Chapter 2
REVIEW OF THE LITERATURE

2.1 INTRODUCTION

In today’s era of global recession and competition it is basic business requirement to supply quality products at competitive prices through reduced manufacturing expenses which is only possible by improving manufacturing performance. This increased global competition is forcing companies to improve and optimize their productivity in order to remain competitive [Huang et al. 2003]. Performance can be defined as the extent to which a company or process fulfills its objectives.

In general, productivity is defined as the ratio of the output to input of a production system. The output of the production system is the products or services delivered while the input consists of various resources like the labour, materials, tools, plant, equipment and others, used for producing the products or services. With a given input, if more outputs of products or services can be produced, then higher productivity efficiency is achieved. Efficiency is doing the things right or it is the measure of the relationship of outputs to inputs and is usually expressed as a ratio. These measures can be expressed in terms of actual expenditure of resources as compared to expected expenditure of resources. They can also be expressed as the expenditure of resources for a given output.

The desired production output is achieved through high availability, which is influenced by equipment reliability and maintainability. The reliability of equipment decreases with time [Vashisth and Kumar, 2011]. That has brought the maintenance functions into focus to improve the production system’s performance. There is consensus among authors [Madu, 1999; Madu, 2000; Cooke, 2000] that equipment maintenance and system reliability are important factors that affect organization’s ability to provide quality and timely services to customers and to be ahead of competition. Manufacturing firms are realizing that there is a critical need for proper maintenance of production facilities and systems to take best use [Luxhoj et al. 1997; Stephen, 2000; Cholasuke et al. 2004; Meulen et al. 2008]. Maintenance
function is therefore vital for sustainable performance of any manufacturing plant. The summary of maintenance objectives is depicted in fig 2.1, in which maintenance strategy is aligned with corporate strategy and maintenance objectives.

![Fig 2.1 A summary of maintenance objectives [Muchiri et al. 2000]](image)

### 2.2 ROLE OF MAINTENANCE IN MANUFACTURING PERFORMANCE IMPROVEMENT

The business performance can be categorized into financial, managerial and plant managerial performances. Financial performance refers to the financial aspects of the company such as sales or profits and is similar to strategic business performance. Managerial aspects are spread over both financial and operational aspects e.g. sales figures and employee satisfaction, respectively. Plant managerial aspects are confined to the aspects of shop floor operations such as productivity, quality and safety, i.e. concerned with manufacturing performance. Effectiveness of manufacturing system is doing the right things and measures the output conformance to specified characteristics. Just-In-Time (JIT), Total Quality Management (TQM), Business Process Re-engineering (BPR), Supply-chain Partnering (SP), Learning Culture (LC), Team-based Working (TW), Concurrent Engineering (CE), Integrated Computer-based Technology (ICT) and Employee Involvement (EI) have been recognized as strong contributors to manufacturing performance both in the
practitioner literature [Schonberger, 1986; Miller and Schenk, 1997; Waterson et al. 1999] and the academic literature [Cleveland et al., 1989; Flynn et al., 1995; Sakakibara et al., 1997].

As discussed in previous section, the performance and competitiveness of manufacturing companies is dependent on the availability, reliability and productivity of their production facilities [Coetzee, 1997; Madu, 2000; Fleischer et al. 2006]. Manufacturing Engineering Society of Australia [MESA, 1995] recognizes maintenance as tool to achieve the required asset capabilities within an economic context. They define maintenance as the engineering decisions and linked actions, necessary and sufficient for optimization of specified equipment ‘capability’ which is the ability to perform a specified function within a range of performance levels that may relate to capacity, rate, quality, safety and responsiveness [Tsang, 1999]. Similarly, Kelly states that the objective of maintenance is to achieve the agreed output level and operating pattern at minimum resource cost within the constraints of the system condition and safety [Kelly, 1989]. Maintenance is also partly responsible for technical system safety and to ensure the plant is kept in good condition and acceptable system image [Visser and Pretorious, 2003].

According to Kelly [1998] the objectives of maintenance are –

1. To ensure the plant availability, reliability and product quality.
2. To ensure the plant achieves its design life.
3. To ensure plant and environmental safety.
4. To ensuring cost effectiveness in operations & maintenance of the manufacturing facilities.

