hozen include

- Uninterrupted operation of equipment
- Flexible operators who can operate and maintain other equipment
- Elimination of defects at the source through active employee participation
- Stepwise implementation of JH activities

The effects of Autonomous Maintenance include:

- Equipment condition is known at all times.
- Unexpected breakdowns are minimized.
- Corrosion is prevented, wear is delayed, and machine life is extended.
- Judgment of machine capability is improved.
- Parts costs are reduced.
- Machine operation ratio is improved.

Through acutnomous maintenance initiatives, production operators are expected to perform the TPM Activities of Cleaning, Lubrication, and Inspection on a Daily basis.

Cleaning

Clean machines are easier to operate, inspect, and maintain. When the machine is dirty and corroded problems cannot be seen. Sixty percent of factory automation maintenance troubleshooting involves problems that could have been addressed with general preventive maintenance. Examples of causes of problems include debris, contaminants, bad connections, loose terminations, intermittent wire, dirty contacts, clogged filters, bad gaskets, low fluid levels, etc.

The following steps outline the initial cleanup of machines:

1. Arrange all items needed for cleaning.
2. Clean equipment completely (with help from Maintenance, if necessary).
3. Remove dirt, dust, stains, oils, and grease.
4. Take care of any oil leaks, loose wires, loose nuts or bolts and worn parts.

After the initial cleanup of machines:

1. Note inaccessible machine areas and sources of contamination.
2. Categorize and tag problem areas. (Use white tags to note problems that operators can solve; red tags note the maintenance department is needed.)
3. Transfer tag contents to a database for a record.

Inspection

Inspect the conditions of each part of equipment using the human senses of sight, hearing, smell, and touch to detect signs of equipment failure. Symptoms of potential problems can include unusual vibrations, noises, abnormal smells, abnormal component heating, or unusual sights, such as smoke, metal chips, or fluid leakage.

By identifying potential problems with inspections, we can plan and implement repair or replacement before a breakdown or defect occurs. Inspection can be aided through the use of stickers affixed to the equipment to show which sense is to be used at which location

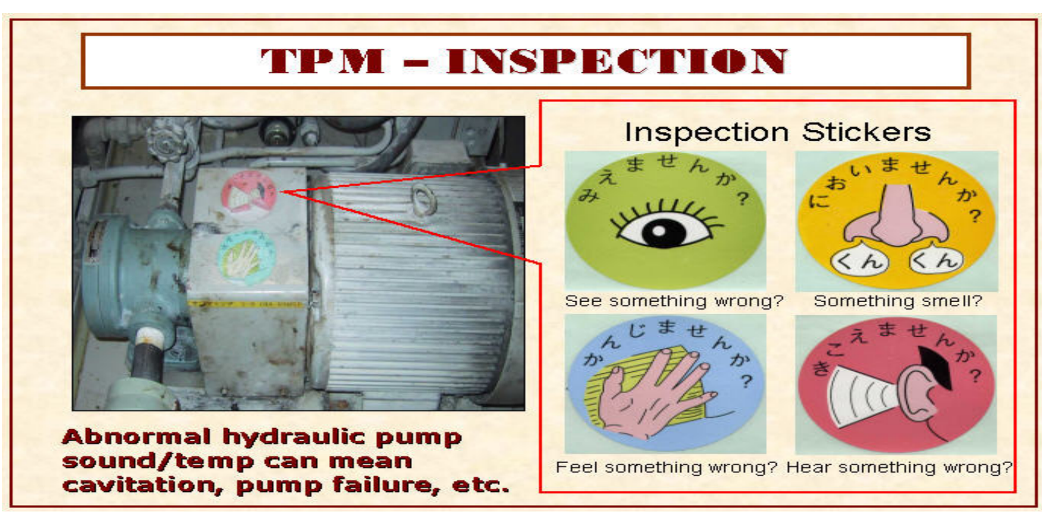


Fig 2.2.3 TPM inspection

Inspection Findings

Address any problems found during inspections with countermeasures.

1. If many screws must be unscrewed to open a cover plate door, use a hinged door instead.
2. Instead of opening a machine inspection door, use a see-through acrylic sheet.
3. Modify machine parts to prevent buildup of chips, dirt, and dust.

Lubrication

Prime movers transfer power so the equipment can do work. This involves a number of moving components, e.g., bearings, gears, shafts, spindles, sprockets, chains, levers, and slides. Without proper lubrication, ALL of these components WILL FAIL.

Machinery must be properly lubricated to reduce surface wear, prevent corrosion, cool moving parts, dampen shock, and seal out contaminants. Proper lubrication involves using the proper type of lubricant in the proper amount at the proper time. Too much lubricant can cause problems including overheating the components; collecting dust, dirt, and debris; and causing slip hazards, etc.

The Lubrication Instruction found in each Denso Machine Operation Manual lists the equipment component to be lubricated, the proper type of lubricant, the interval (how often to lubricate), and the proper amount of lubricant to use. Each machine lubrication location is color coded to match the container used to dispense the lubricant. The storage container is color coded to match the dispenser. Equipment may also have color-coded lubrication labels.

Fig 2.2.4 Color-Coded Lubrication Container Station

Minor Repairs

Production Operators should perform minor repairs and adjustments as training and approval by supervision allows. Minor repairs and adjustments may include:

1. Tightening loose fasteners
2. Replacing consumable parts
3. Tightening loose connections
4. Performing precision checks
5. Adjusting sensors, etc.

Production Data

Part of the Production Operator's job is to record production information such as:

1. Daily Run Sheets
2. In-Progress Rejects Chart
3. Machine Operation Ratio (MOR) Chart
4. Chokotei Charts, etc.

Performance tracking is a very important tool for the management of manufacturing equipment. Performance data can indicate where improvements are needed and helps to prioritize improvement work. We also need to be able to measure the effects of changes or modifications; therefore, performance tracking gives us a baseline to judge the effects of machine improvements and good machine operation. Performance tracking considers production volume, product quality, operation efficiency, and time usage. Performance tracking data is collected on a daily run sheet at each machine. The production operator manually records the following items:

1. Quantity of Good Parts (hourly)
2. Quantity of Scrap Parts (hourly)
3. Quantity of Defect Parts (Hourly)
4. Machine Stop/Downtime, Time Down (Per event)
5. Machine Stop/Downtime, Description (Per event)
6. Scrap Material (Per Shift)

A description of any downtime is also recorded on the daily run sheet.

Below are examples of an MOR Chart and a Volume Chart

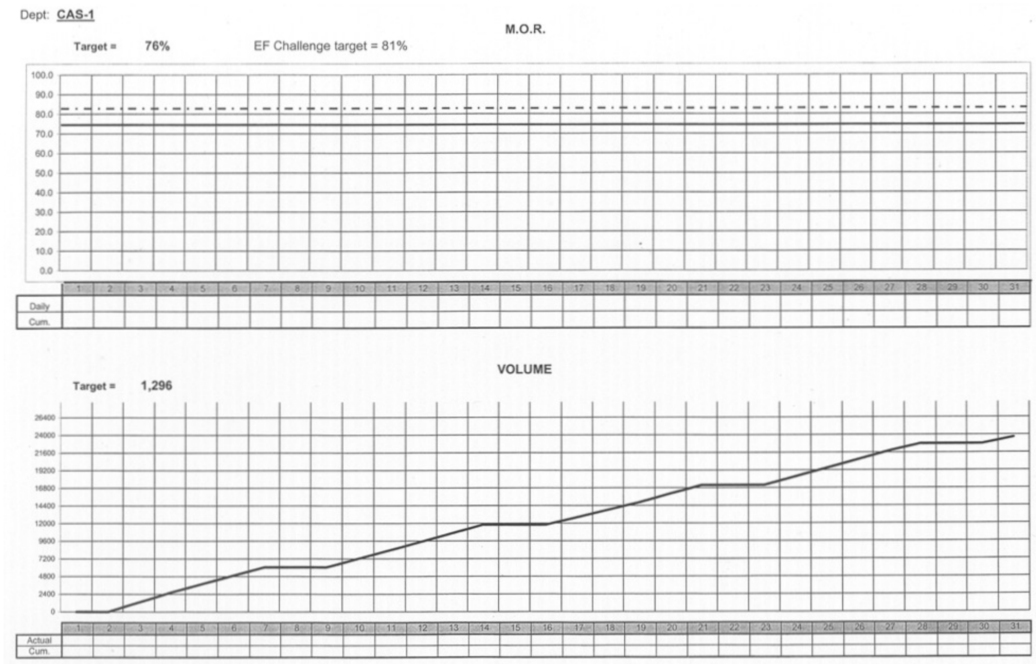


Fig 2.2.5 MOR chart and volume chart

2.2.3 PILLAR 2 – KOBESTU KAIZEN (Focused maintenance)

‘Kai’ means change, and ‘Zen’ means good (for the better). Kaizen is the opposite of big spectacular innovations. Kaizen is small improvements carried out on a continual basis and involves all people in the organization. Kaizen requires no or little investment. The principle behind Kaizen is that a large number of small improvements are more effective in an organizational environment than a few large-scale improvements. Systematically using various Kaizen tools in a detailed and thorough method eliminates losses. The goal is to achieve and sustain zero loses with respect to minor stops, measurement and adjustments, defects, and unavoidable downtimes. Kobetsu Kaizen uses a special event approach that focuses on improvements associated with machines and is linked to the application of TPM.

Kobetsu Kaizen begins with an up-front planning activity that focuses its application where it will have the greatest effect within a business and defines a project that analyses machine operations information, uncovers waste, uses a form of root cause analysis (e.g., the 5 Why approach) to discover the causes of waste, applies tools to remove waste, and measures results. The objective of TPM is maximization of equipment effectiveness. TPM maximizes machine utilization, not merely machine availability. As one of the pillars of TPM activities, Kaizen activities promote efficient equipment and proper utilization of manpower, materials, and energy by eliminating 16 major losses.

Examples of Kobetsu Kaizen to make machines easier to maintain include:

1. Relocating gauges and grease fittings for easier access.
2. Making shields that minimize contamination.
3. Centralizing lubrication points.
4. Making debris collection accessible.

2.2.4 PILLAR 3 - Planned Maintenance

The goal of planned maintenance is to have trouble-free machines and equipment that produce defect-free products for total customer satisfaction. Planned Maintenance achieves and sustains availability of machines at an optimum maintenance cost, reduces spares inventory, and improves reliability and maintainability of machines.

With Planned Maintenance the associates' efforts evolve from a reactive approach to a proactive method and trained maintenance staff helps train the operators to better maintain their equipment.

Policy:

1. Achieve and sustain availability of machines
2. Optimum maintenance cost.
3. Reduces spares inventory.
4. Improve reliability and maintainability of machines.

Target:

1. Zero equipment failure and break down.
2. Improve reliability and maintainability by 50 %
3. Reduce maintenance cost by 20 %
4. Ensure availability of spares all the time

Steps in Planned Maintenance include:

1. Evaluate and record present equipment status.
2. Restore deterioration and improve weaknesses.
3. Build information management system.
4. Prepare time-based data system, select equipment, parts, and team, and make plan.
5. Prepare predictive maintenance system by introducing equipment diagnostic techniques.
6. Evaluate planned maintenance

2.2.5 PILLAR 4 - Quality Maintenance

It is aimed towards customer delight through highest quality through defect free manufacturing. Focus is on eliminating non-conformances in a systematic manner, much like Focused Improvement. We gain understanding of what parts of the equipment affect product quality and begin to eliminate current quality concerns, and then move to potential quality concerns. Transition is from reactive to proactive (Quality Control to Quality Assurance).

QM activities are to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to maintain perfect quality of products. The condition is checked and measure in time series to very that measure values are within standard values to prevent defects. The transition of measured values is watched to predict possibilities of defects occurring and to take counter measures before hand.

Policy:

1. Defect free conditions and control of equipments.
2. QM activities to support quality assurance.
3. Focus of prevention of defects at source.
4. Focus on poka-yoke. (Fool proof system)
5. In-line detection and segregation of defects.
6. Effective implementation of operator quality assurance.

Target:

1. Achieve and sustain customer complaints at zero
2. Reduce in-process defects by 50 %
3. Reduce cost of quality by 50 %.

Data requirements:

Quality defects are classified as customer end defects and in house defects. For customer-end data, we have to get data on

1. Customer end line rejection
2. Field complaints.

In-house, data include data related to products and data related to process

Data related to product:

1. Product wise defects
2. Severity of the defect and its contribution - major/minor
3. Location of the defect with reference to the layout
4. Magnitude and frequency of its occurrence at each stage of measurement
5. Occurrence trend in beginning and the end of each production/process/changes. (Like pattern change, ladle/furnace lining etc.)
6. Occurrence trend with respect to restoration of breakdown/modifications/periodical replacement of quality components.

Data related to processes:

1. The operating condition for individual sub-process related to men, method, material and machine.
2. The standard settings/conditions of the sub-process
3. The actual record of the settings/conditions during the defect occurrence

2.2.6 PILLAR 5 – Training and Education

It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill. It is not sufficient know only 'Know-How' by they should also learn 'Know-why'. By experience they gain, 'Know-How' to overcome a problem what to be done.

This they do without knowing the root cause of the problem and why they are doing so. Hence it becomes necessary to train them on knowing 'Know-why'. The employees should be trained to achieve the four phases of skill. The goal is to create a factory full of experts. The different phase of skills is

Phase 1: Do not know. Phase 2: Know the theory but cannot do. Phase 3: Can do but cannot teach Phase 4: Can do and also teach.

Policy:

1. Focus on improvement of knowledge, skills and techniques.
2. Creating a training environment for self-learning based on felt needs.
3. Training curriculum / tools /assessment etc conductive to employee revitalization
4. Training to remove employee fatigue and make, work enjoyable.

Target:

1. Achieve and sustain downtime due to want men at zero on critical machines.
2. Achieve and sustain zero losses due to lack of knowledge / skills / techniques
3. Aim for 100 % participation in suggestion scheme.

Steps in Educating and training activities:

1. Setting policies and priorities and checking present status of education and training.
2. Establish of training system for operation and maintenance skill up gradation.
3. Training the employees for upgrading the operation and maintenance skills.
4. Preparation of training calendar.
5. Kick-off of the system for training.
6. Evaluation of activities and study of future approach

2.2.7 PILLAR 6 - Office TPM

Office TPM should be started after activating four other pillars of TPM (JH, Kaizen, QM, PM). Office TPM must be followed to improve productivity, efficiency in the administrative functions and identify and eliminate losses. This includes analyzing processes and procedures towards increased office automation. Office TPM addresses twelve major losses. They are

1. Processing loss
2. Cost loss including in areas such as procurement, accounts, marketing, sales leading to high inventories
3. Communication loss
4. Idle loss
5. Set-up loss
6. Accuracy loss
7. Office equipment breakdown
8. Communication channel breakdown, telephone and fax lines

9. Time spent on retrieval of information
10. Non availability of correct on line stock status
11. Customer complaints due to logistics
12. Expenses on emergency dispatches/purchases.

A senior person from one of the support functions e.g. Head of Finance, MIS, Purchase etc should be heading the sub-committee. Members representing all support functions and people from Production and Quality should be included in sub committee. TPM co-ordinate plans and guides the sub committee.

1. Providing awareness about office TPM to all support departments
2. Helping them to identify P, Q, C, D, S, M in each function in relation to plant performance
3. Identify the scope for improvement in each function
4. Collect relevant data
5. Help them to solve problems in their circles
6. Make up an activity board where progress is monitored on both sides - results and actions along with Kaizens.
7. Fan out to cover all employees and circles in all functions.

Kaizen topics for Office TPM

1. Inventory reduction
2. Lead time reduction of critical processes
3. Motion and space losses
4. Retrieval time reduction.
5. Equalizing the work load
6. Improving the office efficiency by eliminating the time loss on retrieval of information, by achieving zero breakdown of office equipment like telephone and fax lines.

Office TPM and its Benefits:

1. Involvement of all people in support functions for focusing on better plant performance
2. Better utilized work area
3. Reduce repetitive work
4. Reduced administrative costs
5. Reduced inventory carrying cost
6. Reduction in number of files
7. Productivity of people in support functions
8. Reduction in breakdown of office equipment
9. Reduction of customer complaints due to logistics

10. Reduction in expenses due to emergency dispatches/purchases
11. Reduced manpower
12. Clean and pleasant work environment.

2.2.8 PILLAR 7 - SAFETY, HEALTH AND ENVIRONMENT:

Target:

1. Zero accident,
2. Zero health damage
3. Zero fires.

In this area focus is on to create a safe workplace and a surrounding area that is not damaged by process or procedures. This pillar will play an active role in each of the other pillars on a regular basis.

A committee is constituted for this pillar, which comprises representative of officers as well as workers. Senior vice President (Technical), heads the committee. Utmost importance to Safety is given in the plant. Manager (Safety) is looking after functions related to safety. To create awareness among employees various competitions like safety slogans, Quiz, Drama, Posters, etc. related to safety can be organized at regular intervals.

Steps in safety health and environment activities include:

SAFETY

- Identify areas which are unsafe places and unsafe practices which will lead to accidents
- Do kaizens / take countermeasures to eliminate them

HEALTH

- Identify areas which will lead to health problems for the employees like smoke, fumes, heat, chemicals etc
- Map the areas for each of them independently
- Do kaizens / take countermeasures to eliminate/reduce them

ENVIRONMENT

- Identify what are the things that are being done in the organisation which are leading to environmental pollution
- Do kaizens / take countermeasures to eliminate /reduce them

2.2.9 PILLAR 8 – INITIAL EQUIPMENT MANAGEMENT / DEVELOPMENT MANAGEMENT

Equipment management is related somewhat to equipment improvement. It refers to the careful design, selection and testing of equipment. The purpose is to ensure a smooth commissioning process with minimal design defects and problems. New equipment management includes vendor selection, evaluating options for maintainability, training personnel in advance and other common-sense techniques.

Equipment management programme-: With the increase in automation and acquisition by many organizations of high-tech equipment as needed for flexible manufacturing systems, the importance of the maintenance function is increasing. High equipment utilization and high performance are a must for a quick return on assets. High equipment availability and high performance can be achieved through efficient equipment management programmes

The activities of the Equipment management programme include-:

- Developing a system to reduce new product / equipment development time
- Developing a system to reduce start-up, commissioning and stabilization time for quality and efficiency
- These systems should ensure ease of operation, cleaning and maintenance
- They should also ensure equipment reliability, quick setup, and low operating costs
- They prevent initial-phase equipment troubles from occurring as well as in promoting the optimal design that can balance initial cost and running cost from the equipment planning/concept stage to the mass production start up

2.3 TPM Implementation Strategies

TPM focuses on optimizing planning and scheduling. Availability, performance and yield are other factors that affect productivity. Availability losses arise from breakdowns and change-over, i.e., the situation in which the line is not running when it should be. Performance losses arise from speed losses and small stops or idling or empty positions. In this case, the line may be running, but it is not producing the quantity it should. Yield losses consist of losses due to rejects and poor start-up behavior in the line producing the products. These losses lead to low values of the overall equipment effectiveness (OEE), which provides an indication of how effective the production process is. TPM helps to raise the value of the OEE by supplying a structure to facilitate the assessment of these losses. Application of TPM leads to both short- and long-term improvements.

TPM entails having a

- Linear organizational structure.
- Multi-skilled workforce.
- Rigorous reappraisal of the way, the thing is done and so improvements are introduced, resulting in simplification and/or standardization.

TPM seeks to encourage the setting of ambitious, but attainable, goals for raising the value of the OEE and to measure any deviations in, what is achieved, relative to the original objective (Eti, et al., 2000). Hermann (2000) states that the introduction of a TPM system is by no means an easy task, because there are several barriers that encumber the implementation process, the driving forces to success have to be identified and well understood, and a process of organizational change has to be managed successfully.

There have been many approaches suggested by different practitioners and researchers for implementing TPM in different organizations, having varying work environments and organizational objectives for garnering strategic manufacturing competencies. It has been observed that many organizations have holistically followed the strict JIPM–TPM implementation process, by strategically employing the 8 pillars approach towards TPM implementation (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 been depicted in Figure 2.3.1.

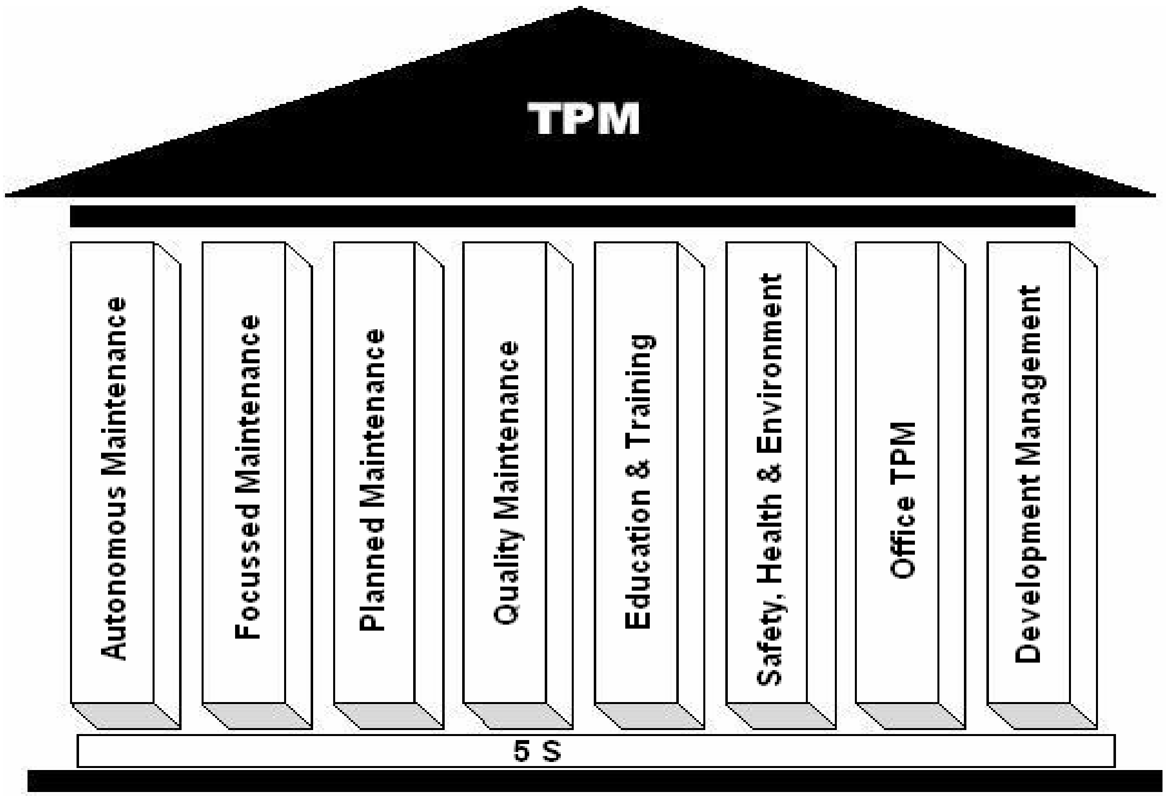


Figure 2.3.1 Eight Pillar approach for TPM (Suggested by JIPM)

Naguib (1993) has proposed a five phase roadmap for TPM implementation which includes: an awareness program to obtain management commitment and support; restructuring of manufacturing organization to integrate maintenance in production modules; planning maps to cover TPM activities related to equipment effectiveness, maintenance management system, and workplace environment enhancements; workforce competencies improvements; an implementation process based on 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) has been presented in Figure 2.3.2. TPM implementation process, at the highest level requires initialization, implementation and institutionalization. In this model, 'Training and Education' is an integral element of all other pillars rather than stand-alone pillar as depicted in the Nakajima model.