Broadly, maintenance can be categorized into two major classes, i.e. preventive maintenance and corrective maintenance [Waeyenbergh and Pintelon, 2002]. Preventive maintenance is performed before machine failure. The objective of preventive maintenance is to promote continuous system production and avoid unplanned maintenance operation, i.e. to reduce the probability of failure in the time period after maintenance has been applied. The purpose of maintenance management is to reduce the adverse effects of breakdown and to maximize the production system availability at minimum cost. Production system breakdown causes loss of output. Corrective maintenance is performed when a machine fails. It usually involves replacing or repairing the component that is responsible for the failure of the overall
system. The objective of corrective maintenance is to restore the system to an operating state in the shortest possible time; it also strives to reduce the severity of equipment failures once they occur. The maintenance work management cycle, as outlined by Campbell [1995], consists of work identification, planning, scheduling, execution and closing the job. Maintenance work is identified from the preventive, predictive and failure finding work orders that are usually generated by proactive maintenance. Repair work arises as a result of failure. At the core of the maintenance function are work planning and scheduling, which defines what gets done and when. To complete the work cycle, effective work execution is vital in ensuring that required equipment condition and performance is attained.

In a survey conducted by Wireman [1990] in USA it was found that maintenance cost for industrial firms has increased by 10–15% per year since 1979 and the amount of money spent on maintenance functions in a selected group of companies was nearly 600 billion dollars in 1989. According to Bevilacqua and Braglia [2000], maintenance cost can reach 15–70% of production costs, variation in this depends upon the type of industry. The goals of maintenance operations include improvement of system availability and reliability, increment of system operating efficiency through reduction of unplanned downtime and frequency of failures. Mobley [2002] underlined that almost one third of all maintenance costs are wasted as the result of unnecessary or improper maintenance activities.

Bateman [1995] classified maintenance programs as reactive, preventive and predictive maintenance. Preventive and predictive maintenance represent two proactive strategies by which companies can avoid equipment breakdowns. In reactive maintenance the equipment is allowed to run until failure and then the failed equipment is repaired or replaced [Paz and Leigh, 1994]. Though under reactive maintenance, temporary repairs may be done in order to return equipment to operational condition and permanent repairs made later time [Gallimore and Penlesky, 1988]. Proactive maintenance is a strategy for maintenance whereby breakdowns are avoided through activities that monitor equipment condition and undertake minor repairs to restore equipment to operational condition. These activities, including preventive and predictive maintenance, reduce the probability of unexpected equipment failures. Preventive maintenance is often referred to as use-based maintenance where maintenance activities are undertaken after a specified period of
time or amount of machine use depending upon the type of machine [Herbaty, 1990; Gits, 1992]. Weil [1998] added another approach in his description of the maintenance spectrum by including Total Productive Maintenance (TPM). TPM is an aggressive maintenance approach that seeks to improve equipment performance while continuing to avoid equipment failures applied to all the equipment as the ultimate objective of any factory is to have a highly efficient integrated system and not brilliant individual equipment [Oechsner et al. 2002]. McKone et al. [2001] described positive impacts of TPM practices on manufacturing performance. The evolution of TPM as a maintenance tool is discussed in section 2.3 and its various pillars are discussed in section 2.4.

Further, manufacturing performance can be measured with four different basic parameters i.e. cost, quality, delivery, and flexibility that are extended in some studies including several measures [Skinner, 1969; Hayes et al. 1988; Schroeder, 1993; Miller and Roth, 1994; Ward et al. 1995].

Fig 2.2 Policies for TPM in the company [Chan et al. 2005]
In general, business performance measures consist of operational and strategic business performance. While the operational business performance assesses daily or weekly performance of operations and the strategic business performance measures major corporate goals such as return on capital, sales and profits. It is suggested by Takahashi and Osada [1990] to measure the effectiveness of TPM through managerial performance and plant managerial performance, i.e. two aspects of operational business performance. Figure 2.2 presents the policies of TPM in a company whereas, figure 2.3 presents a detailed integration of factory efficiency practice area with other practices which are key practices for functioning of a manufacturing company.

![Diagram of integration of factory efficiency practice area with other practices](Fig 2.3 Integration of factory efficiency practice area with other practices [Khadem et al. 2008])
2.3 EVOLUTION OF TOTAL PRODUCTIVE MAINTENANCE (TPM)

The aim of TPM activities is to reinforce corporate structures by eliminating all losses through the attainment of zero defects, zero failures, and zero accidents. Of these, the attainment of zero failures is of the greatest significance, because failures directly lead to defective products and a lower equipment operation ratio, which in turn becomes a major factor for accidents [Shirose, 1996]. The various philosophies (approaches) towards TPM are presented in table 2.1.