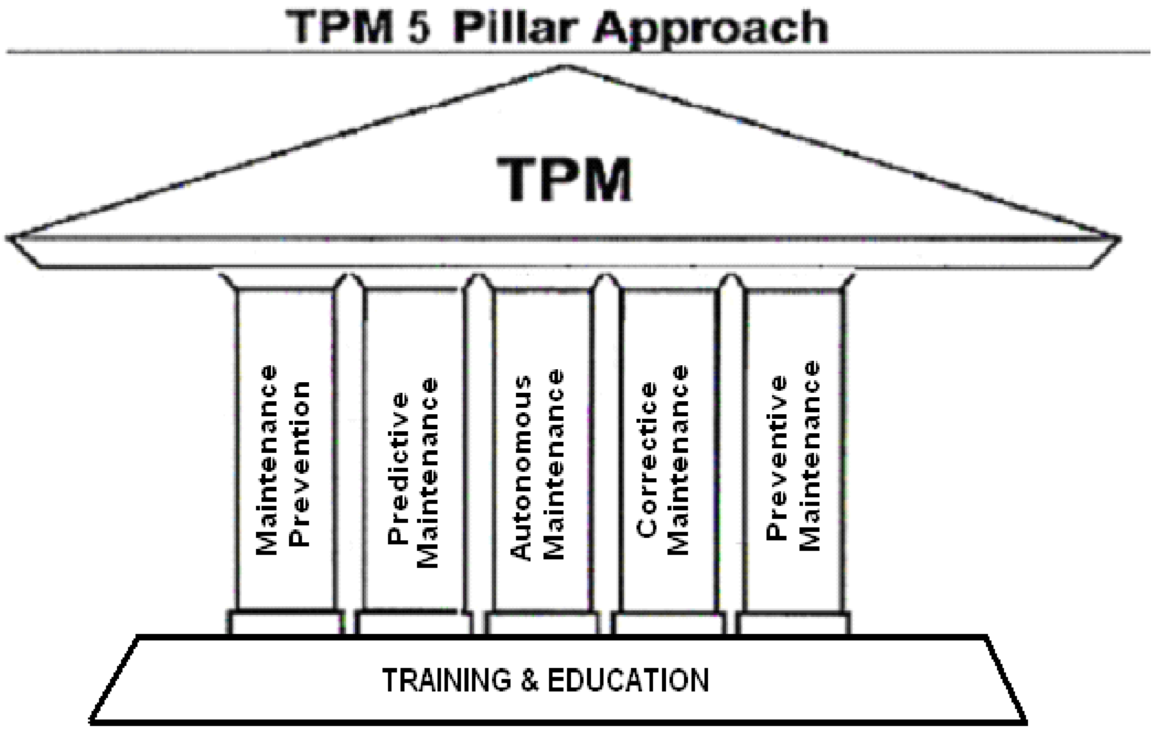


Figure 2.3.2 Steinbacher and Steinbacher Model of TPM Implementation

Willmott (1994) has presented a three-phase, nine-step TPM implementation plan that involves: Condition cycle (criticality assessment, condition appraisal, refurbishment and future asset care), Measurement cycle (evaluating OEE, equipment history) and Improvement cycle (assessment of six losses, problem solving and best practice routines) for realizing optimum equipment condition, that is, easy to operate, requires minimum maintenance work, and capable of reliable, low cost and high quality operation.

Carannantes et al. (1996) have proposed the eight-step approach for implementation of TPM involving: system, measurement, autonomous maintenance, house-keeping, continuous improvement, culture, training and plant design.

Nakajima has also outlined twelve step TPM methodology involving four phases of TPM implementation (Nakajima, 1988; Shirose, 1996). These twelve steps support basic developmental activities, which constitute minimal requirements for the development of TPM. The various steps involved in the TPM implementation methodology have been depicted in Table – 2.5. The 12-step process is designed to implement TPM**:** Accomplish TPM acceptance; Create TPM support from management, unions and employees; Create enthusiasm and positive expectations for TPM; Develop a realistic custom installation plan; and Accomplish world-class results in a timely manner.

Step 1: Announcement of top management decision of implementing TPM: - Top management needs to create an environment that will support the introduction of TPM. Without the support of management, skepticism and resistance will kill the initiative. Detailed TPM articles including TPM objectives should be clearly stated in company's newsletter, newspaper and magazine.

Step 2: TPM education Program and collection of information: - This program will inform and educate everyone in the organization about TPM activities, benefits and its objectives.

For managers: offer seminars/retreats according to level,

For general workers: provide slide presentation.

This step of implementing TPM also consists of collection of information about TPM and to understand how it works. TPM coordinator must understand what TPM is, how it works, its proper implementation sequence, the amount of effort that will be required, how it can be benefited for the plant, how long it will take to implement etc. Information resources include TPM conferences, TPM seminars, TPM books, magazines, the Internet, and conversations with consultants. (McBRIDE, 2004)

Step 3: Establish an organizational structure: - This group will promote and sustain TPM activities once they begin. Team-based activities are essential to a TPM effort. This group needs to include members from every level of the organization from management to the shop floor. This structure will promote communication and will guarantee that everyone is working toward the same goals.

Step 4: Formulate basic TPM policies and goals: - Analyze the existing conditions and set the goals that are Result oriented, Specific, Measurable, Attainable and Realistic. Then predict the results. The established TPM policies and goals should be very much clear to everyone involved in TPM implementation.

Step 5: Master plan for TPM deployment and its presentation: - After establishing TPM policies and goals, a detailed proposed master plan for implementation of TPM is prepared and proposal is presented to management. This activity can be carried out by a consultant, plant personnel, or both. Consultant involvement typically begins with a plant visit to observe production operations, learn about the equipment (type, function, condition, problems and losses etc.), study maintenance operations (structure, size and tasks etc.), gauge orderliness and cleanliness in the plant, and talk to employees to determine their motivation and attitude. The consultant then can develop and conduct the TPM presentation to management, including questions and answers, and covers the following: (Hartmann, 2000)

1. TPM overview .
2. What TPM can do for the plant, its Expected costs and benefits?
3. Sequence of its implementation.
4. Customized implementation strategy.
5. How management and the union must support TPM.
6. How to get organized for implementing TPM.

The presentation also can be made by plant personnel covering the same points with examples and impressions from seminars, conferences, and plant visits. The presentation should end with a recommendation to install TPM. Normally, management will make a positive decision at this point. This decision must include a commitment to strongly support TPM, carry out the necessary training and the feasibility study, appoint a TPM coordinator, and create the TPM steering committee. This plan will identify what resources will be needed and when for training, equipment restoration and improvements, maintenance management systems and new technologies.

Step 6: Feasibility study and its presentation: - According to Hartmann (2000), every successful TPM installation has been preceded by a good feasibility study. The results of the feasibility study, will establish a base line, against which TPM results and progress can be measured and also helps in setting the realistic goals, based on the data obtained. A feasibility study typically includes two to six teams (five to nine members each). It will include overall equipment effectiveness (OEE) observations and calculations for 40 to 100 percent of important equipment. The study will evaluate the condition of these equipments and the required current and future maintenance activities. Skills of plant personnel, cleanliness or orderliness of the plant, and plant culture (attitude, motivation, and management style) will be studied also. Then Feasibility study results are presented. Both management and the union should be present in the presentation. The presentation should propose an installation strategy and identify a pilot installation. It should conclude with a recommendation that TPM is to be installed. At this point, management will make a second and final commitment to install TPM. Now, at this stage, almost everybody has had some exposure or heard about TPM during the execution of the feasibility study. The OEE results are typically much lower than management thought, creating a strong motivation to get going and improve the productivity of equipment and the quality of product. The feasibility study presentation meeting can be regarded as the TPM kickoff.

Step 7: Pilot installation: A TPM pilot installation should cover between 10 and 25 percent of plant equipment, not just a few selected machines. There should be a minimum of six TPM teams to insure survivability of the installation. Areas appropriate for pilot installations are: where major improvement is needed (too many breakdowns, delays, or idle time, or low capacity or productivity) and where quick success is likely. A good feasibility study is required for all pilot areas. All employees in the pilot areas must receive TPM training. Clear goals and deadlines must be established and team meetings must be held on schedule.

Step 8: Plant-wide installation: TPM coordinators of most companies wait too long before expanding the TPM installation over the whole plant. There is no need to wait for final results of the pilot installation. A good and well thought out staggered expansion plan is important, as is a detailed installation plan for each additional area. Expansion initiatives should begin every 3 months (6 months maximum) using the same priorities and decision criteria as for pilots.

Step 9: Introduction audit: According to Hartmann (2000), to insure good progress and a proper and successful installation, audits have proven to be very valuable. There are two types of audits: the first audit is fairly simple and checks if the TPM fundamentals are done correctly (teamwork, organization tasks, PM development, etc.) and whether the program is on schedule. They are typically carried out 6-12 month after launch by internal or external specialists.

Step 10: Progress audit: It is usually the last step before the certification. This audit will point out existing deficiencies (and opportunities) to bring TPM to a successful conclusion. The theoretical part of the audit will be done in the office with the team going over a lot of data followed by a practical part out in the plant around the equipment.

The progress audit comes 18-30 month after launch to determine if and how:

1. Preventive maintenance is carried out by the TPM teams.
2. Equipment improvement activities have been executed according to schedules.
3. Increase in OEE has been reached.
4. The improved equipment condition has been accomplished and documented.
5. The planned levels of skill have been accomplished.

Step 11: Certification: The certification process is gaining more and more importance, because certificate is used to show to the customer that equipment and product quality have been improved and standard procedures are in practice to maintain the equipment to the highest levels. The International TPM Institute certification process is based on a strict set of certification requirements.

Step 12: TPM Award: The final and most rewarding step of a TPM installation is achieving the TPM Award. The award testifies that the plant is world-class: highly productive, produces only top quality product, maintains its equipment in top shape, and has a culture based on teamwork. According to (McBRIDE, 2004) maintenance and reliability as a core business strategy, is key to a successful TPM implementation. Without the support of top management, TPM implementation will be failed. It is certain that Implementing TPM using the above 12 steps will leads to 'zero breakdowns' and 'zero defects.' Ming-Hong (2004) suggests that to be successful, not only support is required from top management, but also from the head of each department. The other key factor is that each employee must feel that they also have been benefited from this activity. This will improve their performance. This improved performance will reflect in their monthly bonus. This will motivate the employee, which in turn will lead to better progress. The design of the activity should be kept as simple as possible.

The literature review reveals that although numbers of strategic TPM models and programs have been suggested by practitioners and researchers for the Western World, the Indian manufacturing organizations are faced with stiff challenge of working out right sequence of initiatives for effectively deploying TPM practices successfully, in the most effective manner.

2.4 Organization Structure for TPM Implementation

The results of TPM implementation depends upon the organization structure. Improper organization structure can lead to the failure of TPM implementation. A typical organizational structure for TPM implementation is as shown in Figure 2.4.1. For this purpose, a person should be made responsible for implementing TPM, i.e. a plant manager should be appointed as TPM coordinator. The coordinator will look over the whole TPM implementation process. According to McBRIDE (2004), TPM requires effective leadership from the top. That is the part of the meaning of 'total' in 'Total Productive Maintenance'. Without effective leadership that links TPM efforts to the business and holds the people accountable, for performing highly specified work, the equipment performance and reliability will continue to decline and TPM initiatives will be short-lived.

Many of today's business leaders have risen through the ranks when maintenance was only responsible for 'fixing things' – not for preventing problems. Viewing maintenance as a non-value-adding support function, many business leaders often subject the maintenance department to severe cost-cutting; this usually results in higher costs due to decreased equipment effectiveness. TPM is not like a standard project, which normally has a starting, and an end that seldom exceeds one year. Rather, TPM is a long range 'living program' which can take more than few years to implement and enjoy the lasting benefits when the whole organization has become strategy focused, instead of evaluating one new program after another, before implementing TPM thoroughly.

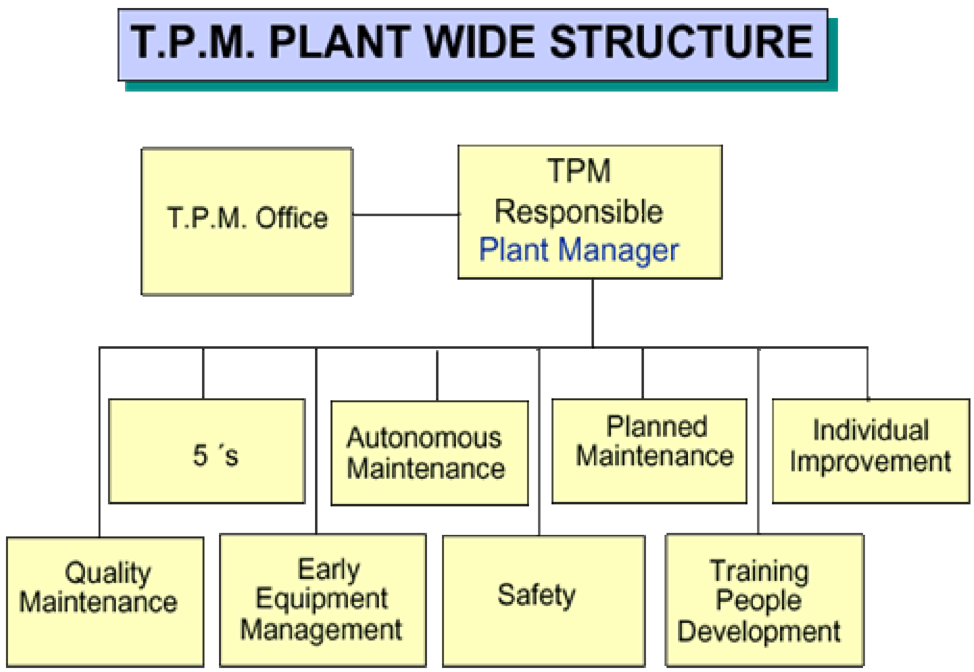


Figure 2.4.1 Organization Structure for TPM Implementation

2.5 Difficulties Faced in TPM Implementation

It has been reported in the literature that TPM implementation is not an easy task by any means. The number of organizations successfully implementing TPM program is considered relatively small. While there are several success stories and research on TPM, there are also documented cases of failures in 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 of TPM teams on 'what and whys of TPM', failure to start with operator-involved maintenance, superficial TPM deployment, ineffective rewards and felicitation mechanisms, 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).

According to Hartmann (2000), at least every second attempt of installation of Total Productive Maintenance (TPM), results in failure. The reasons are many: lack of proper understanding of the total effort required, lack of management support, lack of sufficient TPM staff, union resistance, not enough training carried out, change of priorities, lack of persistence, failure to develop a good installation strategy, and simply choosing the wrong approach. Choyds(2003), concluded that implementing TPM is a dramatic organizational change that can affect organization structure, work-floor management system, employee responsibilities, performance measurement, incentive systems, skill development and the use of information technology. No wonder the success rate of such large-scale change is less than 30% for most organizations and that's why, the TPM is difficult to implement

Implementing TPM is not an easy task as it seems to be. A great infrastructure and commitment of all personnel from top level management to bottom level is required. A lot of problems have to be faced, while implementing it. Some of them are as follows:

1. Sufficient resources like people, money, time, etc. and assistance are not provided.
2. TPM is not a 'quick fix' approach, it involve cultural change to the ways to do the things.
3. Incomplete understanding of the methodology and philosophy by middle management.
4. Many people treat it just another 'program of the month' without paying any focus and also doubt about its effectiveness.
5. Workers show strong resistance to any change.
6. Many people considered TPM activities as additional work or threat.

2.6 Benefits of TPM Implementation

TPM is a world-class approach, which involves everyone in the organization to enhance equipment effectiveness. The literature documents dramatic tangible and intangible operational improvements resulting from successful TPM implementation. Organizations practicing TPM invariably achieve startling results, particularly in reducing equipment breakdowns, minimizing idling and minor stoppages (indispensable in unmanned plants), significantly reducing quality defects and claims, boosting productivity, trimming labor and costs, shrinking inventory, eliminating accidents and promoting employee involvement (Suzuki, 1994). When breakdowns and defects are systematically tracked and eliminated, many benefits are presented: equipment productivity improvement, cost reduction, quality improvement and inventory reduction etc. TPM approach helps increase uptime of equipment, reduce machinery set-up time, and enhance quality and lower costs. Through this approach, maintenance becomes an integral part of manufacturing performance improvement teams (Avery, 1993). The ultimate benefits obtained by implementing TPM program include significantly enhanced organizational profitability and productivity. After successful TPM implementation, organizations have reported 15–30 % reduction in maintenance costs, 90 % reduction in process defects and 40–50% increase in labor productivity an increase in equipment productivity to the tune of 40–50 % (Nakajima, 1988; Willmott, 1994). Chowdhury (1995) has reported that organizations with TPM culture have experienced benefits to the extent of 80 % reduction in defective rate, 90 % reduction in routine breakdowns and 50% increase in production output. Several

Japanese organizations with more experience in the process have realized significant improvements from fully implementing TPM. These improvements include: 50 % rise in equipment availability, 90 % decline in process defects, 75 % decline in customer complaints, 30 % decline in maintenance costs and 50 % reduction in maintenance inventories.

CHAPTER 3

EVALUATING CONTRIBUTIONS OF TPM TOWARDS MANUFACTURING PERFORMANCE ENHANCEMENT

Manufacturing is considered to be an important element in an organization's endeavor to improve overall performance for sustained competitiveness. TPM is a highly structured approach which uses number of tools and techniques to achieve highly effective plants and machinery. With competition in manufacturing industries rising relentlessly, TPM has proven to be the maintenance improvement philosophy boosting the success of an organization (Eti et al., 2004). Thus, an aggressive and effective TPM strategy is urgently needed to cope up with the dynamic needs and discover hidden but unused or under-utilized resources (employee's intellectual competencies, man-hours, machine-hours). TPM methodology has a tremendous potential to meet the challenges faced by organizations. A well conceived TPM implementation program not only improves the equipment efficiency and effectiveness, but also brings appreciable improvements in other areas of manufacturing enterprises. 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, integration of cross-functional teams and effective identification equipment root causes/problems, for reaping significant benefits from TPM implementation programs. It has been reported that careful, efficient planning and preparation are keys to successful organization-wide implementation of TPM. Neely et al. (1995) see performance measurement as process of quantifying action and more specifically specifying it as 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 presented benefits accrued through holistic implementation of TPM 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 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 inter-relations of TPM with other approaches of 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 contextual issues affecting 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 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 relationships among TPM, JIT, TQM and EI for supporting the successful implementation of TPM.

Kutucuoglu et al. (2001) have stated that equipment is a major contributor to the performance and profitability of manufacturing systems. They have classified maintenance performance measures into five categories: equipment related performance, task related performance, cost related performance, immediate customer impact related performance, and learning, growth related performance. The study is aimed at investigation of 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 key features of a successful PMS, namely: goal deployment, cross-functional structure and a balanced view of a system.

Sangameshwran 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 8 – 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 a proactive Indian organization.

Eti et al. (2004) have explored the ways in which Nigerian manufacturing industries have implemented TPM as a strategy, culture for improving its performance, and suggested self-auditing and benchmarking against world-class industries with similar product lines as desirable prerequisites before TPM implementation. They have further reported that Nigerian industry needs to posses a culture dealing more effectively with rapid changes to inculcate a competitive outlook in their manufacturing environments.

Seth and Tripathi (2005) have investigated strategic implications of TQM and TPM in an Indian manufacturing set-up. They have examined the relationship between factors influencing 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 Indian manufacturing environment.

Thun (2006) has described the dynamic implications of TPM by working out inter-relations between various pillars of TPM to analyze fundamental structures and identified most appropriate strategy for implementation of TPM considering the inter-play of different pillars of this maintenance approach. The research focuses upon analyzing the reasons behind successful TPM implementation and identifies inter-relations between the pillars of TPM. The research has been conducted for analyzing the fundamental structures and identification of strategy for successful implementation of TPM.

Pessan (2007) has proposed a multi-skill project scheduling problem model for maintenance activities in the organization. Preventive maintenance activities are usually planned in advance: production is stopped and all maintenance activities should be processed as fast as possible in order to restart production. Moreover, these human resources handled activities which require specific skills and are subjected to precedence constraints. The main difference with Multi-Skill Project Scheduling Problem is that some activities may be submitted to disjunctive constraints due to material constraints of the production channel. He described how these constraints can be used to improve usual Multi-Skill Project Scheduling Problem resolution methods.

Ramayah (2007) has emphasized importance of maintenance in the manufacturing environment. The failure of equipments or machines to produce products on time as required can reflect the inefficiency in operations thus, failure to deliver the products to the customers. The objective of TPM is to create an active participation of all employees in maintenance and production functions, including the operators who operate the machines and equipments. The results suggest important aspects of autonomous maintenance and planned maintenance activities that contributed to the improvement in quality and cost

Khanna (2008) has described that a large percentage of the total cost of doing business is due to maintenance-related activities in the organization. One approach to improve performance of maintenance activities is to implement and develop Total Productive Maintenance (TPM). TPM methods and techniques had been successfully implemented in Japan over the past three decades, and more recently in India. Inherent within the TPM concept are the aspects of enhancing the overall equipment effectiveness. The research shares some of the experiences of TPM implementation in Mayur Uniquoters, India and achievements made while adopting and implementing TPM. It also identifies some of the difficulties faced during implementation, relates with the concept of TPM and proposes some solutions to eliminate them

Marcello et. al. (2009) has described overall equipment effectiveness (OEE) as a key metric to measure the performance of individual equipment .However, when machines operate jointly in a manufacturing line, OEE alone is not sufficient to improve the performance of the system as a whole. He showed how to overcome this limitation, by presenting a new metric (overall equipment effectiveness of a manufacturing line – OEEMIL) and an integrated approach to assess the performance of a line

Kodali (2009) demonstrated the use of a multi-attribute decision - making (MADM) model, namely , the analytic hierarchy constant sum method (AHCSM) for justification of world class maintenance systems by analyzing the performance measures of an organization .The model showed that WMS is the best among the alternatives considered for the given circumstances. Before starting the implementation top management should be convinced of the necessary justification, which requires analysis of various qualitative and quantitative factors apart from analyzing various tangible and intangible benefits. In such a situation, the conventional, financial justification techniques alone cannot be used.