Table 2.1 Various philosophies of TPM

<table>
<thead>
<tr>
<th>Philosopher</th>
<th>Year</th>
<th>Definition / Philosophy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thomas R. Pomorski</td>
<td>2004</td>
<td>Total Productive Maintenance (TPM) is a structured equipment-centric continuous improvement process that strives to optimize production effectiveness by identifying and eliminating equipment and production efficiency losses throughout the production system life cycle through active team based participation of employees across all levels of the operational hierarchy.</td>
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<tr>
<td>Cooke</td>
<td>2000</td>
<td>TPM is intended to bring both functions (production and maintenance) together by a combination of good working practices, team working, and continuous improvement.</td>
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<tr>
<td>Lawrence</td>
<td>1999</td>
<td>TPM is the general movement on the part of businesses to try to do more with less.</td>
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<tr>
<td>McKone and Schroeder</td>
<td>1999</td>
<td>TPM is a program that addresses equipment maintenance through a comprehensive productive-maintenance delivery system covering the entire life of the equipment and involving all employees from production and maintenance personnel to top management.</td>
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<tr>
<td>Blanchard</td>
<td>1997</td>
<td>TPM is an integrated life-cycle approach to</td>
</tr>
<tr>
<td>Author(s)</td>
<td>Year</td>
<td>Description</td>
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<td>-------------------------------</td>
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<tr>
<td>SME</td>
<td>1995</td>
<td>TPM is a way of working together to improve equipment effectiveness.</td>
</tr>
<tr>
<td>SME</td>
<td>1995</td>
<td>TPM is a methodology and philosophy of strategic equipment management focused on the goal of building product quality by maximizing equipment effectiveness. It embraces the concept of continuous improvement and total participation by all employees and by all departments.</td>
</tr>
<tr>
<td>Robinson and Ginder</td>
<td>1995</td>
<td>TPM is a production-driven improvement methodology that is designed to optimize equipment reliability and ensure efficient management of plant assets.</td>
</tr>
<tr>
<td>Robinson and Ginder</td>
<td>1995</td>
<td>TPM is a method for bringing about change. It is a set of structured activities that can lead to improved management of plant assets when properly performed by individuals and teams.</td>
</tr>
<tr>
<td>Steinbacher and Steinbacher</td>
<td>1993</td>
<td>TPM is about all of the strategies needed to sustain a healthy maintenance log.</td>
</tr>
</tbody>
</table>

There are two main approaches found in TPM literature i.e. Western approach and the Japanese approach, both having similarity. The Japanese approach is promoted by Japanese Institute of Plant Maintenance (JIPM) and described by Nakajima [Nakajima, 1984; Nakajima, 1989], Tajiri and Gotoh [Tajiri and Gotoh, 1992] and Shirose [Shirose, 1996] whereas, Western approach is described by Wireman [Wireman, 1991], Hartmann [Hartmann, 1992] and Willmott [Willmott, 1994]. There is a narrow gap between the Western approach and the Japanese approach. Willmott, [1994], keeping Japanese approach in view offers his own definition that is based on teamwork but does not necessarily require total employee participation, i.e. emphasis has been laid on the use of teams to achieve specific operational targets. He further states that the concept of TPM process is that all the assets on which production depends are kept always in optimum condition and
available for maximum output. Hartmann [1992] presents a similar definition to Willmott and states that Total Productive Maintenance permanently improves the overall effectiveness of equipment with the active involvement of its operators. The Japanese approach emphasizes on the role of teamwork, small group activities and the participation of all employees in the TPM process to achieve equipment improvement objectives. Hence, it is more people and process focused, while the Western approach focuses on the equipment with understanding that operator involvement and participation in the TPM effort is required, hence, it is focused on equipment improvement objectives.

While comparing Japanese and Western approaches to TPM, Ames [2003], finds that the Japanese are just as focused directly on the results as the Western approach is, and suggests that although there is very little real difference in the approaches, the Western definition emphasizes on results as a marketing or selling tool to gain the interest of Western managers. Similarly, the Japanese Institute of Plant Maintenance also advocates company wide application of TPM rather than equipment focus.

According to Nakajima [1984] who is considered father of TPM, the TPM -

- aims to maximize equipment effectiveness.
- establishes a thorough system of Preventive Maintenance (PM) for the equipment’s entire life span.
- is cross-functional, implemented by various departments (engineering, operators, maintenance, managers).
- involves every single employee.
- is based on the promotion of Preventive Maintenance through the motivation of management and autonomous small group activity.

Shirose [1996] presents a similar view as –

- TPM strives for maximum equipment effectiveness.
- TPM establishes a total system of Preventive Maintenance for the entire life of the equipment.
- TPM includes participation by all sectors of the organization that plan, use, and maintain equipment.
- TPM participation is from top management to the frontline staff.
Execution of TPM is based on small group activity.