CHAPTER 4
TPM IN THE INDIAN CONTEXT

An insight into the country's manufacturing scenario reveals that maintenance and human factors have remained as neglected areas since long in the Indian manufacturing organizations. Traditionally, maintenance has been treated as a necessary evil and seen as an uncontrollable black box in the operation. The maintenance efforts have usually been directed to maintain basic equipment conditions of manufacturing facilities with a reasonable success and maintenance has often been a disregarded issue in the manufacturing organizations. In the Indian context, maintenance has been viewed as a reactive problem-fixing strategy and an operating expense to be minimized (Seth and Tripathi, 2005). Due to the callous attitude of the Indian entrepreneurs towards maintenance in the past, they have found it very hard to compete effectively with the Western world in the wake of liberalization of the economy since the early 1990s.

In the present context, as also revealed by literature review, maintenance function has to be regarded as an equal partner in the organization, having a huge potential in enhancing the competitive advantage of the organization. Thus, Indian manufacturing organizations have been forced to look out for proactive strategic maintenance improvement initiatives in the recent past for harnessing their manufacturing competencies. In the last one-and-a-half decades, leading Indian manufacturing entrepreneurs have adopted proactive steps and initiatives to imbibe the state-of-the-art maintenance improvement initiatives and philosophies in the organizations to realize enhanced manufacturing performance. As a result, the maintenance function has been accepted as a potential source of cost savings and competitive advantage. TPM is being looked upon as a potential profit source, capable of leading the organizations to meet the challenges posed by globalization. In the Indian context, most of the manufacturing organizations are currently in the introductory stage of TPM implementation, with less than three years of TPM deployment experience, while only a handful of organizations have been able to break the shackles with serious interventions. Over the past decade, there have been a lot of changes in attitude and mindset of the employees due to the ever increasing challenges to survival of their organizations (Chandra and Krishna, 1998).

TPM Club India had been established in 1998, under the ambit of Confederation of Indian Industries (CII), to promote Total Productive Maintenance concepts and practices in Indian enterprises. According to the Confederation of Indian Industries (CII) – TPM Club India, nearly 300 odd organizations across the country have shown interest in adapting TPM programmes and have initiated strategic proactive initiatives towards implementing TPM practices. TPM Club India has grown to become one of the most effective interventions for the manufacturing industry and has facilitated more than 105 plants receiving TPM excellence awards in India, making us the second largest country of recipients of TPM awards, outside Japan. During the course of development, more than 300 companies have become members of the Club, with over 200 organizations receiving consultancy and training services from CII trained counselors.

It has been observed through a detailed survey that till date, only a reasonable number of organizations (approximately 110–115 organizations) have shown highly satisfactory results by reaping excellent results through holistic TPM implementation. In their pursuit for TPM implementation, many Indian organizations have been honored to receive Award for Excellence in Consistent TPM Commitment-Second Category, Award for Excellence inconsistent TPM Commitment – First Category and Award for TPM Excellence from JIPM. Although a reasonable number of Indian entrepreneurs have experienced organizational success and transformations through TPM implementations, very few studies have been reported highlighting achievements of the Indian entrepreneurs through TPM initiatives.

In the pursuit for TPM implementation, many Indian organizations have been honored to receive Award for Excellence in Consistent TPM Commitment–Second Category, Award for Excellence in Consistent TPM Commitment – First Category and Award for TPM Excellence from Japan Institute of Plant maintenance (JIPM). The selected Indian organizations having successfully achieved breakthroughs in manufacturing performance and received recognition for their efforts towards TPM by JIPM include: Vikram Cement Limited (AV Birla Group; 1995), Sundram Fasteners Limited (TVS Group; 1998), Tanfac Limited (AV Birla Group; 1999), Birla Tyres (2000), Grasim Industries Limited (2001), Hindustan Lever Limited (2001), Usha Beltron (2001), Vikram Cement Limited (2001), Indo Gulf Corporation Limited (2002), Tata Metaliks Limited (2002), Tata Iron and Steel Company – (Bearings Division, Hot Strip Mill, Wire Rod Mill; 2004), Tata Bearings (2004), Bajaj Auto Limited (2005), AVTEC Limited (Power Unit Plant; 2005), Brakes India Limited (Brake Division, Foundry Division; 2005), TTK-LIG Limited (2005), Mukand Limited (2005), Tata Cummins Limited (2005), Bajaj Auto Ltd. (2006), Balasore Alloys Ltd. (2006), Bharat Seat Ltd. (2006), Brakes India Limited, Nanjangud (2007), Galaxy Surfactants Limited, Tarapur Plant (2007).

Kodali and Chandra (2001) and Kodali (2001) have highlighted the benefits realized through TPM implementation in Indian Industry. Tripathi (2005) has conducted a study highlighting the TPM achievements in the Indian Industry. The literature reveals that very limited information is available regarding the contributions of TPM initiatives towards harnessing core competencies in the organizations. Thus, in the present context, the study highlighting TPM implementation issues in terms of achieving manufacturing competencies through TPM initiatives in Indian industry assumes great significance

Figure 4.1.1 depicts rising acceptance of TPM initiatives in the Indian industry. The data reveals that there is an increasing trend among Indian entrepreneurs towards adopting proactive maintenance improvement initiatives through TPM interventions in their organizations as a potential weapon to meet global competition. Figure 4.1.2 reveals the success of selected Indian entrepreneurs with TPM initiatives with increasing number of organizations being recognized for their exploits with TPM initiatives.

This is testimony to the confidence shown by Indian entrepreneurs on TPM initiatives towards garnering core competencies for sustainable organizational development. Thus, TPM has an immense potential to affect dramatic manufacturing performance improvements. Although a reasonable number of Indian entrepreneurs have experienced organizational success and transformations through TPM implementations, very few studies have been reported highlighting achievements of the Indian entrepreneurs through TPM initiatives. Kodali and Chandra (2001) have highlighted benefits realized through TPM implementation in Indian Industry.

Tripathi (2005), Seth and Tripathi (2005) have conducted study highlighting TPM accomplishments in Indian Industry.

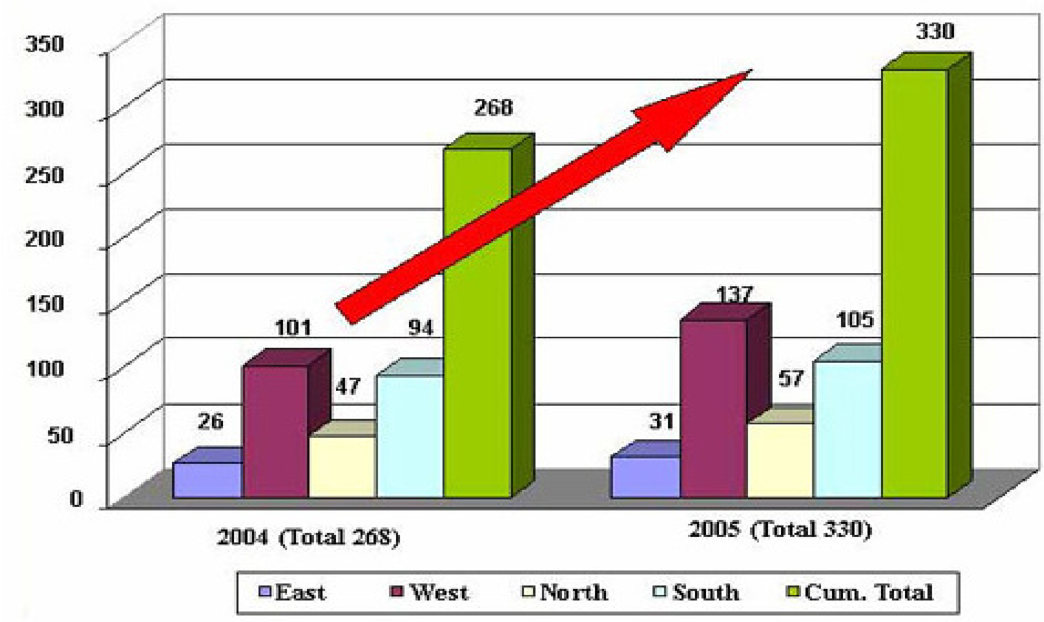


Figure 4.1.1 Trend of Indian Organizations joining TPM movement

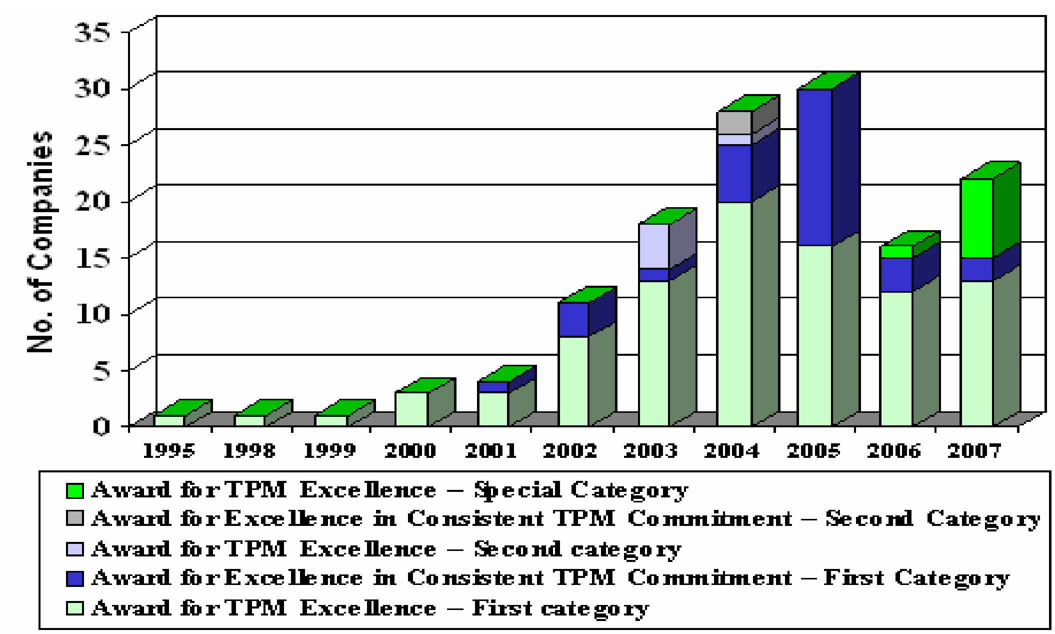


Figure 4.1.2 Trend of TPM award winning Indian Organizations

CHAPTER 5
RESEARCH OBJECTIVES AND METHODOLOGY

The thesis has been carried out in the large scale manufacturing organizations in the country that have successfully implemented TPM and have reaped significant benefits as a result of TPM implementation, to study the TPM implementation issues and achievements realized as a result of strategic TPM implementation. The approach has been directed towards justification of TPM implementation for its support to competitive manufacturing in the Indian industry.

For effectively conducting the survey, the exploits of the manufacturing organizations regarding strategic TPM initiatives will be explored through extensive plant visits, interviews/discussions with TPM practitioners, investigation of TPM initiatives deployed over the period of time and close analysis of achievements made through TPM initiatives. This thesis will focus upon evaluating exploits of Indian entrepreneurs with TPM practices and would highlight the contributions of TPM in realizing the overall organizational goals and objectives. The steps to be followed in the dissertation have been elaborated below:

1. Literature review and overview of TPM
2. Literature review on TPM practices adopted by western world
3. Evaluating the status of TPM implementation in Indian manufacturing industries through specially designed questionnaire
    a. Design of questionnaire.
    b. Validation of Questionnaire.
    c. Creation of industrial data base for obtaining responses of questionnaire from selected industries.
    d. Mailing of questionnaire to industries for seeking response.
    e. Obtaining feedback from Indian manufacturing industries regarding exploits with strategic TPM implementation practices.
    f. Compilation of results based on the data collected.
    g. Statistical analysis of data collected through questionnaire to ascertain TPM competencies of Indian manufacturing industries.
4. Evolving management process -: In the questionnaire of TPM the inputs will be pillars of the TPM and questions will be asked to the industries on issues related to various pillars of TPM which lead to successful implementation of TPM.
5. Analysis of data received through questionnaire to ascertain contribution of TPM towards manufacturing performance enhancement.

Inputs categories (pillar initiatives) are -:

JISHU HOZEN issues are related to cleaning, lubrication, tightening (C-L-T) standards and autonomous maintenance tasks carried out by the operators throughout the organization

KOBETSU KAIZEN issues are related to tracking the root cause of all the losses affecting the equipment performance through OEE and focused equipment kaizens are being deployed by productive operators for elimination of 16 major losses

PLANNED MAINTENANCE issues are related to the planned and time based maintenance initiatives effectively deployed for addressing equipment life cycle performance issues in the organization and how far counter measures are effectively deployed under the PM program for achieving zero breakdowns

QUALITY MAINTENANCE issues are related to major defects and customer complaints that need to be identified & tracked for improving the system performance and use of seven quality control tools for addressing quality defects & customer complaints

TRAINING & EDUCATION issues are related to training needs of employees to improve there skills from time to time as per organization's requirements. In this employee skills are consistently evaluated and in-house OJT training modules effectively worked out and deployed for employee training

OFFICE TPM issues are related to inventory management systems and streamlined procedures to avoid production stoppages and optimizing organizational revenues. In this the procedural hassles in the administrative work are identified and consistently reviewed to improve various support functions

SAFETY, HEALTH & ENVIRONMENT issues are related to identification of cause of injuries and accidents. It includes safe operating procedures, safety competitions and one point lessons to be effectively deployed for promoting safety consciousness among employees of the industry.

DEVELOPMENT MANAGEMENT issues are related to getting feedback from customers, production, quality control departments for improving system's design, reliability, maintainability and operatability. It may also include deployment of experiences with existing equipment on new products for developing maintenance Prevention programs

The output consists of tangible and intangible benefits of the TPM It will include the effect of TPM on production, cost, quality, delivery, safety and morale. It may also include the extent by which the organizations have reaped the benefits by implementation of TPM.

TPM EFFECT ON PRODUCTION (P)	
1	Improvement in equipment Availability
2	Reduction in number of failures & unplanned downtime
3	Improvement in Overall equipment effectiveness (OEE)

TPM Effect on Quality (Q)	
1	Superior Manufacturing Quality
2	Improvement in Customer Order Compliance
3	Reduction in number of customer warranty problems
TPM Effect on Cost (C)	
1	Reduction in additional capital investments required
2	Reduction in operating costs
3	Reduction in energy consumption
TPM Effect on Delivery (D)	
1	Dependable & Faster deliveries
2	Greater order size flexibility
3	Reduction in cycle time to develop new products
TPM Effect on Safety (S)	
1	Reduction in number of accidents
2	Reduction in number of injuries
3	Reduction in man days lost due to accidents/injuries
TPM Effect on Morale (M)	
1	Increase in worker involvement in TPM SGA's
2	Increase in number of kaizens suggested by operators
3	Increase in number of one point lessons developed

Table 5.1 Benefits reaped from TPM implementation

6. Scope of the future research work and conclusions.

CHAPTER 6
DESIGN OF STUDY

The study has been carried out in the medium and large scale manufacturing organizations in the country that have successfully implemented TPM or are in the process of implementing TPM, to study the TPM implementation issues and achievements realized as a result of strategic TPM implementation programs. In this study, a reasonably large number of manufacturing organizations (40 organizations) have been extensively surveyed, to ascertain contributions made by TPM initiatives towards realization of manufacturing competencies. The approach has been directed towards evaluation of contribution made by strategic TPM initiatives in Indian Industry for enhanced manufacturing performance. The methodology employed in the Thesis has been depicted in Figure 6.1.1.

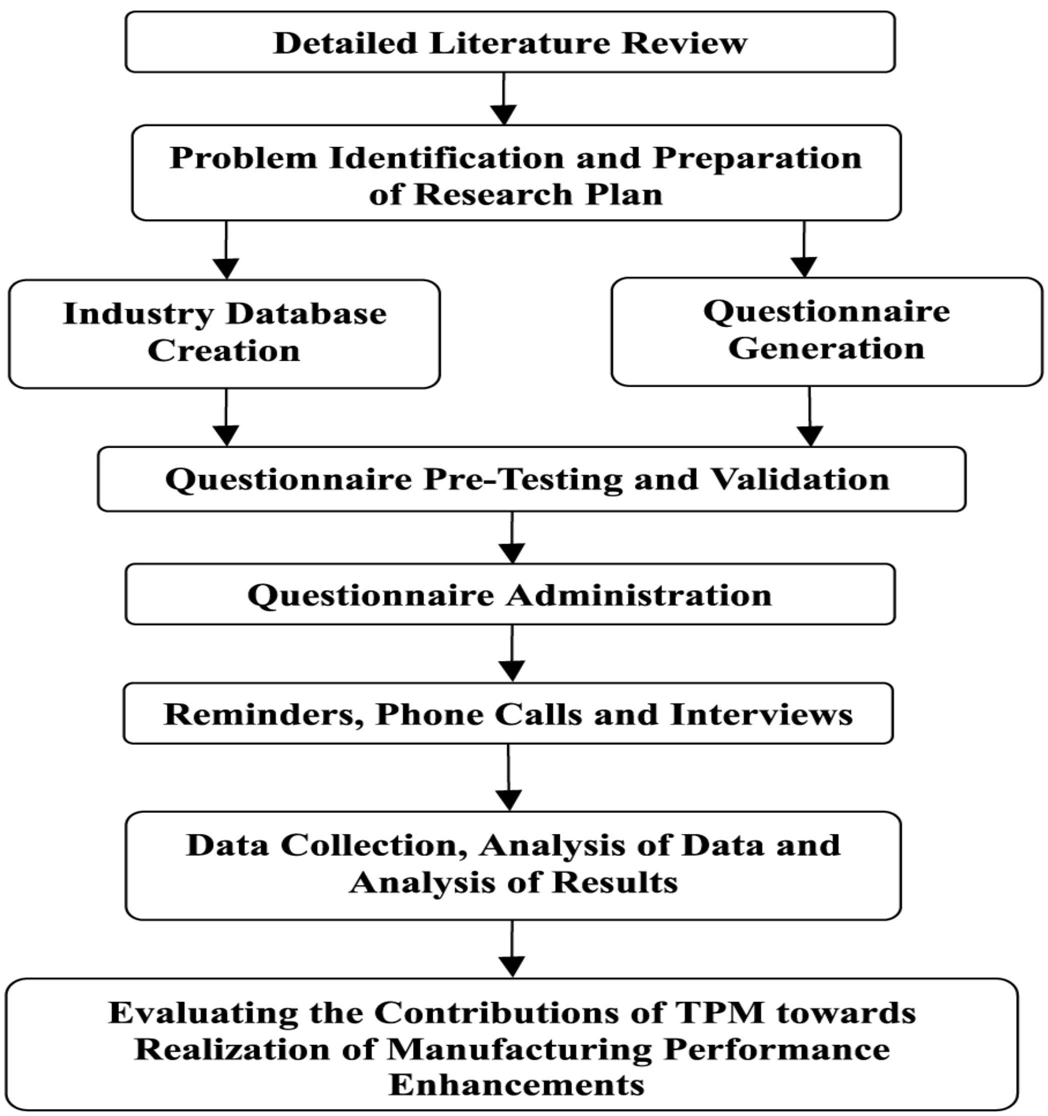


Fig 6.1.1 Diagram showing methodology employed for research work

In order to ascertain the contributions of TPM initiatives towards realization of manufacturing performance improvements, a detailed ‘TPM Questionnaire’ has been designed for accessing the maintenance capabilities of the Indian manufacturing industry. The questionnaire survey technique has been deployed in the present thesis for seeking information on the status of TPM implementation issues and the realization of various manufacturing performance enhancements. For effectively conducting the survey, the TPM Questionnaire has been designed through extensive literature review and validated through peer review from academicians, consultants, TPM councilors, and practitioners (TPM Coordinators) from the industry.

We have performed a literature review on the current status of TPM in Indian industry and from that literature review we jolted down all the important points that are required for us to frame our questionnaire on TPM. We studied deeply about the pillars of TPM and we also studied the important parameters that affect the TPM .We have also goggled various websites especially TPM club India website to get list of companies year wise in which year company was given TPM by JIPM.

We have also visited confederation of Indian industry for getting a detailed list of the companies that have implemented TPM in their industries and about those industries also who are in implementation phase of TPM from past two year or from past one year. We also purchased directory from there which contained valuable data about the industries. So finally we made a list of 150 companies in excel to which we were going to send our questionnaire for getting the answers.

After the questionnaire was designed it was forwarded to industrial resource person for seeking their comment regarding the questionnaire. This was done for validating the questionnaire and for seeking the opinion of the concerned person about the relevance of the issues which were taken in the questionnaire with the effectiveness of implementation of TPM in Indian industries. So we mailed the questionnaire to the industries and we got the opinions and some valuable suggestions from experts. Feedback from industrial resource person and from academicians was inducted in the questionnaire to make it relevant in the TPM implementation issue. .

The suggestions from the peers, consultants, TPM councilors, senior executives from the industries and academicians have been incorporated to make the questionnaire relevant to the purpose and bring out key outcomes as a result of strategic TPM implementation. We emailed the questionnaire to certain companies and we also send our questionnaire to around 200 companies with speed post for getting there answers or feedback on how the TPM is contributing in improving there manufacturing performance. Figure 6.1.2 depicts the steps undertaken in finalization of the TPM questionnaire. A structured approach has been employed in this study for managing the TPM implementation process effectively to enhance the probability of success through such initiatives. This underlines the significance of identifying metrics to track progress of TPM program in the organization.

There are several key measures that can assist in tracking progress during TPM implementation. Thus, the performance evaluation has been based on multiple inputs and multiple outputs. Since the evaluation involves multiple inputs and multiple outputs, it can be thought of as a multi-criteria decision problem. In order to ascertain the benefits realized by an effective TPM approach, it becomes imperative that the different TPM success factors and manufacturing performance parameters be scrutinized carefully to analyze the contributions made by TPM program in an organization. In the present thesis, eight key TPM success factors autonomous maintenance (X1), focused improvement (X2), planned maintenance (X3), Quality Maintenance (X4), education and training (X5), office TPM (X6), safety, health and environment (X7),development management (X8) and six manufacturing performance parameters productivity enhancements (Y1), quality enhancements (Y2),cost optimizations (Y3), delivery compliance (Y4), safety enhancements (Y5) and morale enhancements (Y6) have been identified as significant for analyzing the impact of TPM initiatives towards achieving manufacturing performance improvements.

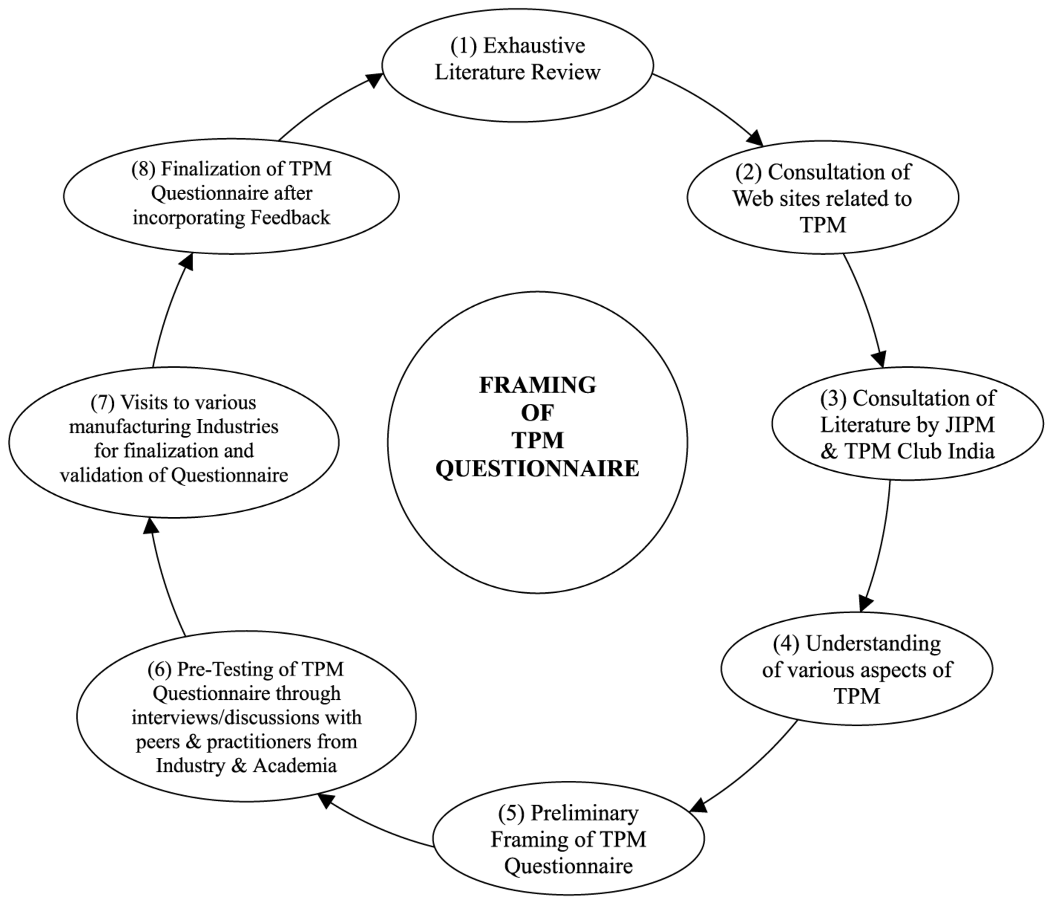


Fig 6.1.2 Framing of TPM questionnaire

Further, the inter-relationships between TPM success factors and manufacturing performance parameters have also been evaluated in the present thesis to develop an understanding of the contributions of the various TPM success factors towards realization of specific manufacturing performance improvements. Moreover, the effect of realization of strategic manufacturing performance enhancements with respect to ‘time frame of TPM implementation’ has also been ascertained to validate the fact that TPM implementation is not an overnight program and it requires a reasonable period of holistic interventions, varying between three to five years, to realize the true potential of TPM. The research has revealed improvements in manufacturing performance over time extending up to five years and beyond. The thesis employs various statistical tools for extracting significant factors contributing effectively towards realization of manufacturing performance improvements. For this purpose, the various statistical analysis tools like Cronbach's Alpha, Pearson Correlation Coefficient, t test, Multiple Regression Analysis, Canonical Correlation and Two Tailed t test have been employed to investigate the contributions of holistic TPM implementation initiatives towards realization of manufacturing performance improvements in the manufacturing organizations. The extensive survey of Indian manufacturing scenario has revealed that nearly 300 organizations in the country have been registered with TPM Club India, and are involved with the TPM implementation. But out of these 300 organizations, only 55 percent (about 165 organizations) of the organizations have made reasonably significant interventions regarding adapting TPM initiatives in a serious manner, while rest of the organizations have yet to made a significant head-start regarding effective TPM implementation.

The target respondents for the 'TPM Questionnaire' have been the organizations that have made serious interventions in the field of TPM and realized significant achievements through adoption of strategic TPM initiatives. The manufacturing organizations across the country were first screened, and an industrial database was created for the purpose of mailing the 'TPM Questionnaire'.

The 'TPM Questionnaire' was mailed to the selected organizations, and were subsequently contacted through postal mail, e-mail and telephonically to explain the context of the present research work, its significance and to clarify any queries/doubts to facilitate comprehensive and clear-cut responses to the TPM Questionnaires. A total of 36 responses regarding the 'TPM Questionnaire' have been received from the leading Indian manufacturing organizations (out of significant 165) at different stages of TPM implementation. Thus the sample size of 36 organizations in the present thesis represents about 35 percent of the total number of organizations practicing the TPM principals rigorously.

Most of the respondents to 'TPM Questionnaire' belonged to the top brass of management executives that included several Vice Presidents, Head – Operations, Head – Quality Assurance, General Managers (GM), Heads of Maintenance, Head – process engineering, TPM coordinators, Head – Improvement Management, Chief Managers, Manufacturing Managers, GM – TPM, Head – TPM, GM – Technical, Quality Managers, TPM Secretaries and President – Operations etc. The responses thus received have been compiled and analyzed critically to ascertain the performance of the Indian Industry regarding various TPM related issues.

Now after getting responses and suggestions we finally arranged the data or feedback year wise i.e. for how many years ago the companies started implementing TPM. So we arranged the data in a manner that less than one year companies are separated from companies from one to three years those they took to start implementing TPM. So after we separated our data year wise we made a sheet in excel to fill total data obtained to get a precise outlook of results and we filled total data in this sheet to analyze this data for getting valuable results so in this way we completed the design of questionnaire and our next step was to analyze this data with various statistical tools

CHAPTER 7
ANALYSIS OF QUESTIONNAIRE

The data collected through the questionnaire has been critically analyzed to evaluate the performance of Indian manufacturing enterprises related to various maintenance management attributes. Figure – 7.1.1 depicts performance of the organizations regarding adequacy of maintenance organization structure in the organizations. The data reveals that 6 % of the organizations do not have a well planned organization, 8% (3 out of 36 organizations) have partially planned organization and 86% (31 out of 36 organizations) have well planned organization and structured maintenance organization in their plant. So we can say that most of the organizations have well planned organizations while few of them need an improvement in their organization.

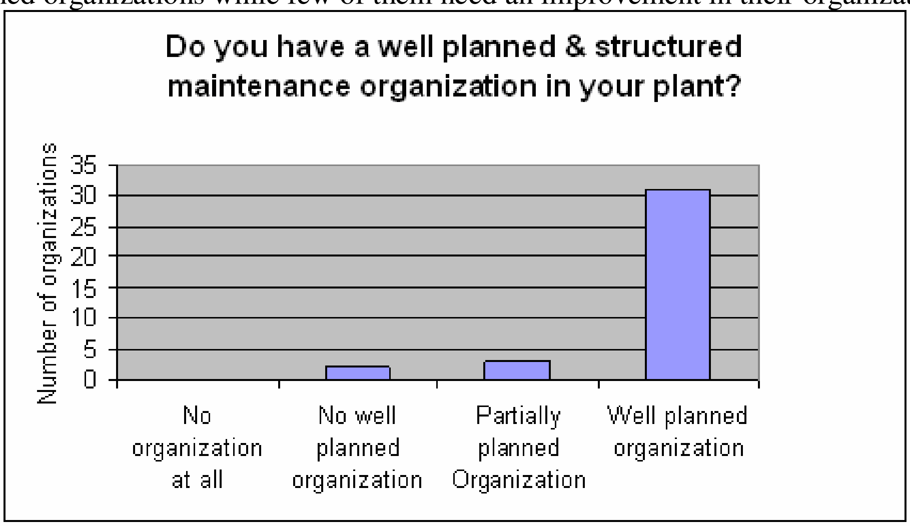


Fig 7.1.1 Performance of the organizations regarding adequacy of maintenance organization structure in the organizations

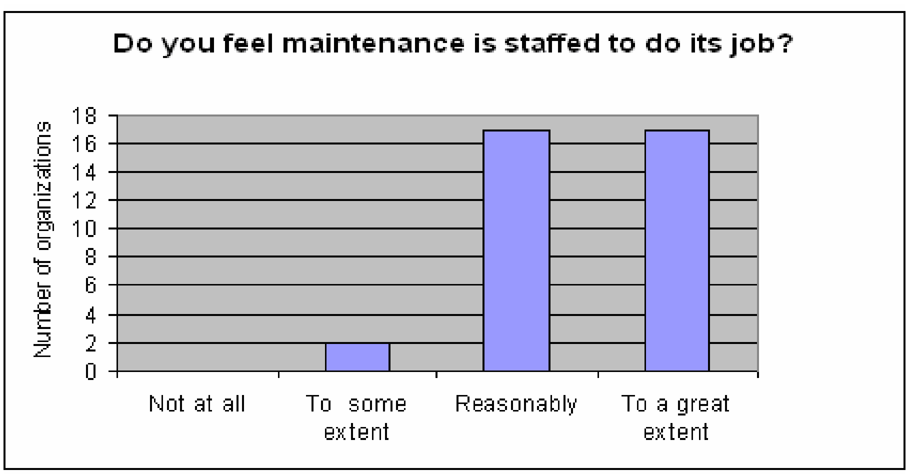


Fig 7.1.2 Status of maintenance staff

Figure-7.1.2 depicts the status of maintenance staff to do their maintenance job in the organization. from this figure we can see that 5% (2 out of 36 organizations) feel that they have small maintenance staff to do its job, while 47% (17 out of 36 organizations) feel that they have a reasonably maintenance staff to do its job and also 47% (17 out of 36 organizations) feel that they have a large maintenance staff to do its job. So we can say that still there are 53%organizations that lack maintenance staff so they should employ maintenance staff to carry out maintenance tasks.

Figure 7.1.3 reveals the assigning of maintenance job descriptions to all positions in the organization. So from this figure we can see that 5% (2 out of 36 organizations) have some maintenance job descriptions, 58% (21 out of 36 organizations) have reasonably maintenance job descriptions and 36% (13 out of 36 organizations) have made maintenance job descriptions and responsibilities available for all positions to a great extent .So majority of these organizations have assigned job descriptions to all the positions.

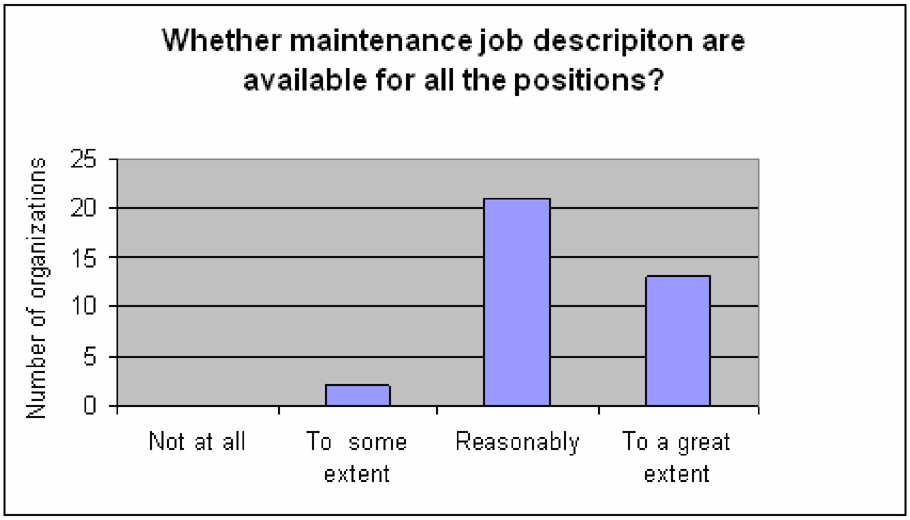


Fig 7.1.3 Assigning of maintenance job descriptions to all positions

Figure 7.1.4 shows the performance of the organizations regarding the PM programs running in their plants. So from this figure we have 11% (4 out of 36 organizations) have an some PM programs in their plants, 55% (20 out of 36 organizations) have reasonably well PM programs running in their plant while 33% (12 out of 36 organizations) have highly effective PM programs running in their plants.

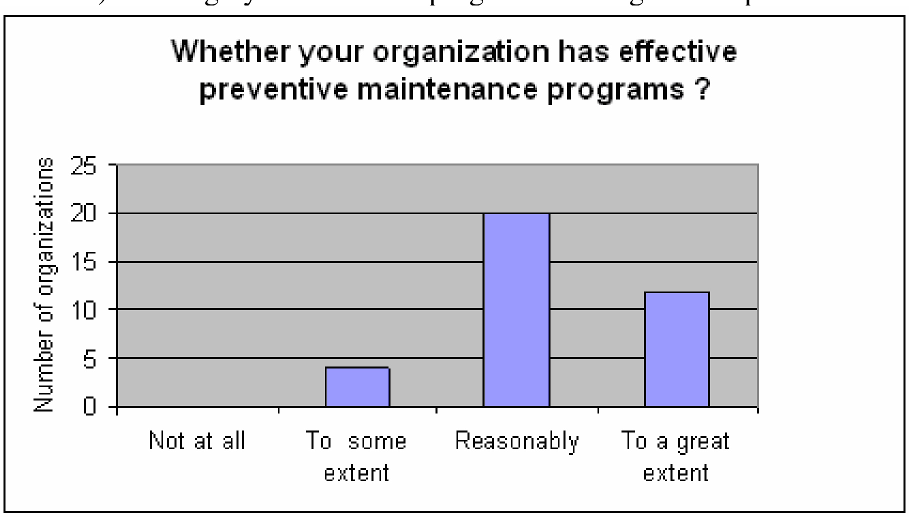


Fig 7.1.4 Performance of the organizations regarding the PM programs

Figure7.1.5 depicts the percentage of plant equipment of the organization which is covered by PM program. So from this figure we have 6% (2 out of 36 organizations) have 10 to 30% of plant equipment is covered by PM program, 39% (14 out of 36 organizations) have 30 to 65% of plant equipment is covered by PM program and 56% (20 out of 36 organizations) have 65 to 100 % of plant equipment is covered by PM program. So majority of these organizations have 65 to 100% plant equipment which is covered by PM program.

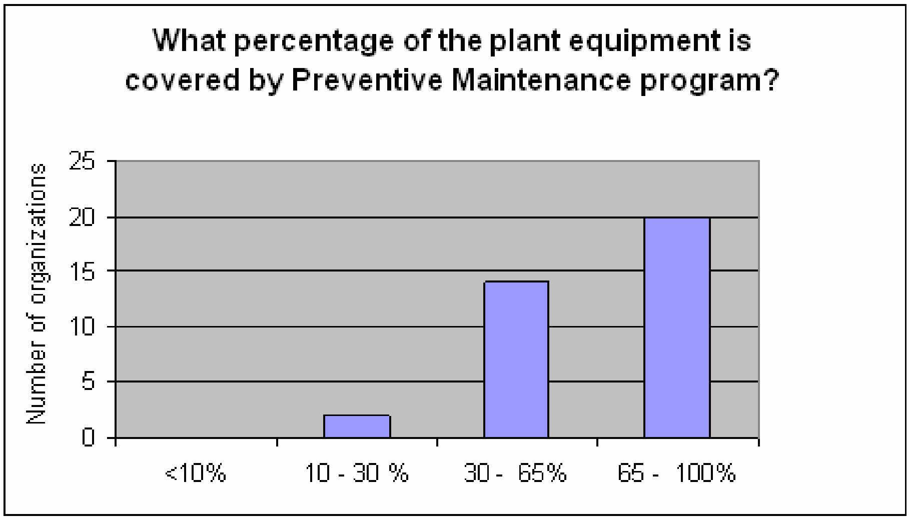


Fig.7.1.5 Percentage of plant equipment covered by PM program

Figure 7.1.6 depicts the maintenance program regarding its adequacy to contain all the procedures to maintain equipment. So from this figure we have 11% (4 out of 36 organizations) whose maintenance programs occasionally includes procedures, practices to maintain and correct equipment deficiencies, 61% (22 out of 36 organizations) whose maintenance programs usually includes procedures, practices to maintain and correct equipment deficiencies and 27% (10 out of 36 organizations) whose maintenance programs includes procedures, practices to maintain and correct equipment deficiencies to a great extent. So the maintenance program needs a lot of improvement to explain all procedures to maintain equipment in a good working condition

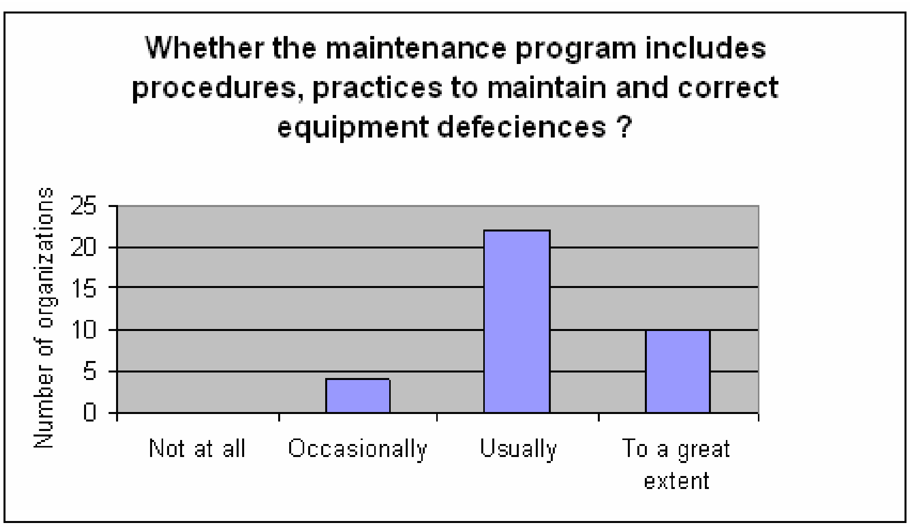


Fig 7.1.6 Maintenance program of various organizations

Figure 7.1.7 depicts performance of the organization regarding effective PM program. From this figure we have 6% (2 out of 36 organizations) that have not at all any effective maintenance program, 44% (16 out of 36 organizations) that have some predictive maintenance program and 25% (9 out of 36 organizations) that have reasonably well predictive maintenance program and also 25% (9 out of 36 organizations) that have predictive maintenance program running in their organizations to a great extent. So there is a scope of improvement of PM programs to make it effective to a large extent to benefit the organization

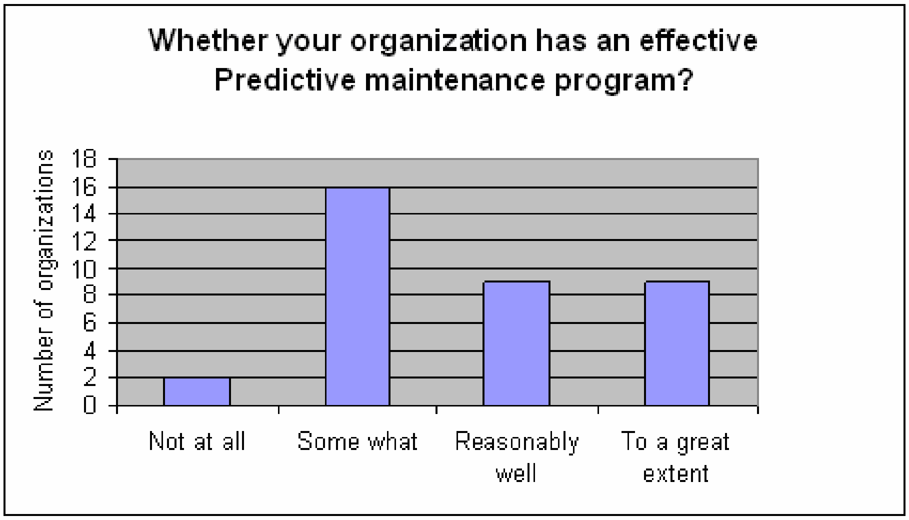


Fig 7.1.7 Performance of the organization regarding effective PM program

Figure 7.1.8 reflects the extent to which organizations use CMMS to carry out maintenance activities .So from this figure we have 11% (4 out of 36 organizations) that do not use CMMS to analyze, record and improve maintenance activities, 30%(11 out of 36 organizations) that use some CMMS to analyze, record and improve maintenance activities, 30% (11 out of 36 organizations) that use reasonably well CMMS to analyze, record and improve maintenance activities and 28% (10 out of 36 organizations) that use highly effective PDM program and CMMS to analyze, record and improve maintenance activities. So there is a scope of improvement to make a reasonable well PM program to a highly effective PM program.