According to JIPM [1996] TPM aims at:

- establishing a corporate culture that will maximize production system effectiveness.
- organizing a practical shop-floor system to prevent losses before they occur throughout the entire production system life cycle, with a view to achieving zero accidents, zero defects and zero breakdowns.
- involving all the functions of an organization including production, development, sales and management.
- achieving zero losses through the activities of overlapping small groups.

The origin of TPM

Earlier Productive Maintenance was originated in the United States of America in the late 1940’s and early 1950’s and it was developed from scheduled Preventive Maintenance techniques with the objective to improve the reliability and availability of production equipments. The TPM is a modified form of United States-style productive maintenance fit to the Japanese industrial environment [Nakajima, 1984]. The Japanese Institute of Plant Engineers (JIPE) was created after study of American Productive Maintenance in the year 1953 and 1962 by a research group formed by twenty Japanese companies. The JIPE was converted into Japanese Institute of Plant Maintenance (JIPM) in the year 1969 [Ireland and Dale, 2001]. Nippondenso, a Japanese automotive component manufacturer used first time Total Productive Maintenance in the year 1961 with the theme ‘Productive Maintenance with Total Employee Participation’ for improvement in manufacturing performance. Then, it was spread to Toyota, Mazda, Nissan and their associated vendors [Robinson and Ginder, 1995]. The earliest Japanese TPM implementations got a limited success and only a few companies adopted it [Tajiri and Gotoh, 1992]. Actually, in the early 1970’s, adoption of TPM began to accelerate as a means to improve manufacturing effectiveness, soon after Japan faced a decline in economy [Ireland and Dale, 2001]. TPM extended to United States and the Western world during 1980’s and 1990’s when companies strived to quality improvement with programs such as Total Quality Management (TQM) [Ireland and Dale, 2001]. According to Suzuki [1994], adoption of TPM was started in prestigious companies
such as Dupont, Exxon, Kodak, Alcoa, AT&T, Ford, Hewlett-Packard and Proctor & Gamble. Nakajima [1988], Nakajima [1989], Hartmann [1992], Willmott [1994] and Shirose [1996] documented the successful application of TPM in various industries by late 1990’s and many companies have been awarded TPM prize by JIPM and the success story is continued world wide.

2.4 PILLARS OF TPM

The principle activities of TPM are exercised under its various pillars. Different researchers have presented different pillars but, most accepted model is Nakajima’s model of eight pillars [Nakajima, 1984, Nakajima, 1988]. Some Western TPM practitioners have presented more simplified models [Steinbacher and Steinbacher, 1993; SME, 1995; Yeomans and Millington, 1997]. A comparison between all these models has been presented in table 2.2

<table>
<thead>
<tr>
<th>Nakajima Model</th>
<th>Yoemans &amp; Millinton Model</th>
<th>Steinbacher &amp; Steinbacker Model</th>
<th>SME Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Focused Improvement</strong></td>
<td>Increase Equipment Effectiveness</td>
<td>Corrective Maintenance</td>
<td>Improve Equipment Effectiveness</td>
</tr>
<tr>
<td><strong>Autonomous Maintenance</strong></td>
<td>Autonomous Maintenance</td>
<td>Autonomous Maintenance</td>
<td>Involve Operators In Daily Maintenance</td>
</tr>
<tr>
<td><strong>Preventive Maintenance</strong></td>
<td>Planned Preventive Maintenance</td>
<td>Predictive Maintenance / Preventive Maintenance</td>
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<tr>
<td><strong>Education and Training</strong></td>
<td>Training</td>
<td></td>
<td>Education and Training</td>
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<tr>
<td><strong>Maintenance Prevention</strong></td>
<td>Early Equipment Management</td>
<td>Maintenance Prevention</td>
<td>Design and Management of Equipment for Maintenance</td>
</tr>
</tbody>
</table>

Table 2.2 Comparison of various pillars of TPM
A detailed discussion about all the pillars is presented in the coming sections.