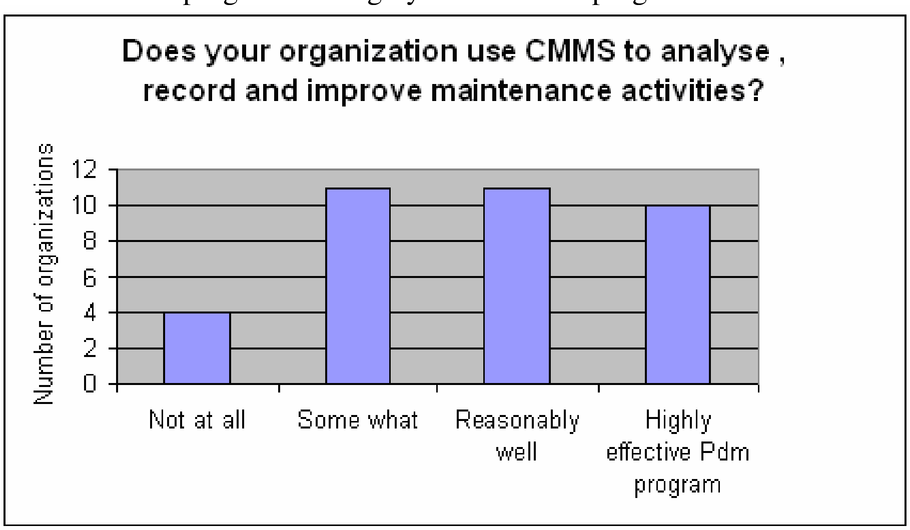


Fig 7.1.8 Use of CMMS in the organization to analyze and improve maintenance tasks

Figure 7.1.9 depicts the use of CMMS reports to generate management decisions in the organization. So from this figure we have 11% (4 out of 36 organizations) where management decisions are not made from CMMS reports because they don't have CMMS, 28%(10 out of 36 organizations) that don't often use CMMS reports to generate management decisions, 39% (14 out of 36 organizations) that use CMMS reasonably to generate management decisions and 22% (8 out of 36 organizations) that extensively employ CMMS reports to generate management decisions. So majority of decisions are made from CMMS reports in the organization

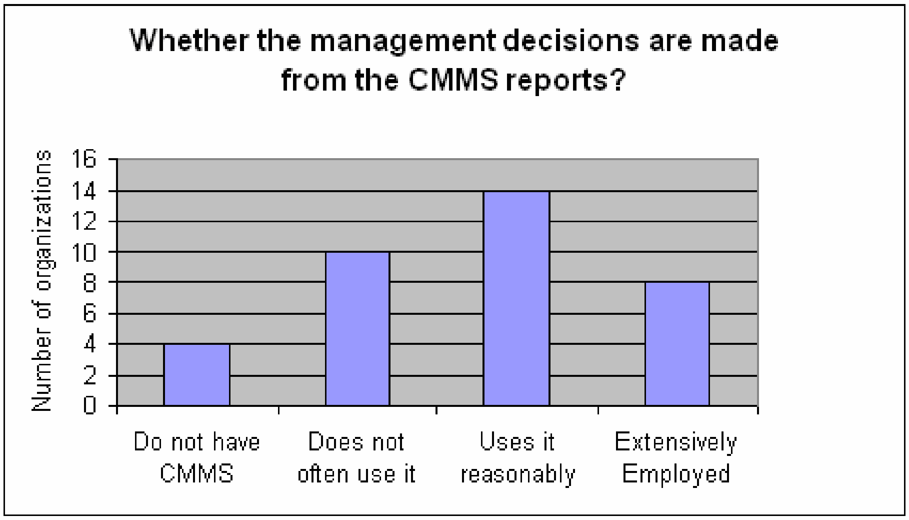


Fig 7.1.9 Use of CMMS to generate management decisions

Figure 7.1.10 depicts the percentage of workers covered by training every year in the organization. So from this figure we have 6% (2 out of 36 organizations) that occasionally cover production workers for training every year, 25% (9 out of 36 organizations) usually cover production workers for training every year and 69 % (25 out of 36 organizations) that cover production workers for training every year to a great extent. So majority of organizations arrange training programs for their workers to improve the organization productivity and to inculcate new skills in workers.

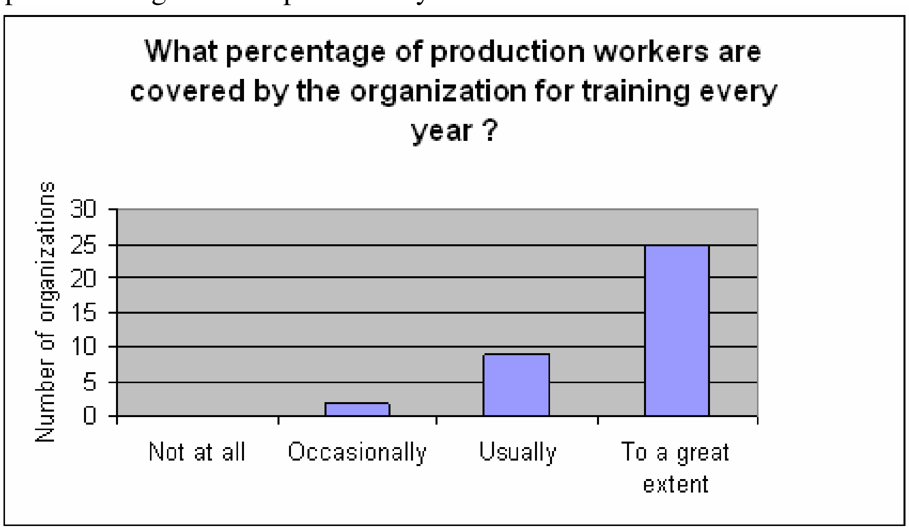


Fig 7.1.10 Percentage of workers covered by training every year in the organization

Figure 7.1.11 shows the time span of implementation of TPM in the organization. So from this figure we have 22% (8 out of 36 organizations) that have less than one year ago to start implementing TPM, 11% (4 out of 36 organizations) that lie in between one to three years ago to start implementing TPM, 31% (11 out of 36 organizations) that lie in between three to five years ago to start implementing TPM and 36% (13 out of 36 organizations) that have more than five years ago to start implementing TPM. So majority of our data is from the organizations that have been implementing TPM from more than 5 years in the organization

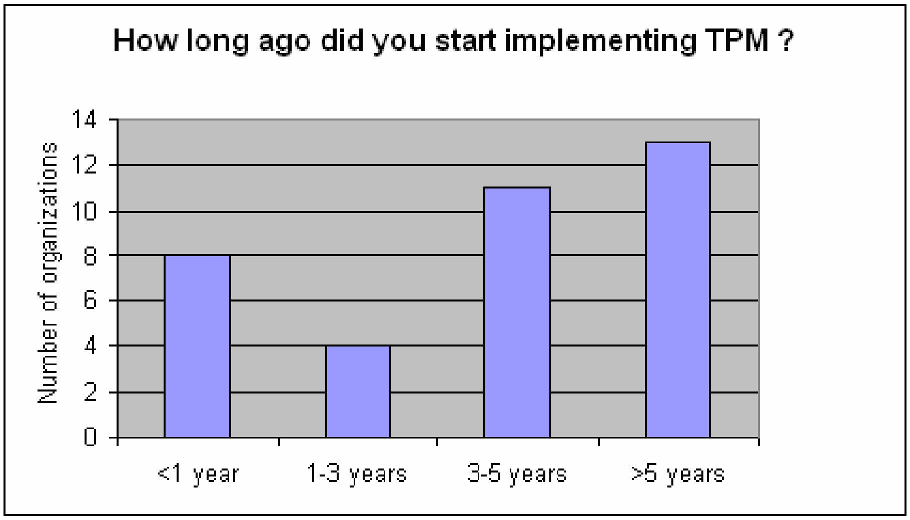


Fig 7.1.11 Time span of TPM implementation in the organizations

Figure7.1.12 shows the number of organizations that have a TPM Quality manual and policies. So from this figure we have 8% (3 out of 36 organizations) that have partially worked out TPM quality manual and quality policy, 47% (17 out of 36 organizations) that have reasonably worked out TPM quality manual and quality policy, and 44% (16 out of 36 organizations that have extensively worked out TPM quality manual and quality policy). So majority of the organizations have extensively worked on TPM quality manual and policy.

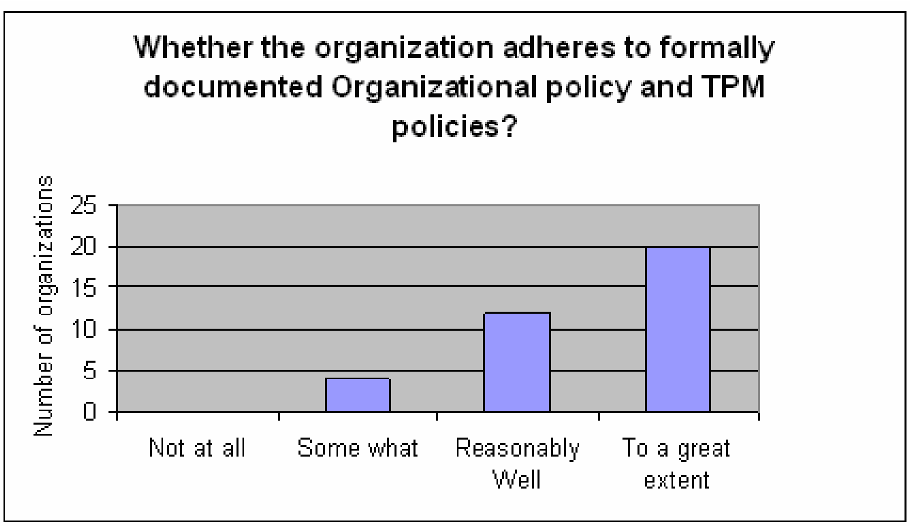


Fig 7.1.12 Extent of TPM Quality manual and policies in the organizations

Figure 7.1.13 depicts the current status of TPM in the organizations. So from this figure we have 17% (6 out of 36 organizations) that are in early stages of TPM implementation, 14% (5 out of 36 organizations) that are in approximately midway stage of TPM implementation, 42% (15 out of 36 organizations) that have completed majority and are continuing stages of TPM implementation and 28% (10 out of 36 organizations) that have successfully completed TPM implementation in their organization. So majority of the organizations have completed and have succeeded in the TPM implementation in their organizations

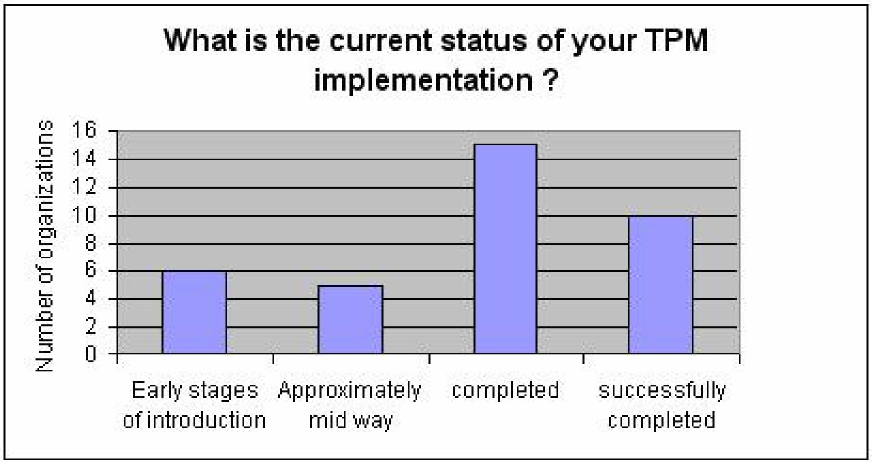


Fig 7.1.13 Current status of TPM implementation in the organizations

Figure 7.1.14 depicts the adherence of the organization to formally documented TPM policies. So from this figure we have 11% (4 out of 36 organizations) where organization some what adheres to formally documented organizational policy and TPM policies, 33% (12 out of 36 organizations) where organization adheres reasonably well to formally documented organizational policy and TPM policies and 55% (20 out of 36 organizations) where organization adheres to formally documented organizational policy and TPM policies to a great extent .So majority of the organizations have well defined TPM policies that they use to improve the productivity of the organization

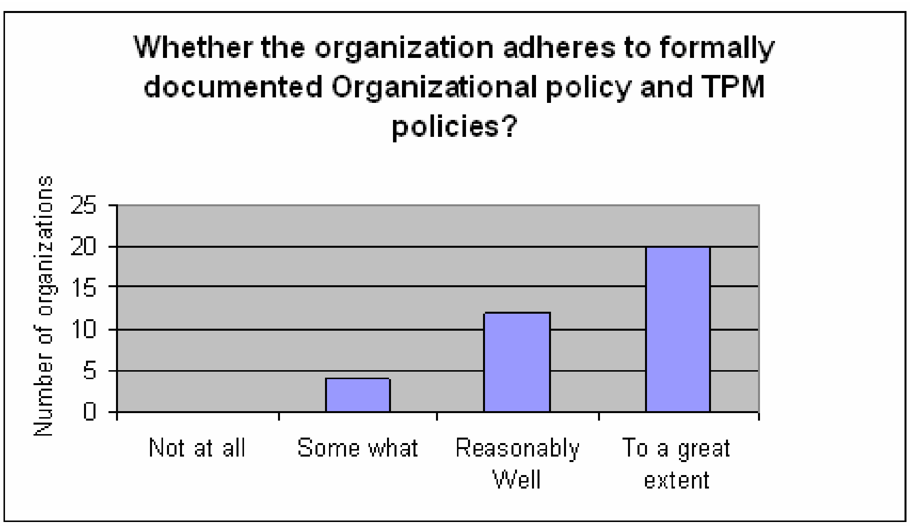


Fig 7.1.14 Number of organizations adhering to TPM policies

Figure 7.1.15 depicts the performance of the organization regarding preparation of master plan towards TPM implementation. So from this figure we have 6% (2 out of 36 organizations) where the management has partially worked out complete masterplan towards TPM implementation, 36% (13 out of 36 organizations) that have reasonably worked out complete masterplan towards TPM implementation and 58% (21 out of 36 organizations) that have extensively worked out complete masterplan towards TPM implementation. So majority of these have made a master plan to implement TPM in the organization.

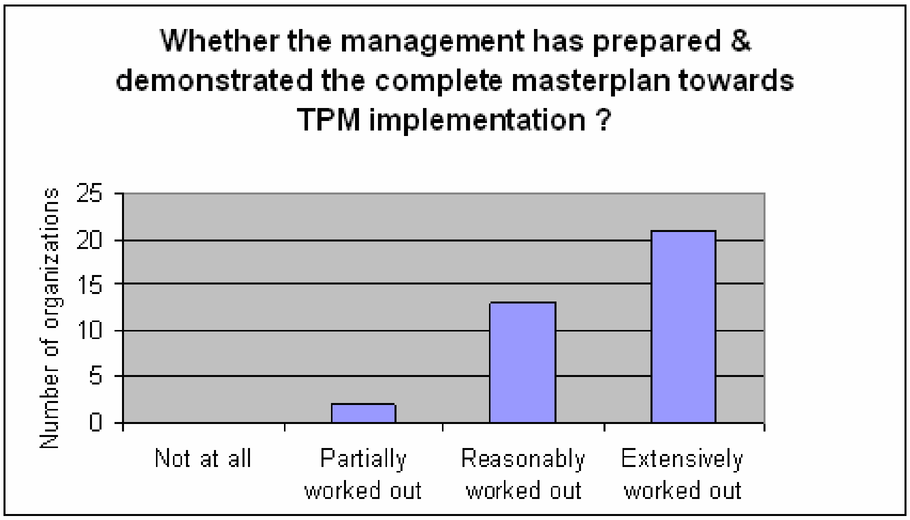


Fig 7.1.15 Performance of the organization regarding preparation of master plan towards TPM implementation

Figure 7.1.16 depicts the integration of TPM promotion with the management structure. So from this figure we have 11% (4 out of 36 organizations) where TPM promotion organization is somewhat integrated within management structure, 39% (14 out of 36 organizations) where TPM promotion organization is reasonably well integrated within management structure and 50% (18 out of 36 organizations) where TPM promotion organization is integrated within management structure to a great extent . So majority of these organizations have TPM promotion organization well integrated in the organization and they have good maintenance policies.

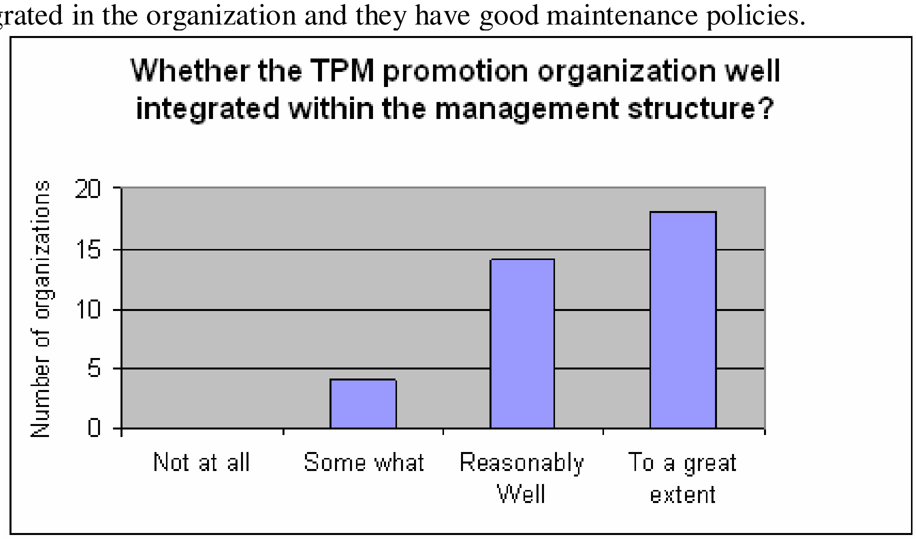


Fig 7.1.16 Integration of TPM promotion with management structure

Figure 7.1.17 depicts the performance regarding existence of structured TPM at the organization including the steering committee. So from this figure we have 6% (2 out of 36 organizations) where organization of TPM is partially structured, 47% (17 out of 36 organizations) where organization of TPM is reasonably worked out and also 47% (17 out of 36 organizations) where organization of TPM is extensively worked out to give it a proper structure. So majority of the organizations have structured TPM organization and they have made steering committee to check whether TPM is implemented properly at organizational level or not.

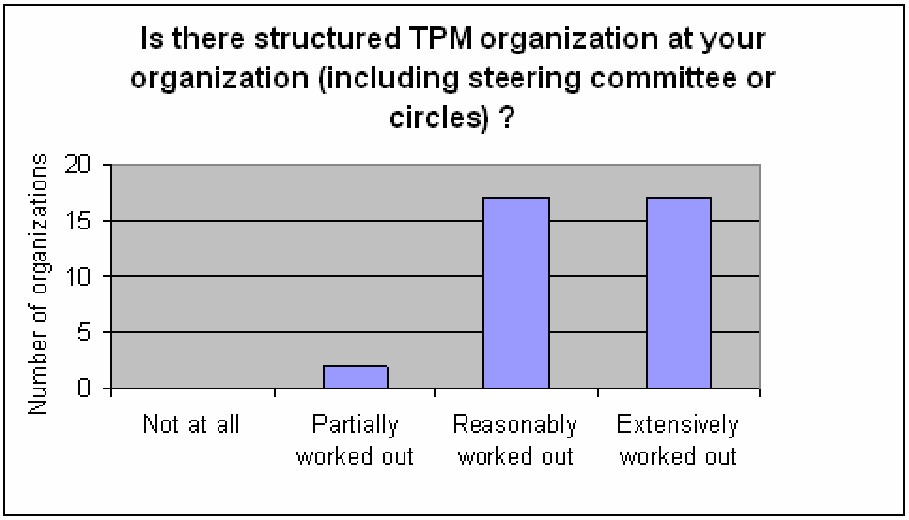


Fig 7.1.17 Implementation of structured TPM at organization including steering committee or circles

Figure 7.1.18 depicts the use of 5S principles and standards at organizational level. So from this figure we have 6% (2 out of 36 organizations) where some of the 5S principles and standards are employed in the organization, 58% (21 out of 36 organizations where 5S principles and standards are reasonably employed in the organization and 36% (13 out of 36 organizations) where 5S principles and standards are extensively employed in the organization which clearly shows the positive attitude of organization towards use of 5S principles to have good house keeping and towards proper maintenance and storage of spare parts and necessary tools.

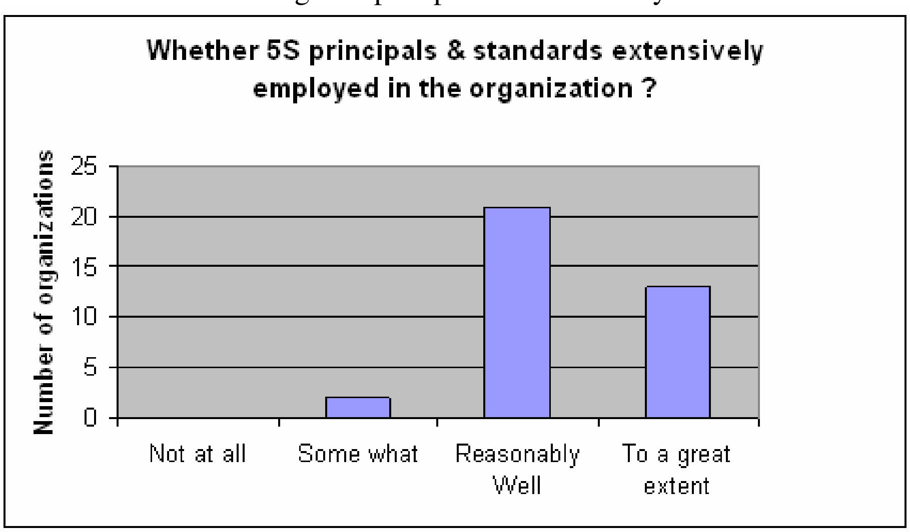


Fig 7.1.18 Use of 5S principals and standards in the organization

Figure 7.1.19 depicts the benefits reaped from implementation of TPM by better coordination between employees and management. So from this figure we have 6% (2 out of 36 organizations) feel that TPM has some what lead to a better coordination between the employees and the management, 55% (20 out of 36 organizations) feel that TPM has lead to a reasonably well coordination between the employees and the management and 39% (14 out of 36 organizations) feel that TPM has lead to a better coordination between the employees and the management to a great extent. So it clearly shows that implementation of TPM will lead to a better coordination between employees and management and they will collectively work to increase the productivity of organization and overcome misunderstandings between employees and the management.

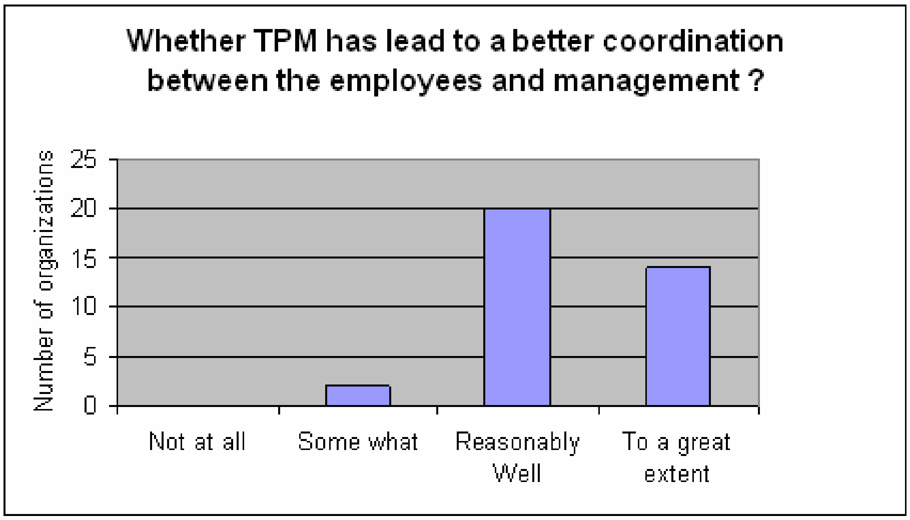


Fig 7.1.19 Coordination between employees and management after implementation of TPM in the organization

7.2 Significance of the study

Although a reasonable number of Indian entrepreneurs have experienced organizational success and transformations through TPM implementations, very few studies have been reported highlighting achievements of the Indian entrepreneurs. The literature reveals that very limited information is available regarding the contributions of TPM initiatives towards harnessing manufacturing performance achievements in the Indian manufacturing organizations.

The objective of this paper is to study the contributions of the various TPM pillar initiatives towards the realization of manufacturing performance achievements in the Indian manufacturing industry. The approach has been directed towards justification of TPM implementation for its support to competitive manufacturing in the context of Indian manufacturing industries. Moreover, the critical success factors in implementing TPM are also elaborated based on the learning from the study. The study reveals that holistic TPM implementation has contributed significantly towards the realization of enhancement in manufacturing competencies in the manufacturing organizations.

7.3 Correlation between TPM pillar initiatives and manufacturing performance achievements

The TPM pillar initiatives have been classified into eight categories namely autonomous maintenance (X1), focused improvement (X2), planned maintenance (X3), Quality Maintenance (X4), education and training (X5), office TPM (X6), safety, health and environment (X7) and development management (X8). The manufacturing performance achievements have been classified into six categories namely, productivity enhancements (Y1), quality enhancements (Y2), cost optimizations (Y3), delivery compliance (Y4), safety enhancements (Y5) and morale enhancements (Y6). In order to evaluate the extent of deployment of the various TPM pillar initiatives, a four-point Likert scale has been evolved in this study as described below:

TPM pillar initiatives	Manufacturing performance achievements
1 No emphasis at all 2 Very little emphasis 3 Reasonable emphasis 4 Extensive emphasis	1 Nominal gain 2 Reasonable gain 3 High gain 4 Extremely high gain

Table 7.3.1 Likert scale used for assessing deployment of various TPM pillar initiatives and resulting manufacturing performance achievements thereof

The Cronbach's alpha for various categories of inputs and outputs has been evaluated to ascertain the reliability of the input and output data collected through the TPM questionnaire (Table 7.3.4). The Cronbach's alpha values for all the inputs and outputs should be significantly greater than 0.50 regarding for validating the high reliability of data for various input and output categories.

Category	X1	X2	X3	X4	X5	X6	X7	X8
Cronbach's alpha	0.703	0.755	0.749	0.631	0.642	0.647	0.848	0.815

Table 7.3.2 Cronbach's alpha for input categories (TPM pillar initiatives)

Category	Y1	Y2	Y3	Y4	Y5	Y6
Cronbach's alpha	0.918	0.877	0.784	0.829	0.937	0.852

Table 7.3.3 Cronbach's alpha for output categories (manufacturing performance achievements).

The Cronbach's alpha for various sections of the questionnaire like maintenance organization and resource issues and for the total productive maintenance issues have also calculated. The Cronbach's alpha for various inputs and output categories in our questionnaire exceed 0.647 which indicates the high reliability of our data. The Pearson's Correlation coefficient 'r' between TPM Pillar Initiatives and Manufacturing Performance Achievements has also been computed. Here the TPM Pillar Initiatives are the eight input parameters i.e. eight pillars of TPM and the Manufacturing Performance Achievements are the six outputs which are can be elaborated as the benefits reaped from the implementation of the TPM

	Y1	Y2	Y3	Y4	Y5	Y6
X1	0.476923	0.673038	0.602781	0.615181	0.668487	0.517752
X2	0.567234	0.501036	0.53887	0.646444	0.746365	0.447171
X3	0.703969	0.637725	0.726709	0.688733	0.743405	0.673173
X4	0.394698	0.654551	0.607794	0.659637	0.568929	0.540464
X5	0.546913	0.46591	0.587006	0.482288	0.584662	0.345917
X6	0.612373	0.809825	0.769759	0.699315	0.762144	0.623371
X7	0.600578	0.605507	0.566241	0.87821	0.737288	0.838756
X8	0.635625	0.726564	0.654665	0.641139	0.59803	0.526413

Table 7.3.4 Pearson's Correlation 'r' between TPM Pillar Initiatives and Manufacturing Performance Achievements

		Y1	Y2	Y3	Y4	Y5	Y6
X1	t	3.163923	5.306128	4.405011	4.549912	5.241085	3.528787
	p	0.003273	<0.0001	0.0001	<0.0001	<0.0001	0.00122
X2	t	4.016138	3.375814	3.730017	4.940461	6.539103	2.915129
	p	0.000309	0.001854	0.000697	<0.0001	<0.0001	0.006251
X3	t	5.779545	4.827624	6.168481	5.53915	6.480994	5.308066
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
X4	t	2.504829	5.048367	4.462965	5.117607	4.033864	3.745596
	p	0.017208	<0.0001	<0.0001	<0.0001	0.000294	0.000667
X5	t	3.804199	3.070299	4.227866	3.210228	4.202182	2.149739
	p	0.000557	0.004186	0.000168	0.002894	0.000181	0.038778
X6	t	4.516642	8.048871	7.031469	5.704529	6.864331	4.648574
	p	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
X7	t	4.379802	4.436425	4.005782	10.70678	6.363567	8.981959
	p	0.000108	<0.0001	0.000318	<0.0001	<0.0001	<0.0001
X8	t	4.800913	6.165862	5.049905	4.871418	4.350841	3.610192
	p	<0.0001	<0.0001	<0.0001	<0.0001	0.000117	0.000974

Table 7.3.5 't' value with significance factor 'p' between TPM Pillar Initiatives and Manufacturing Performance Achievements

On the basis of the responses received from the industry, an assessment of association of the various TPM pillar initiatives with manufacturing performance parameters has been made. Table 7.3.4 and Table 7.3.5 depicts the Pearson correlations, 't' values and significance level 'p' values for pairs of inter-relationships between various TPM pillar initiatives and manufacturing performance achievements. Only those pairs with Pearson correlation 'r' greater or equal to 50% and statistically significant at 5% level of significance are considered as having a significant association. The 't Critical' value for the confidence limits corresponding to n – 2 (= 34) degrees of freedom and significance level of 5%, from statistical 't' tables, works out to be 2.02 , which is lower than the 't' values obtained for the various input-output combinations as revealed in Table 7.3.5. This further validates the high correlation between the various TPM pillar initiatives and manufacturing performance achievements.

In order to investigate critical success factors for achieving results through holistic TPM implementation, the significant correlations thus obtained as a result of Pearson's Correlation and t Test are validated through 'Multiple Regression Analysis' as depicted in Table below. The notations depicted in the table will include: β = Regression coefficient (beta coefficient), R = Multiple correlation coefficient. The significant factors with (β) significance level, multiple correlation coefficient (R) and F values for each performance parameter are indicated in the Table 7.3.6. The results imply that there is a significant contribution of various TPM success factors depicted in the table with the respective manufacturing performance parameters reported

The research provides an empirical evidence of a strong relationship between TPM pillar initiatives and manufacturing performance enhancements. The critical examination of the Pearson's correlations and 't' test results explicitly depict that holistic adaptation of strategic TPM pillar initiatives in the organizations have significant impact on the realization of the overall manufacturing performance enhancements in the organizations. This has been validated through high Pearson's coefficients, varying from 0.721 to 0.844, between various TPM pillar initiatives and overall manufacturing performance improvements.

It has been observed that Y1 is closely associated with X3 for the realization of the overall manufacturing performance enhancements through efficient and effective planning and deployment of preventive, predictive and time based maintenance initiatives for the production systems over the entire equipment life cycle.

The X6 and X8 can facilitate organizations to harness significant Y2 by eliminating the barriers between various organizational functions, improving synergy between different business functions, deploying appropriate organization structure and resources, eliminating procedural hassles, optimization of inventory and other resources associated with the production system, adopting 5 S principals for effective workplace management .X8 is also closely associated with the realization of the overall manufacturing performance enhancements by addressing problems and running in time on new equipments, deploying learning from existing systems to new facilities and effectively implementing maintenance prevention and improvement initiatives The X6and X3 can facilitate organizations to harness significant Y3 by streamlining the production facilities, improvements in equipment reliability, ensuring better upkeep of the production facilities, ensuring zero defects .

Performance Parameter	Significance Factor	Beta Value β	t Value	Significance (p Value)	R Value	F Value
Y1	**X3**	0.757346	3.142944	0.003524	0.720407	17.80251
Y2	**X6**	0.815094	4.765316	< 0.0001	0.848727	42.49982
	X8	0.530723	2.759277	0.009378		
Y3	**X3**	0.39886	2.438824	0.020281	0.80917	31.29222
	X6	0.575667	3.47932	0.001434		
Y4	**X6**	0.228886	2.103579	0.04312	0.893476	65.3041
	X7	0.862913	7.113153	< 0.0001		
Y5	**X2**	0.709371	3.207658	0.002972	0.824915	35.1407
	X6	0.600921	3.570356	0.001118		
Y6	**X7**	0.979739	5.48349	< 0.0001	0.84491	41.16661

Table 7.3.6 Results of Multiple Regression Analysis between TPM Pillar Initiatives and Manufacturing Performance Achievements

The X3 influences Y3 the most by focusing on addressing cost related issues and facilitating working through self managed (autonomous) project teams and problem solving groups by stabilization of production systems, affecting maintenance prevention improvements on the production system, enhancing the human resource capabilities and affecting improvements in the reliability of manufacturing systems. Effective planned maintenance programs can strategically contribute towards productivity improvements by improving the basic equipment conditions, reducing unplanned downtimes and setup times, minimizing troubles related with equipment upkeep and operations.

Furthermore, X6 and X7 have exhibited significant linkage with Y4 by affecting improvements in equipment reliability, ensuring better upkeep of the production facilities, improving autonomous maintenance capabilities of production operators, providing safe working environment, improvements in operational efficiency, affecting improvements in employee skill base, providing training related to basic maintenance related skills, quality improvement tools and conducting analysis for the maintenance improvement initiatives

It has been observed that Y5 are closely associated with X2 and X6, since the successful implementation of continuous improvement initiatives in the form of Kaizens for addressing major and minor losses/wastages associated with production systems can strategically lead to significant enhancement in the performance of production facilities thereby contributing towards streamlining of production system performance, permanently improving responsiveness and flexibility of production systems, ensuring competitive pricing of the products and quality assurance as per laid out standards. Effective focused improvement initiatives can strategically contribute towards improving the competitive position of organizations leading to enhanced productivity, returns on net assets and returns on capital employed.

The results highlight that X7 can contribute effectively towards improvement of Y6 in the organization by affecting significant improvements in equipment reliability, ensuring better upkeep of production facilities, providing safe working environment, improving autonomous maintenance capabilities of production operators, improvements in operational efficiency, affecting improvements in employee skill base, providing training related to basic maintenance related skills, quality improvement tools and conducting analysis for the maintenance improvement initiatives.

7.4 Effect of TPM implementation period on manufacturing performance Improvements

To investigate the effect of TPM implementation period on the extent of manufacturing performance parameters accrued, the responses obtained from various manufacturing organizations have been classified into three categories depending upon the experience gained over an extended period, by various manufacturing enterprises towards implementing TPM initiatives, as indicated in Table below. The Table 7.4.1 summarizes the improvements in various manufacturing performance parameters based upon the TPM implementation time period. The table depicts the average and standard deviations of gains accrued for various manufacturing performance parameters as a result of adaptation of effective TPM implementation of

Results of Two Tailed ‘t’ Test for improvements in Manufacturing Performance Achievements with respect to variable time periods									
Performance Parameters	Mean and Standard deviation						t (II/I)	t (III/I)	t (III/II)
	Phase–I		Phase–II		Phase-III				
	Introductory Phase		Stability Phase		Maturity Phase				
	Less than 3 years		3 – 5 Years		> 5 Years				
	N=15		N=9		N=12				
	MEAN	SD	MEAN	SD	MEAN	SD			
Y1	0.56	0.21	0.91	0.05	0.87	0.11	6.17 (<0.0001)	3.0450 (0.0060)	1.1150 (0.2800)
Y2	0.54	0.19	0.84	0.08	0.90	0.12	5.3730 (<0.0001)	5.9940 (<0.0001)	1.3720 (0.1850)
Y3	0.59	0.14	0.83	0.06	0.82	0.17	5.8090 (<0.0001)	3.7740 (0.0010)	0.1890 (0.8530)
Y4	0.64	0.17	0.76	0.10	0.85	0.12	2.1770 (0.0400)	3.7560 (0.0010)	1.8720 (0.0760)
Y5	0.67	0.19	0.94	0.11	0.95	0.09	4.4080 (<0.0001)	5.0440 (<0.0001)	0.2230 (0.8260)
Y6	0.64	0.19	0.81	0.08	0.93	0.11	3.0450 0.006	4.9630 (<0.0001)	2.8940 (0.0090)

Table 7.4.1 Results of Two Tailed ‘t’ Test for improvements in Manufacturing Performance Achievements with respect to variable time periods

initiatives in the organizations. It has been observed that the mean values of the manufacturing performance improvements accrued in Phase-II and Phase-III are significantly higher than those obtained in Phase-I, while the mean values of the manufacturing performance improvements accrued in Phase-III are only marginally higher than those obtained in Phase-II.

The marginal improvement (not significant) in manufacturing performance parameters in the maturity phase (Phase-III) as compared to stabilization phase (Phase-II) can be attributed to the fact that TPM implementation in the Indian industry is still gaining momentum, with only a few manufacturing organizations having experience exceeding 5-6 years regarding TPM practices.

Thus in the absence of responses from large number of organizations having reasonably longer experience with TPM implementation, the enhanced contributions of TPM with time for Phase III with respect to Phase II cannot be validated. Table 7.4.1 depicts the comparative analysis of manufacturing performance improvements accrued in various time periods by effective TPM implementation program, using a Two-tailed t test, at the significance level p of 0.05. The tests t (II/I), t (III/I) and t (III/II) have been conducted to ascertain the statistical difference in effectiveness of various manufacturing performance improvements accrued as a result of successful TPM implementation initiatives.

7.5 Result discussion for effect of TPM implementation time period on manufacturing performance enhancement

The t (II/I) values, indicated in Table 7.4.1, for various manufacturing performance improvements validate the significant realization of manufacturing performance improvements in the stabilization phase as compared to the introductory phase.
Similarly, the t (III/I) values validate the significant realization of manufacturing performance improvements in the maturity phase as compared to the introductory phase. However, t (III/II) values reveal only a marginal improvement (not significant) in the manufacturing performance parameters in the maturity phase as compared to the stabilization phase.

This can be attributed to the fact that most of the organizational responses in the Phase-II have been observed to be pretty close to the higher TPM implementation period, that is, marginally below five years, while most of the organizational responses in the Phase-III have been observed to be pretty close to the lower limit of TPM implementation period, which is marginally above five years.

Thus the significance of manufacturing performance improvements accrued in Phase III as compared to Phase II, could not be validated in the present context. Thus, in the context of the present study, it can be concluded that usually 3 to 5 years of whole hearted TPM implementation is needed to realize significant results.

7.6 Scope of future research work

- The study is based upon manufacturing units. Similar study can be extended further for process industries, service sector industries (Finance, Marketing) and also to administration sector.

- The study has been conducted in the Manufacturing Sector as a whole. However sector wise study can also be conducted considering specific areas of manufacturing industry.

- Here we have conducted an empirical study of data obtained through questionnaire using various statistical tools. The results obtained through questionnaire can be validated or substainted by performing case studies on selected manufacturing, process and service sector industries.

- The study can also be conducted in finance/accounting, marketing and also to administrative sector in order to have a proper work culture to boost the morale of the employed person over there and also to have an increased customer satisfaction.

CHAPTER 8
CONCLUSIONS

Maintenance is of ever-increasing importance to industry as technology becomes more sophisticated, spiraling inflation strains capital investment and energy problems adversely affect profits. The success of organizational objectives relies heavily on effectiveness of managing the maintenance function. The maintenance function may also be a source of competitive advantage thereby achieving a sustainable edge over competitors. Effective maintenance extends equipment life, improves equipment availability and retains equipment in appropriate condition. Maintenance, as a support function in enterprises, plays an important role in backing up several emerging business and operation strategies (Pun et al., 2002). Given the significance of maintenance in today's operating environment, excellence in maintenance performance becomes a strategic issue of capital intensive organizations.

As organizations across the globe have faced stiff cut-throat competition in last three decades, Indian industry too could not escape the brunt of globalization. In the globalized era, Indian manufacturing organizations have been faced with seven C's of change, complexity of change, challenges, competition, competitiveness, customers and creativity. Total Productive Maintenance (TPM) has emerged as the most potent business strategy for affecting significant improvement in manufacturing performance to meet global challenges. In last one and a half decades, leading Indian manufacturing entrepreneurs have taken proactive initiatives to imbibe state-of-art TPM initiatives to realize enhanced manufacturing performance.

The strategic implications of quality and maintenance to improve competitiveness have been well understood by Indian business captains in the beginning of last decade. In the present context, Indian manufacturing organizations have risen to the occasion and progressed to envisage efficient maintenance policies for helping the enterprises to enhance production system reliability, cost effectiveness of production operations, thereby enabling organizations to realize competencies for mitigating the challenges posed by global competition.

Finally, study reveals that TPM is the most significant proactive strategic initiative which can lead Indian manufacturing organizations to attain new levels of achievements and can really differentiate between success and failure.

REFERENCES

- Adler, P.S. (1993), 'Time-and-motion regained', Harvard Business Review, Vol. 71, No. 1, pp. 97-108.
- Ahuja, I.P.S. and Khamba, J.S. (2007) 'An evaluation of TPM implementation initiatives in an Indian manufacturing enterprise', Journal of Quality in Maintenance Engineering, Vol. 13, No. 4, pp. 338–352.
- Ahuja, I.P.S. and Khamba, J.S. (2008) 'Investigation of manufacturing performance achievements through strategic total productive maintenance initiatives', International Journal of Productivity and Quality Management (IJPQM), Vol. 4, No. 2, pp. 129–152.
- Ahuja, I.P.S., Khamba, J.S. and Choudhary, R. (2006) 'Improved organizational behavior through strategic total productive maintenance implementation', Proceedings of 2006 ASME International Mechanical Engineering Congress and Exposition (IMECE), at Chicago, Illinois (U.S.A.) from 5-10 November, pp. 1-8. (Paper No. IMECE2006-15783).
- Ahuja, I.P.S., Singh, T.P., Sushil and Wadood, A. (2004) 'Total productive maintenance implementation at Tata Steel for achieving core competitiveness', Productivity, Vol. 45, No. 3, pp. 422–426.
- APEC (1998) 'Eco-efficiency in small and medium enterprises – a best practice manual: the steel and metal products industry', Asia-Pacific Economic Cooperation (APEC), Singapore
- Argyris, C. (1998) 'Empowerment: the emperor's new clothes', Harvard Business Review, Vol. 76, No. 3, pp. 98-105.
- Ashayeri, J. (2007) 'Development of computer-aided maintenance resources planning (CAMRP): a case of multiple CNC machining centers', Robotics and Computer Integrated Manufacturing, Vol. 23, No. 6, pp. 614–623.
- Askin, R. and Standridge, C.R. (1993) Modeling and Analysis of Manufacturing Systems, John Wiley and Sons, New York, NY.
- Avery, S. (1993) 'World Class redefines role of maintenance', Purchasing, Vol. 144, No. 4, pp. 14–18.
- Bamber, C.J. Sharp, J.M. and Hides, M.T. (1999) 'Factors affecting successful implementation of total productive maintenance: a UK manufacturing case study perspective', Journal of Quality in Maintenance Engineering, Vol. 5, No. 3, pp. 162-181.
- Basu, R. (2001) 'Six sigma to fit sigma', IIE Solutions, Vol. 33, No. 7, pp.28–33.
- Becker, S.W. (1993) 'TQM does work: Ten reasons why misguided efforts fail', Management Review, Vol. 82, No. 5, pp. 30–34.
- Ben-Daya, M. and Duffuaa, S.O. (1995) 'Maintenance and quality: the missing link', Journal of Quality in Maintenance Engineering, Vol. 1, No. 1, pp. 20–26.
- Ben-Daya, M., Duffuaa, S.O. and Raouf, A. (Eds) (2000) Maintenance, Modeling and Optimization, Kluwer Academic Press,Boston, MA.
- Besterfield, D.H., Besterfield-Michna, C., Besterfield, G.H. and Besterfield-Sacre, M. (1999) Total Quality Management, 2nd edition, Englewood Cliffs, NJ: Prentice-Hall International, Inc., pp. 473–477.
- Blanchard, B.S. (1997) 'An enhanced approach for implementing total productive maintenance in the manufacturing environment', Journal of Quality in Maintenance Engineering, Vol. 3, No. 2, pp. 69–80.

- Blischke, W.R. and Murthy, D.N.P. (2000) Reliability, John Wiley and Sons, NewYork,NY.
- Braglia, M., Carmignani, G., Frosolini, M. and Grassi, A. (2006) 'AHP-based evaluation of CMMS software', Journal of Manufacturing Technology Management, Vol. 17, No. 5, pp. 585–602.
- British Standards Institution (1993) BS3811:1993, British Standard Glossary of Maintenance Management Terms in Terotechnology, BSI, Hemel Hempstead.
- Brown, C.B. and Yao, T.P. (1983) 'Fuzzy sets and structural engineering', Journal of Structural Engineering, Vol. 109, pp. 1211-1225.
- Bulmer, M. and Eccleston, J.E. (2002) 'Photocopier reliability modelling using evolutionary algorithms', in Blischke, W.R. and Murthy D.N.P. (Eds), Case Studies in Reliability and Maintenance, John Wiley and Sons, New York, NY.
- Cai, K.Y. (1996) 'System failure engineering and fuzzy methodology. An introductory overview', Fuzzy Sets and Systems, Vol. 83, pp. 113-133.
- Cai, K.Y., Wen, C.Y. and Zhang, M.L. (1991) 'A critical review on software reliability modeling', Reliability Engineering and System Safety, Vol. 32, pp. 357-371.
- Campbell, J.D (1995) Up Time, Productivity Press, Portland, OR, .
- Campbell, J.D. (1995) 'Outsourcing in maintenance management: a valid alternative to self provision', Journal of Quality in Maintenance Engineering, Vol. 1 No. 3, pp. 18-24**.**
- Campbell, J.D. and Jardine, A.K.S. (Eds) (2001) Maintenance Excellence: Optimizing Equipment Life-Cycle Decisions, Marcell Dekker, New York, NY.
- Carannantes, T., Haigh, R.H. and Morris, D.S. (1996) 'Implementing total productive maintenance: A comparative study of the UK and Japanese foundry industries', Total Quality Management, Vol. 7, No. 6, pp. 605–611.
- Carter, R.A. (2001) 'Shovel maintenance gains from improved designs, tools and techniques', Elsevier Engineering Information, Vol. 106, No. 8, p. S7.
- Cen, Y.T. (1996) 'Fuzzy quality and analysis on fuzzy probability', Fuzzy Sets and Systems, Vol. 83, pp. 283-90.
- Champion, D. and Carr, N.G. (2000), 'The next B2B boom', Harvard Business Review, Vol. 78 No. 4.
- Chan, F.T.S., Lau, H.C.W, Ip, R.W.L., Chan, H.K., Kong, S., (2003) Implementation of Total Productive maintenance, A case study, International Journal of Production Economics, pp 71-94
- Chand, G. and Shirvani, B. (2000) 'Implementation of TPM in cellular manufacturing', Journal of Material Processing Technology, Vol. 103, pp. 149-154.
- Chandra, S and Krishna, M.G. (1998) 'Total productive maintenance – implementation in Indian industry', Indian Management Journal, Vol. 37, No. 11, pp.49–58.
- Chen, F (1994) 'Benchmarking: preventive maintenance practices at Japanese transplants', International Journal of Quality and Reliability Management, Vol. 11 No.8, pp.19-26
- Chen, S.H. (1985) 'Ranking fuzzy numbers with maximizing and minimizing set', Fuzzy Sets and Systems, Vol. 17 No. 2, pp. 113-129.
- Cho, D. and Parlar, M. (1991) 'A survey of maintenance models for multi-unit systems', European J. Operational Research, Vol. 51, No. 13, pp. 1-23.
- Chowdhury, C. (1995) 'NITIE and HINDALCO give a new dimension to TPM', Udyog Pragati, Jan – March, Vol. 22, No. 1, pp. 5–11.

- ChoyDS, S.Y. (2003) TPM Implementation Experiences, an article on Maintenance Resources.com, a monthly online Magazine, http://www.maintenance resources.com
- Clamp, A.C. (1996) Profit from your Maintenance, Work Structuring Ltd, Surrey**.**
- Coetzee, J.L. (1999) 'A holistic approach to the maintenance problem', Journal of Quality in Maintenance Engineering, Vol. 5, No. 3, pp. 276–280.
- Cousens, D.R., Wood, B.J., Wang, J.Q. and Atrens, A. (2000) 'Implications of specimen preparation and of surface contamination for the measurements of grain boundary carbon concentration of steels using x-ray microanalysis in a UHVFESTEM', Surface and Interface Analysis, Vol. 29, pp. 23-32.
- Crawford, K.M., Blackstone, J.H. (Jr.) and Cox, J.F. (1988) 'A study of JIT implementation and operating problems', International Journal of Production Research, Vol. 26, No. 9, pp. 1561–1568.
- Cross, J. (1995) 'IT outsourcing: British Petroleum's competitive approach', Harvard Business Review, Vol. 73, No. 3, pp. 94-102.
- Cross, M. (1988) 'Raising the value of maintenance in the corporate environment', Management Research News, Vol. 11, No. 3, pp. 8-11.
- Cua, K.O., McKone, K.E. and Schroeder, R.G. (2001) 'Relationships between implementation of TQM, JIT, and TPM and manufacturing performance', Journal of Operations Management, Vol. 19, No. 6, pp. 675–694.
- Cua, K.O., McKone, K.E. and Schroeder, R.G. (2006) 'Improving Performance through an Integrated Manufacturing Program', The Quality Management Journal, Vol. 13, No. 3, pp. 45–60.
- Dal, B., Tugwell, P. and Greatbanks, R. (2000) 'Overall equipment effectiveness as a measure for operational improvement', International Journal of Operations and Production Management, Vol. 20, No. 12, pp.1488–1502.
- Davenport, T.H. (1998) 'Putting the enterprise into the enterprise system', Harvard Business Review, Vol. 76, No. 4, pp. 121-131.
- Davies, A. (1990) 'Management guide to condition monitoring in manufacturing', The Institution of Production Engineers, Holbrook and Son, London.
- Davis, R. and Willmott, P. (1999) Total Productive Maintenance, Asset Maintenance Management, Oxford: Alden Press.
- De Groote, P. (1995) 'Maintenance performance analysis: a practical approach', Journal of Quality in Maintenance Engineering, Vol. 1, No. 2 , pp. 4-24.
- Dekker, R. (1996) 'Applications of maintenance optimization models: a review and analysis', Reliability Engineering and System Safety, Vol. 51, pp. 229-240.
- Dekker, R., Wildeman, R.E. and van der Duyn Schouten, F.A. (1997) 'Review of multi-component models with economic dependence', Zor/Mathematical Methods of Operations Research, Vol. 45, No. 3, pp. 411-435.
- Dossenbach, T. (2006) 'Implementing total productive maintenance: a successful TPM program will help you eliminate defects, machine breakdowns and accidents', Wood and Wood Products, Vol. 111, No. 2, pp. 29–32.
- Duffuaa, S.O., Raouf, A. and Campbell, J.D. (1999) Planning and Control of Maintenance Systems: Modelling and Analysis, John Wiley, New York.
- Dunn, R.L (1992) 'Plant engineering management at John Deere', Plant Engineering, Vol. 46, No.1, pp.78-82.
- Dwyer, J. (1999) 'More than a maintenance technique', Works Management, Vol. 52, No. 9, pp. 15–16.

- Eisingier, S. and Rakowsky, U.K. (2001) 'Modeling uncertainties in RCM – a probabilistic approach', Reliability Engineering and System Safety, Vol. 71, No.4, pp. 159-164.
- Elangovan, K., Selladurai, V., Devadasan, S.R., Goyal, S.K. and Muthu, S. (2007) 'Quality and productivity improvement of executive decisions in maintenance engineering: an ESS-based approach', International Journal of Productivity and Quality Management, Vol. 2, No. 1, pp. 112–139.
- Environment protection Agency, USA (2006) Total Productive Maintenance (TPM), Lean Manufacturing and the Environment, http://www.epa.gov/lean/thinking/TPM.htm
- Eti, M.C., Ogaji, S.O.T. and Probert, S.D. (2004) 'Implementing total productive maintenance in Nigerian manufacturing industries', Applied Energy, Vol. 79, No. 4, pp. 385–401.
- Eti, M.C., Ogaji, S.O.T. and Probert, S.D. (2006) Reducing the cost of preventive maintenance (PM) through adopting a proactive reliability-focused culture, Applied Energy, Vol.83, No.11, pp. 1235–1248.
- Foster, G. and VanTran, H. (1990) 'Maintenance and Money', Information Strategy: The Executive's Journal, Spring, pp. 40–45.
- Garg, A. and Deshmukh, S.G. (2006) 'Maintenance management: literature review and directions', Journal of Quality in Maintenance Engineering, Vol. 12, No. 3, pp.205–238.
- George, M. (2002) Lean Six Sigma: Combining Six Sigma Quality with Lean Speed, New York: McGraw-Hill.
- Gertsbakh, I.B. (1977) Models of Preventive Maintenance, North-Holland Publishing Company, New York, NY
- Ghalayini, A.M. and Noble, J.S. (1996) 'The changing basis of performance measurement', International Journal of Operations and Production Management, Vol. 16 No. 8, pp. 63-80.
- Giegling, S., Verdini, W.A., Haymon, T. and Konopka, J. (1997) 'Implementation of overall equipment effectiveness (OEE) system at a semiconductor manufacturer', Proceedings of IEEE/CPMT International Electronics Manufacturing Technology Symposium, pp. 93-97.
- Gits, C. (1992) 'Design of maintenance concepts', International Journal of Production Economics, Vol. 24, No. 3, pp. 217-226.
- Gits, C.M. (1994) 'Structuring maintenance control systems', International Journal of Operations and Production Management, Vol. 14, No. 7, pp. 5-17.
- Gits, C.W. (1986) 'On the maintenance concept for a technical system: II. Literature review', Maintenance Management International, Vol. 6, No.3, pp. 181-196.
- Gomes, C.F., Yasin, M.M. and Lisboa, J.V. (2006) 'Performance measurement practices in manufacturing firms: an empirical investigation', Journal of Manufacturing Technology Management, Vol. 17, No. 2, pp.144–167.
- Gosavi, A. (2006) 'A risk-sensitive approach to total productive maintenance', Automatica, Vol. 42, No. 8, pp. 1321–1330.
- Gregory, A. (2006) 'Number cruncher – overall equipment effectiveness and total productive maintenance', Works Management, Vol. 59, No. 7, pp.18–20.
- Hall, R.K. (1990) Total Productive Maintenance: Reduce Breakdowns, Improve Quality, and Increase Profit through Time-based Equipment Management, American National Can,
- Hannan, R. and Keyport, D. (1991) 'Automating a Maintenance Work Control System', Plant Engineering, Vol. 45, No. 6, pp. 108–110.

- Hartmann, E., ‘Prescription for total TPM success’, Maintenance Technology Magazine online 13, no. 4, April 2000
- Heizer, J. and Render, B. (2001) Principles of Operations Management, 4th ed., Prentice-Hall, Englewood Cliffs, NJ, pp. 698-710**.**
- Hermann, N. (2004) The key success factor of implementing TPM activity, A case study, Katalog
- Heston, T. (2006) ‘Culture change for maintenance’, Fabrication and Metalworking, Vol. 5, No. 9, pp.70–72.
- Hura, G.S. and Atwood, J.W. (1988) ‘The use of Petri nets to analyze coherent fault trees’, IEEE Transactions on Reliability, Vol. 375, pp. 469-474.
- Ireland, F. and Dale, B.G. (2001) ‘A study of total productive maintenance implementation’, Journal of Quality in Maintenance Engineering, Vol. 7, No. 3, pp.183–192.
- Ireland, F. and Dale, B.G. (2006) ‘Total productive maintenance: criteria for success’, International Journal of Productivity and Quality Management, Vol. 1, No. 3, pp.207–223.
- Jardine, A.K.S. (1973) Maintenance, Replacement, and Reliability, Pitman/Wiley, London.
- Jardine, A.K.S. and Buzacott, J.A. (1985) ‘Equipment reliability and maintenance’, European Journal Operational Research, Vol. 19, No.5, pp. 285-296.
- Jeong, K-Y. and Phillips, D.T. (2001) ‘Operational efficiency and effectiveness measurement’, International Journal of Operations and Production Management, Vol. 21, No. 11, pp. 1404–1416.
- Karuppuswamy, P., Sundararaj, G. and Elangovan, D. (2007) ‘Application of computerized maintenance management system coupled with risk management techniques for performance improvement of manufacturing systems’, International Journal of Business Performance Management, Vol. 9, No. 1, pp. 7–21.
- Keller, A.Z. and Kara-Zaitri, C. (1989) ‘Further applications of fuzzy logic to reliability assessment and safety analysis’, M&R, Vol. 29, pp. 399-404.
- Kelly, A. (1989) Maintenance and its Management, Ashford Press Ltd.
- Kennedy, R. (2005) Examining the Process of RCM and TPM, The Center for TPM (Australasia), The Plant Maintenance Resource Center, pp 9-13.
- Khanna, V.K.(2008),‘Total productive maintenance experience: case study’ International Journal of Productivity and Quality Management , Vol. 3, No.6 , pp.12-32
- Kodali, R. (2001) ‘Quantification of Total Productive Maintenance (TPM) benefits through AHP model’, Productivity, Vol. 42, No. 2, pp. 265–274.
- Kodali, R. and Chandra, S. (2001) ‘Analytical hierarchy process for justification of total productive maintenance’, Production Planning and Control, Vol. 12, No. 7, pp. 695–705.
- Konopka, J. and Trybula, W. (1996) ‘Overall equipment effectiveness (OEE) and cost measurement’, Proceedings of IEEE/CPMT International Electronics Manufacturing Technology Symposium, pp. 137-140.
- Kodali ,R.and Prasad , R.(2009) , ‘Methodology and theory Justification of world –class maintenance systems using analytic hierarchy constant sum method ’, Journal of Quality in Maintenance Engineering Vol. 15, No 1 , pp. 47-77.
- Kutucuoglu, K.Y., Hamali, J., Irani, Z. and Sharp, J.M. (2001) ‘A framework for managing maintenance using performance measurement systems’, International Journal of Operations and Production Management, Vol. 21, No. 1/2, pp. 173–194.

- Leachman, R.C. (1995) Closed-loop measurement of equipment efficiency and equipment capacity', Proceedings of IEEE/SEMI Advanced Semiconductor Manufacturing Conference, pp. 115-126.
- Leblanc, G. (1995) 'Tapping the true potential of TPM: are you maximizing the value of your plant's program?' Plant Engineering, Vol. 49, No. 10, pp. 143–148.
- Levitt, J. (1996) Managing Factory Maintenance, Medison Avenue, New York: Industrial Press Inc.
- Lewis, J. (2006) 'Eliminating defective product waste', FDM (Des Plaines), Vol. 78, No. 13, pp. 73–76.
- Liang, H.C. and Weng, M.C. (2002) 'Using fuzzy approaches to evaluate quality improvement alternative based on quality costs', International Journal of Quality and Reliability Management, Vol. 19, No. 2, pp. 122-136.
- Ljungberg, O. (1998) 'Measurement of overall equipment effectiveness as a basis for TPM activities', International Journal of Operations and Production Management, Vol. 18 No. 5, pp. 495-507.
- Madu, C.N. (2000) 'Competing through maintenance strategies', International Journal of Quality and Reliability Management, Vol. 17, No. 9, pp. 937–949.
- Maggard, B.N, Rhyne, D.M (1992) 'Total productive maintenance: a timely integration of production and maintenance', Production and Inventory Management Journal, Vol. 33 No. 4, pp. 6-10.
- Maier, F.H., Milling, P.M. and Hasenpusch J. (1998) Total Productive Maintenance: An International Analysis of Implementation and Performance, Mannheim, Germany, web site http://iswww.bwl.uni-mannheim.de/lehrstuhl/publikationen/TPM.pdf.
- Makis, V. and Jardine, A.K.S. (1992) 'Optimal replacement in the proportional hazards model', INFOR, Vol. 30 No. 1, pp. 172-183.
- Marcus, D. (2004) 'World class maintenance', Modern Casting, Vol. 94, No. 8, p. 44.
- McBRIDE, D. (2004) Implementing TPM Total Productive Maintenance (TPM), Lean Manufacturing Consulting and Training, EMS Consulting Group (http://www.emsstrategies.com)
- McCall, J.J. (1965) 'Maintenance policies for stochastically failing equipment: a survey', Management Science, Vol. 11, pp. 493-524.
- McCarthy, D. (2004) Lean TPM, UK: Butterworth Heinemann.
- McKone, K., Schroeder, R. and Kristy, C. (1999) 'Total productive maintenance: a contextual view', Journal of Operations Management, Vol. 17, No.3, pp. 123-144.
- Mileham, A.R., Culley, S.J., McIntosh, R.I., Gest, G.B. and Owen, G.W. (1997) 'Set-up reduction (SUR) beyond total productive maintenance (TPM)', Proceedings of Institution of Mechanical Engineers, Vol. 211, part B, pp. 253-260.
- Ming-Hong, L. (2004) Factors affecting the implementation of Total Productive Maintenance System,
- Mishra, R.P., Anand, G. and Kodali, R. (2007) 'Strengths, weaknesses, opportunities and threats analysis for frameworks of world-class maintenance', Proceedings of the I MECH E Part B Journal of Engineering Manufacture, Vol. 221, No. 7, pp. 1193–1208.
- Miyake, D.I. and Enkawa, T. (1999) 'Matching the promotion of total quality control and total productive maintenance: an emerging pattern for nurturing of well-balanced manufactures', Vol. 10, No.2, pp.243-269.
- Mobley, R.K. (1990) 'An Introduction to Predictive Maintenance', Van Nostrand Reinhold, New York, NY.

- Monahan, G.E. (1982) ‘A survey of partially observable Markov decision processes: theory, models and algorithms’, Management Science, Vol. 28, pp. 1-16.
- Mora, E. (2002) The Cost of not implementing TPM, article on TPMonline.com.
- Mora, E. (2002) The Right Ingredients for a Successful TPM or Lean Implementation, article on TPMonline.com.
- Mora. E. (2002) TPM is easier to get started than you thought, article on TPMonline.com.
- Moubray, J. (1991) Reliability Centered Maintenance, Butterworth -Heinemann, Oxford.
- Moubray, J. (1997) Reliability Centered Maintenance, 2nd ed., Butterworth-Heinemann, Oxford.
- Moubray, J. (2000) available at: www.maintenanceresources.com
- Naguib, H (1993) ‘A Roadmap for the Implementation of Total Productive Maintenance (TPM) in a Semiconductor Manufacturing Operations’, Semiconductor Manufacturing Science Symposium, ISMSS–1993., IEEE/SEMI International, 19–20 July, pp. 89–97.
- Nakajima, S. (1988) An Introduction to TPM, Productivity Press, Portland, OR.
- Nakajima, S. (1989) TPM Development Program: Implementing Total Productive Maintenance, Cambridge: Productivity Press Inc.
- Neely, A.D., Gregory, M.J. and Platts, K.W. (1995) Performance Measurement System design – a literature review and research agenda, International Journal of Operations and Production Management, Vol.15, No.4, pp. 80–116.
- Niebel, B. (1985) Engineering Maintenance Management, MarcelDekker,New York,NY.
- Niebel, B.W. (1996) Engineering Maintenance Management, 2nd ed., Marcel Dekker, New York, NY.
- Noori, H. and Radford, R. (1995) Production and Operations Management: Total Quality and Responsiveness, McGraw-Hill, New York, NY.
- Ogaji, S.O.T., Eti, M.C. and Probert, S.D. (2006) ‘Impact of corporate culture on plant maintenance in the Nigerian electric-power industry’, Applied Energy, Vol. 83, No. 4, pp. 299–310.
- Ollila, A. and Malmipuro, M. (1999) ‘Maintenance has a role in quality’, The TQM Magazine, Vol. 11, No. 1, pp.17–21.
- Onisawa, T. (1988) 'An approach to human reliability in man-machine system using error possibility’, Fuzzy Sets and Systems, Vol. 27, No. 2, pp. 87-103.
- Patterson, J.W, Fredendall, L.D, Kennedy, W.J., McGee, A (1996) ‘Adapting total productive maintenance to Austin, Inc.’, Production and Inventory Management Journal, Vol. 37, No.4, pp.32-36.
- Patterson, J.W, Kennedy, W.J, Fredendall, L.D (1995) ‘Total productive maintenance is not for this company’, Production and Inventory Management Journal, Vol. 36, No.2, pp. 61-63.
- Pierskalla, W.P. and Voelker, J.A. (1976) ‘A survey of maintenance models: the control and surveillance of deteriorating systems’, Naval Research Logistics Quarterly, Vol. 23, No.7, pp. 44-49
- Pintelon, L. and Gelders, L. (1992) ‘Maintenance management decision making’, European Journal of Operational Research, Vol. 58, No.2, pp. 301-317.
- Pintelon, L., Pinjala, S.K. and Vereecke, A. (2006) ‘Evaluating the effectiveness of maintenance strategies’, Journal of Quality in Maintenance Engineering, Vol. 12, No. 1, pp. 7–20.

- Pessan, Cedric (2007), 'Multi-skill Project Scheduling Problem and Total Productive Maintenance', European Journal of Operational Research Vol.78 No.2, pp. 146 – 161
- Pintelton, L.M. and Gelders, L. (1992) 'Maintenance management decision making', European Journal of Operations Research, Vol. 58, No.4, pp. 301-317.
- Pramod, V.R., Devadasan, S.R. and Raj, V.P.J. (2007) 'Receptivity analysis of TPM among internal customers', International Journal of Technology, Policy and Management, Vol. 7, No. 1, pp.75–88.
- Raouf, A. (1994) 'Improving capital productivity through maintenance', International Journal of Operations and Production Management, Vol. 14, No. 7, pp. 44-52.
- Raouf, A., Ben-Daya, M (1995) 'Total maintenance management: a systematic approach', Journal of Quality in Maintenance Engineering, Vol. 1, No.1, pp.6-14
- Rhyne, D.M. (1990) 'Total plant performance advantages through total productive maintenance', Conference Proceedings, APICS, Birmingham, pp. 683-686.
- Roberts, J. (1997) TPM Total Productive Maintenance, History and Basic Implementation Process, Technology Interface / fall.
- Robinson, C.J. and Ginder, A.P. (1995) Implementing TPM: The North American Experience, Productivity Press, Portland, OR.
- Rodrigues, M. and Hatakeyama, K. (2006) 'Analysis of the fall of TPM in companies', Journal of Materials Processing Technology, Vol. 179, Nos. 1–3, pp.276–279.
- Ramayah,T.(2007), 'Total Productive Maintenance And Performance: A Malaysian SME Experience' International Review of Business Research Papers Vol 4 No. 4 , pp.237-250
- Rose, E., Odom, R., Dunbar, R., Hinchman, J. and Harris Semiconductor (1995) 'How TOC and TPM work together to build the quality toolbox of SDWTs', Proceedings of IEEE/CPMT International Electronics Manufacturing Technology Symposium.
- Ross, T. (1995) Fuzzy Logic with Engineering Applications, McGraw-Hill, New York, NY.
- Ruxton, S. and Wang Jin, T. (2001) 'A fuzzy logic-based approach to qualitative safety modeling for marine systems', Reliability Engineering and System Safety, Vol. 73, No.2, pp. 19-34.
- Sanderson, M.N, Shelton, M.S, Mulligan, S.P (1993) 'IBM Austin Industrial Business Center total productive maintenance – the beginning', Proceedings of the 1993 IEEE/CHMT International Electronics Manufacturing Technology Symposium, pp. 212-214.
- Sangameshwran, P. and Jagannathan, R. (2002) 'HLL's Manufacturing Renaissance', Indian Management, Vol. 14, No. 11, pp. 30–35.
- Sarkar, B.N. (2007) 'Capability enhancement of a metal casting process in a small steel foundry through six sigma: a case study', International Journal of Six Sigma and Competitive Advantage, Vol. 3, No. 1, pp.56–71.
- Scarf, P.S. (1997) 'On the application of mathematical models to maintenance', European Journal of Operations Research, Vol. 63, No. 5, pp. 493-506.
- Schuman, C.A. and Brent, A.C. (2005) 'Asset life cycle management: towards improving physical asset performance in the process industry', International Journal of Operations and Production Management, Vol. 25, No. 6, pp. 566–579.
- SEMI Semiconductor Equipment and Materials International (1992) SEMI Standards:Equipment Automation/Hardware Volume, Semiconductor Equipment and Materials International, Mountain View, CA.

- Seth, D. and Tripathi, D. (2005) 'Relationship between TQM and TPM implementation factors and business performance of manufacturing industry in Indian context', The International Journal of Quality and Reliability Management, Vol. 22, Nos. 2/3, pp. 256–277.
- Sharma, R.K., Kumar, D. and Kumar, P. (2005) 'FLM to select suitable maintenance strategy in process industries using MISO model', Journal of Quality in Maintenance Engineering, Vol. 11, No. 4, pp. 359–374.
- Sharma, R.K., Kumar, D. and Kumar, P. (2006) 'Manufacturing excellence through TPM implementation: a practical analysis', Industrial Management and Data Systems, Vol. 106, No. 2, pp. 256–265.
- Sherif, Y.S. and Smith, M.L. (1986) 'Optimal maintenance models for systems subject to failure – a review', Naval Logistics Research Quarterly, Vol. 23, No.3, pp. 47-74.
- Sheu, C. and Krajewski, L.J. (1994) 'A decision model for corrective maintenance', International Journal of Production Research, Vol. 32, No. 6, pp. 1365-1382.
- Shirose, K. (1992) TPM for Operators, Productivity Press Inc., Portland, Oregon.
- Singer, T. (1999) 'Are you using all the features of your CMMS? Following this 7-step plan can help uncover new benefits', Plant Engineering, Vol. 53, No. 1, pp. 32–34.
- Smith, A.M. (1993) Reliability-centerd Maintenance, McGraw-Hill, New York, NY.
- Stecke, K.E. and Aronson, J.E. (1985) 'Review of operator/machine interference models', International Journal of Production Research, Vol. 23, No. 1, pp. 129-151.
- Steinbacher, H.R. and Steinbacher, N.L. (1993) TPM for America, Productivity Press, Portland, Oregon.
- Suehiro, S. (1992) Eliminating Minor Stoppages on Automated Lines, Productivity Press, Cambridge, MA.
- Suzuki, T. (1994) TPM in Process Industries, Productivity Press Inc., Portland, Oregon.
- Swanson, L. (2001) 'Linking maintenance strategies to performance', International Journal of Production Economics, Vol. 70, pp. 237-244.
- Tajiri, M. and Gotoh, F. (1992) TPM implementation: A Japanese Approach, McGraw-Hill Inc., N.Y.
- Thomas, L.C. (1986) 'A survey of maintenance and replacement models for maintainability and reliability of multi-item systems', Reliability Engineering, Vol. 16, pp. 297-309.
- Thun, J.H. (2006) 'Maintaining preventive maintenance and maintenance prevention analyzing the dynamic implications of Total Productive Maintenance', System Dynamics Review, Vol. 22, No. 2, pp. 163–179.
- Townson, P., Murthy, D.N.P. and Gurgenci, H. (2002) 'Optimal bucket-size for dragline', in Blischke, W.R. and Murthy, D.N.P. (Eds), Case Studies in Reliability and Maintenance, John Wiley and Sons, New York, NY.
- Tripathi, D. (2005) 'Influence of experience and collaboration on effectiveness of quality management practices: the case of Indian manufacturing', International Journal of Productivity and Performance Management, Vol. 54, No. 1, pp. 23–33.
- Tsang, A. (1995) 'Condition-based maintenance: tools and decision making', Journal of Quality in Maintenance Engineering, Vol. 1, No. 3, pp. 3-17.
- Tsang, A.H.C. (1998) 'A strategic approach to managing maintenance performance', Journal of Quality in Maintenance Engineering, Vol. 4, No. 2, pp. 87-94.
- Tsoukalas, L. and Uhrig, R. (1997) Fuzzy and Neural Applications in Engineering, Wiley, New York, NY.

- Valdez-Flores, C. and Feldman, R.M. (1989) 'A survey of preventive maintenance models for stochastically deteriorating single-unit systems', Naval Research Logistics Quarterly, Vol. 36, No.4, pp. 419-446.
- Van Ackere, A. (1993) 'The principal/agent paradigm: Its relevance to various functional fields', European Journal of Operational Research, Vol. 70, No.1 , pp. 83-103.
- Venkatesh, J. (2003) 'An introduction to total productive maintenance', available at: http://plantmaintenance. com/article/TPM intro.shtml (accessed 25 April 2005).
- Venkatesh, J. (2005) An Introduction to Total Productive Maintenance (TPM), The Plant Maintenance Resource Center, pp 2-3
- Voss, C.A. (2005) 'Paradigms of manufacturing strategy re-visited', International Journal of Operations and Production Management, Vol. 25, No. 12, pp.1223–1227.
- Waeyenbergh, G and Pintelon, L. (in press) 'CIBOCOF: a framework for industrial maintenance concept development', International Journal of Production Economics, Corrected proof available online 1 March, pp. 1–8.
- Wang, F.K. (2006) 'Evaluating the efficiency of implementing total productive maintenance, total quality management', Vol. 17, No. 5, pp 655–667.
- Wang, J.Q. and Atrens, A. (2002) 'Microstructure and grain boundary analysis of X70 pipeline steel', Journal ofMaterial Science, Vol. 37.
- Wang, J.Q., Atrens, A. and Mitchell, D.R.G. (2001) 'Grain boundary characterisation of X42 pipeline steel in relation to IGSCC', Corrosion 2001, paper 01210, NACE International Houston, TX.
- Wang, J.Q., Atrens, A., Cousens, D.R. and Kinaev, N.N. (1999b) 'Microstructure of X52 and X65 pipeline steels', Journal of Material Science., Vol. 34, pp. 1721-1728.
- Wayenbergh, G. and Pintelon, L. (2002) 'A framework for maintenance concept development', International Journal of Production Economics, Vol. 77, No.3, pp. 299-313.
- Williamson, R.M. (2000) 'TPM: An often misunderstood equipment improvement strategy', Maintenance Technology Magazine online Vol. 13, no. 4
- Willmott, P. (1994) 'Total quality with teeth', The TQM Magazine, Vol. 6, No. 4, pp 48–50.
- Willmott, P. (1994) Total Productive Maintenance: The Western Way, Butterworth Heineman, Oxford.
- Wireman, T (1990) World Class Maintenance, Industrial Press, New York, NY.
- Witt, C.E. (2006) 'TPM: the foundation of lean', Material Handling Management, Vol. 61, No. 8, pp. 42–45.
- Yager, R.R. (1980) 'A general class of fuzzy connectives', Fuzzy Sets and Systems, Vol. 4, pp. 235-242.
- Yager, R.R. and Filev, D.P. (1994) Essentials of Fuzzy Modeling and Control, Wiley-Interscience, New York, NY.
- Yang, Y., Liang, S. and Danyluk, S. (1999) 'Application of a specialized capacitance probe in bearing diagnosi', Wear, Vol. 225, No. 2, pp. 1215-1221.
- Zimmermann, H. (1996) Fuzzy Set Theory and its Applications, 3rd ed., Kluwer Academic Publishers, London.

APPENDIX

APPENDIX – I

TOTAL PRODUCTIVE MAINTENANCE QUESTIONNAIRE

M. TECH.
RESEARCH WORK

Evaluation of Contributions of Total Productive Maintenance towards manufacturing performance enhancement

By
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TOTAL PRODUCTIVE MAINTENANCE QUESTIONNAIRE

GENERAL ORGANIZATIONAL INFORMATION

Organization's Name	
Organization's Address	
City, State, Postal Code	
Respondent's Name & Designation	
Respondent's E-Mail Address	

i.	PRODUCTS OF THE ORGANIZATION				
ii.	NUMBER OF EMPLOYEES	< 500	501 – 750	751 – 1000	> 1000
iii.	NUMBER OF MAINTENANCE PLANNERS	No Maintenance Planners	< 2 %	2 – 5 %	< 5 %
iv.	NUMBER OF MAINTENANCE OPERATORS	< 2 %	2 – 5 %	5 – 10 %	> 10 %
v.	MARKET SHARE	< 10 %	10 – 25 %	25 – 40 %	> 40 %
vi.	PRESENT TURNOVER (In Crores of Rupees)	< 25 Crores	25 – 100 Crores	100 – 250 Crores	> 250 Crores

ORGANIZATIONAL STRUCTURE & TRADITIONAL MAINTENANCE PRACTICES EMPLOYED					
S. No.	**MAINTENANCE ORGANISATION & RESOURCES ISSUES**				
1	Do you have a well planned & structured maintenance organization in your plant?	No organization at all	No well planned organization	Partially planned Organization	Well planned organization
2	Do you feel maintenance is staffed to do its job?	Not at all	To some extent	Reasonably	To a great extent
3	Whether the maintenance job descriptions and responsibilities are available for all the positions?	Not at all	Some what	Reasonably	To a great extent
4	Whether your organization has an effective Preventive Maintenance (PM) program?	Not at all	Some what	Reasonably Well	Highly effective PM Program
5	What percentage of the plant equipment is covered by the PM program?	< 10%	10 – 30%	30 – 65%	65 – 100%
6	Whether the maintenance program includes procedures, practices to maintain & correct equipment deficiencies?	Not at all	Occasionally	Usually	To a great extent
7	Whether your organization has an effective Predictive Maintenance (Pd.M) program?	Not at all	Some what	Reasonably Well	To a great extent
8	Does your organization use CMMS to analyse, record, improve maintenance activities?	Not at all	Some what	Reasonably Well	Highly effective PdM Program
9	Whether the management decisions are made from the CMMS reports?	Do not have a CMMS	Does not often use it	Uses it reasonably	Extensively Employed
10	What percentage of production workers are covered by the organization for training every year?	Not at all	Occasionally	Usually	To a great extent
TOTAL PRODUCTIVE MAINTENANCE ISSUES					
1	How long ago did you start implementing TPM?	< 1 year	1 – 3 years	3 – 5 years	> 5 years
2	Do you have a TPM Quality Manual & Quality Policy?	Not at all	Partially worked out	Reasonably worked out	Extensively worked out
3	What is the current status of your TPM implementation?	Early stages of introduction	Approximately midway	Completed majority, continuing	Program successfully completed
4	Whether the organization adheres to formally documented Organizational policy & TPM policies?	Not at all	Some what	Reasonably Well	To a great extent
5	Whether the management has prepared & demonstrated the complete master plan towards TPM implementation?	Not at all	Partially worked out	Reasonably worked out	Extensively worked out

6	Whether the TPM promotion organization well integrated within the management structure?	Not at all	Some what	Reasonably Well	To a great extent
7	Is there a structured TPM organization at your organization? (including Steering committee / Circles)	Not at all	Partially worked out	Reasonably worked out	Extensively worked out
8	Whether 5 S principles & standards extensively employed in the organization?	Not at all	Some what	Reasonably Well	To a great extent
9	Whether TPM has lead to a better coordination between the employees and the management?	Not at all	Some what	Reasonably Well	To a great extent
ISSUES RELATED TO VARIOUS PILLARS OF TPM IMPLEMENTATION					
JISHU HOZEN ISSUES		Not at all 1	To Some Extent 2	Reasonably Well 3	To a great extent 4
1	Whether the cleaning, lubrication, tightening (C-L-T) standards developed / implemented in the organization?	1	2	3	4
2	Whether machine adjustment / readjustment, inspection being carried by the productive operators?	1	2	3	4
3	Whether autonomous maintenance is being carried by the productive operators throughout the organization?	1	2	3	4
KOBETSU KAIZEN					
1	How far efforts are being made to track the root cause of all the losses affecting the equipment performance?	1	2	3	4
2	Whether focused equipment kaizens are being deployed by productive operators for elimination of losses?	1	2	3	4
3	Whether OEE assessment has been tracked & effectively improved on all the production systems?	1	2	3	4
PLANNED MAINTENANCE					
1	How far the planned & time based maintenance initiatives effectively deployed for addressing equipment life cycle performance issues in the organization?	1	2	3	4
2	How far counter measures effectively deployed under the PM program for achieving zero breakdowns?	1	2	3	4
3	Whether the Condition based maintenance initiatives effectively deployed for addressing equipment life cycle performance issues?	1	2	3	4

QUALITY MAINTENANCE					
1	Whether major defects being identified & tracked for improving the system performance?	1	2	3	4
2	How far customer complaints being identified & tracked for improving the system performance?	1	2	3	4
3	Whether 7 QC tools (Old/New) effectively deployed for addressing quality defects & customer complaints?	1	2	3	4
TRAINING & EDUCATION					
1	Whether the training needs of employees at various levels are ascertained throughout the organization?	1	2	3	4
2	Whether the in-house OJT training modules effectively worked out & deployed for employee training?	1	2	3	4
3	Whether employee skills consistently evaluated and efforts made to improve the skills from time to time as per organization's requirements?	1	2	3	4
OFFICE TPM					
1	Whether the procedural hassles in the administrative work identified and consistently reviewed to improve various support functions?	1	2	3	4
2	Whether inventory management systems and procedures streamlined to avoid production stoppages and optimizing organizational revenues?	1	2	3	4
3	Whether 5-S initiatives applied consistently in the office area?	1	2	3	4
SAFETY, HEALTH & ENVIRONMENT					
1	Whether the incidents of injuries & accidents identified and counter measures effectively implemented on the regular basis?	1	2	3	4
2	Whether the safe operating procedures developed & adequately deployed at all levels in the organization?	1	2	3	4
3	Whether Safety Competitions / one point lessons effectively deployed for promoting safety & affecting consciousness and affecting workplace improvements?	1	2	3	4

DEVELOPMENT MANAGEMENT					
1	Whether inputs from customers, production, quality control departments adequately tracked for improving system's design, reliability?	1	2	3	4
2	Whether inputs from various sources tracked for improving the system's maintainability, operatability?	1	2	3	4
3	Whether the experiences with existing equipment deployed on new products for developing Maintenance Prevention programs & affecting design improvements?	1	2	3	4
CONTRIBUTIONS OF TPM INITIATIVES TOWARDS ENHANCING MANUFACTURING PERFROMANCE					
To what extent your organization has reaped the benefits of TPM implementation? (Please Quantify)					
TPM BENEFITS		Nominal Gain (< 15%) 1	Reasonable Gain (15 – 35 %) 2	High Gain (35 – 60 %) 3	Extremely High Gain (> 60 %) 4
TPM EFFECT ON PRODUCTION (P)					
1	Improvement in equipment Availability	1	2	3	4
2	Reduction in number of failures & unplanned downtime	1	2	3	4
3	Improvement in Overall equipment effectiveness (OEE)	1	2	3	4
TPM Effect on Quality (Q)					
1	Superior Manufacturing Quality	1	2	3	4
2	Improvement in Customer Order Compliance	1	2	3	4
3	Reduction in number of customer warranty problems	1	2	3	4
TPM Effect on Cost (C)					
1	Reduction in additional capital investments required	1	2	3	4
2	Reduction in operating costs	1	2	3	4
3	Reduction in energy consumption	1	2	3	4
TPM Effect on Delivery (D)					
1	Dependable & Faster deliveries	1	2	3	4
2	Greater order size flexibility	1	2	3	4
3	Reduction in cycle time to develop new products	1	2	3	4

TPM Effect on Safety (S)					
1	Reduction in number of accidents	1	2	3	4
2	Reduction in number of injuries	1	2	3	4
3	Reduction in man days lost due to accidents/injuries	1	2	3	4
TPM Effect on Morale (M)					
1	Increase in worker involvement in TPM SGA's	1	2	3	4
2	Increase in number of kaizens suggested by operators	1	2	3	4
3	Increase in number of one point lessons developed	1	2	3	4

BARRIERS TO TPM IMPLEMENTATION (Please Specify)	
1	
STEPS TAKEN FOR RESOLVING THESE PROBLMS (Please Specify)	
1	

(SIGNATURE OF RESPONDENT & SEAL OF THE ORGANIZATION)

APPENDIX – 2

Details of Respondents to TPM Questionnaire

No.	Organization Name	Organization's Address	Respondent's Name & Designation	TPM Impl Years	Products of Organization	Turn Over In crores
1	Bharat Forge LTD	Bharat Forge Ltd, Mundhwa, Pune : 411036	Sh. Sunil Mutha Associate Vice President, Machined Component Division (TQM)	< 1 yr	Auto Components Manufacturing, Forgings & Machining; Crankshafts, Steering Knuckles, Axle Beams, Connecting Rods	> 100 Crores
2	Mahindra and Mahindra LTD	Sahibzada Ajit singh nagar Mohali	Sahil Khurana Senior Engineer	< 1 yr	Swaraj tractors	100-250 crores
3	Sona okegawa precision forgings ltd	Sona enclave ,village begumpar khatola postbox 90	Mr Vishal raj engineer management services	< 1 yr	precision forged components like bevel gears	100-250 crores
4	Uniproducts(India) LTD	84 Km Milestone Delhi Jaipur Highway Rewari Haryana 123401	Amit Mittal Manager TPM	< 1 yr	Non woven Textile Automotive components and NUH and head shields	100-250 crores
5	Acey Engineering Private LTD	105 , GIDC , Antalia Bilmora Gujrat	Mayank A. Choski MD	< 1 yr	Machine components and camshafts	> 100 Crores
6	Badve Engineering Private LTD	14/2 Raghuvanahali banglore	Nitin sharma	< 1 yr	Chasis silencer for bajaj	100-250 crores
7	El forge LTD	P.B. NO 11 Denkani kotta road Hosur tamilnadu	N.balakrishnan DY. Managing director	< 1 yr	Connecting rods , rocker arms ,wheel hubs	100-250 crores
8	Bunge india limited	Edamalaiputti pudur trichy Tamilnadu	K.R varma DGM -Works	< 1 yr	Food products	100-250 crores
9	Hindalco Industries LTD	P.O. Renukoot Dist. Sonbhadra U.P.	K.S. Nagraj Manager TPM	1-3 yrs	Alumina chemicals , copper products	100-250 crores
10	ABC Paper LTD	SAILA KHURD Hoshiarpur	Iqbal Kaur Dhillon , TPM sect	1-3 yrs	Paper	100-250 crores
11	Sundaram Clayton LTD	Padi , CH-50 Chennai , Tamilnadu 600050	Hemant Kumar , Manager TPM	1-3 yrs	Aluminium Die Castings	>250 crores

12	Wrigley (I) PVT. LTD	Village Katha Baddi Himachal Pradesh	Naveen pilane Executive TPM	1-3 yrs	Nonchoclate conficenory chewing gum bubble gum	100-250 crores
13	K.M. Gases Pvt. LTD	Motinagar U.P. P.O. 12	S.C. Agarwal Executive Director	1-3 yrs	Gas pipes	100-250 crores
14	Lakshmi Machine Works LTD	Arasur Coimbatore Machine tools Division	P.Ganesan SR. GM TPM	1-3 yrs	CNC machine tools	100-250 crores
15	Menon Pistons LTD	182, SHIROLI kohlapur Maharashtra	G.S. Rao DY. Manager	1-3 yrs	Aluminium alloy pistons , gudgeon pins	100-250 crores
16	Mosaerbaer India LTD	66, UDYOG Vihar Greater noida U.P. G.B. nagar	Abhai Krishna DGM quality	3-5 yrs	optical storage media	>250 crores
17	Sansera Engineering PVT. LTD	261/ C , Bommasandra INDL area Banglore karnataka	Padma Parshad Jain engineer -Maintenance	3-5 yrs	engineering automotive connecting rods	>250 crores
18	TVS srichakra LTD	Perumalpatti Road , Vellarippati Madurai Tamilnadu	S.Murali Manager TPM	3-5 yrs	Automotive tyres and tubes	>250 crores
19	Tractors Engineers LTD	Powai campus saki vihar road mumbai P.O. 8913	V.J. parandekar .G.M. operations	3-5 yrs	appron feeders , centrifugal pumps etc.	100-250 crores
20	GPI Textiles LTD	Bharatgarh road solan h.p. Nalagarh	L.K. Singh Executive director	3-5 yrs	polyseter and cotton combed yarns	>250 crores
21	JK Tyres	KRS Road karnataka	S.p. shipra DGM quality	3-5 yrs	tyres	>250 crores
22	Balasore Alloys LTD	Balgopalpur ,Balasore Orrisa 756020	Sudhir Behera , Asst. Manager (Buisness Excellence) Jyoti shankar Dey Executive TPM	3-5 yrs	High Carbon Ferrochrome Manufacturing	>250 crores
23	Omax autos LTD	PLOT NO.26 b, SEC - 32 institutional area Gurgaon ,Haryana 122001	Mr M.M LAL General Manager (TPM and Projects)	3-5 yrs	Auto Components and home furnishing components	>250 crores
24	ABI Showatech (INDIA) LTD	Pulivalam (village & post) , Banavaram Sholinghur , Vellore city Tamilnadu 632505	C.Jayakumar Senior Engineer	3-5 yrs	precision automative components, ancalliries	100-250 crores
25	Tata Steel LTD	Jamshedpur , jharkhand pin -831001	Pankaj Kumar Head TPM	>5yrs	Steel products (flat and long)	>250 crores
26	Vikram Ispat	A unit of Grasim Ltd village salav dist. raigar, Maharashtra 402202	Niranjan puramdare Head World class manufacturing Cell	>5yrs	Sponge iron	>250 crores

27	Sono Koyo Steering LTD	38/6 Delhi Jaipur highway Gurgaon Haryana	Bhupesh sharma AGM -Quality Systems	>5yrs	Automotive	>250 crores
28	Emami Paper Mills LTD	Balgopalpur ,Balasore Orrisa 756020 RASALPUR	K.ROYCHOUDHARY	>5yrs	Newsprint and Writing / Printing paper	>250 crores
29	Indian Oil Corporation LTD	Panipat refinery Panipat -132140	Lt COL Suresh kumar sharma Sr. Manager TPM	>5yrs	Petroleum Products and petrochemicals	>250 crores
30	Mahindra and Mahindra LTD	Akurli Road , Kandivli (E) Mumbai -400101 Maharastra	Jai Prakash Chaurasia	>5yrs	Muti Utility vehicles ,Axles, Transmissions ,Engines & Castings	>250 crores
31	Brakes india LTD	NO.30 Arakkonam Road distt.Vellore Tamilnadu	V.. Narasimhan DM-TPM	>5yrs	brakes systems and parts and brakes fluid	>250 crores
32	Reliance Industries LTD	Dahej Manufacturing Division Village dahej Barauch , Gujrat	Raman Grewal DGM	>5yrs	pvc , hpde , Meg	>250 crores
33	Munjal Showa LTD	9-11 , Maruti industrial Area Gurgaon -122015	Ankush kaul Asst. Engg. TPM	>5yrs	Shock absorber, struts and window balancer	>250 crores
34	Tanfac Industries LTD	NO.14 Sipcot industrial complex Tamilnadu Cuddalore	R.Sivakumar MGR -TECH services and mgt. reprsentative	>5yrs	aluminium flouride cryolite	>250 crores
35	EnduranceTechnologies PVT. LTD	B_22 Chalkan MIDC Village nighoje pune Maharashtra	S.P. Samwatsare TPM coordinator	>5yrs	casting , suspension , braking , transmission	>250 crores
36	Innova Rubbers PVT. LTD	A-26 , MIDC Ambad Nashik Maharashtra	Manish. D. Naoghare TPM Mananger	>5yrs	rubber parts, silent block bushes, anti vibration mountings	>250 crores