### 2.4.1 Focused improvement pillar (Kobetsu Kaizen)

According to Suzuki [1994] Focused improvement encompasses all activities that maximize the overall effectiveness of equipment, processes, and plants and improves the performance through complete elimination of losses. It aims at equipment to perform fullest on product manufacturing task and it is the responsibility of operators, technicians, engineers, or managers to handle the machines in order to serve the purpose. It is obvious that better performance of the equipment will lead to higher productivity on shop floor [Leflar, 2001]. According to Nakajima [1988] maximizing equipment effectiveness requires the complete elimination of failures, defects, wastes and losses. Leflar [2001] advocates the replacement of equipment only when the technology is obsolete not because it has deteriorated into a poorly performing machine. Since, the practicing on the equipment makes it more possible to learn and maintain the machine. Focused Improvement has been, and still is, the primary methodology for productivity improvement [Thomas, 2003]. The equipment restoration is a prime initial step in focused improvement. Wireman [1991] underlined that during maintenance of equipment tasks like cleaning, lubricating, adjusting, and tightening are neglected. The equipment failure is eliminated by exposing and eliminating hidden defects that deliberately interrupt equipment operation before breakdown [Nakajima, 1988; Tajiri and Gotoh, 1992]. Shirose [1996] puts importance to minor defects in order to vanish effects created due to the accumulation of minor defects. Similarly, Suehiro [1987] considers the elimination of minor defects to be one of the highest priorities of continuous improvement, even in large production units overall improvement arrives as an accumulation of improvements designed to
eliminate slight defects. So, it becomes important for factories to make slight defects their primary focus. Further, it is significant to note that focused improvement and equipment restoration is a continuous process and continues for the entire life of the equipment [Wireman, 1991].

2.4.2 Autonomous maintenance pillar (Jishu Hozen)

Autonomous maintenance is the activity in which operators accept and join hands with maintenance personnel for the performance and upkeep of their equipment [Robinson and Ginder, 1995]. Autonomous maintenance involves the participation of each and every operator, each maintaining his own equipment and conducting activities to keep it in the proper condition and running correctly. This takes with the shift in perception of operator from ‘I run the equipment, maintenance person fix it’, to ‘I own the performance of my equipment’. This philosophy is the creation of ‘expert equipment operators’ for the purpose of ‘protecting their own equipment’ [Shirose, 1996]. According to Komatsu [1999] autonomous maintenance is the cornerstone of TPM activities. It is associated with focused improvement in that both TPM pillars support equipment restoration and sustaining basic equipment conditions. Shirose [1996] states that the prime requirement for operators is to have the ability to detect abnormalities in the working of equipment with respect to operation and quality of output, based on a sense that ‘there is something wrong’. Autonomous maintenance activities are the most important assets in achieving continuous improvement, since, the operator is actively involved in daily inspection and cleaning of his or her equipment [SME, 1995]. Tajiri and Gotoh [1992] underlined two main aims of autonomous maintenance, i.e. to cultivate the knowledge and skills in the operators necessary to operate and maintain their equipment and to establish an organized shop floor, where the operators may easily detect any abnormality.

JIPM [1997] underlined the essential skills of operator for autonomous maintenance as given below:

- Ability to discover abnormalities in working of the equipment.
- Ability to remove cause of abnormalities and restore equipment optimal condition.
- Ability to set & maintain equipment optimal conditions.
Autonomous maintenance targets on prevention of equipment deterioration through appropriate operation and daily inspections, restoration and proper management of equipment and establishment of the basic conditions essential to keep the equipment up [Suzuki, 1994].

2.4.3 Planned maintenance pillar

According to Suzuki [1994], exercising planned maintenance establishes and maintains optimal equipment and process conditions. Japanese Institute of Plant Maintenance viewed planned maintenance as a system which when exercised raises output (zero failures, zero defects and zero abnormalities) and improves the quality of maintenance technicians and in turn increases equipment availability. Implementing following activities (presented in table 2.3) efficiently can reduce input to maintenance tasks. Following are the various maintenance plans.

- Regular preventive maintenance (periodic maintenance, predictive maintenance) to stop failures.
- Corrective maintenance and daily maintenance prevention to reduce the risk of failure.
- Breakdown maintenance to restore machines to working order as soon as possible after failure.
- Providing guidance and assistance in autonomous maintenance.

Table 2.3 Description of various types of maintenance plans

<table>
<thead>
<tr>
<th>Type of maintenance</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Breakdown Maintenance (BM)</td>
<td>This is the maintenance activity performed after equipment failure, stoppage or equipment performance gone dangerous.</td>
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<tr>
<td>Time-Based Maintenance (TBM)</td>
<td>This is the type of preventive maintenance activity which is scheduled based on suitable interval of time i.e. daily, weekly and monthly etc. The objective of predictive maintenance is to prevent the function of equipment from break down. Preventive maintenance keeps equipment in proper condition by maintaining equipment components, assemblies, subassemblies,</td>
</tr>
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</table>
accessories and attachments in good condition.

<table>
<thead>
<tr>
<th>Type of Maintenance</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Usage-Based Maintenance (UBM)</strong></td>
<td>This is the type of preventive maintenance activity which is scheduled based on some measure of equipment usage i.e. volume of material removed, number of units processed, number of production cycles, operating hours etc. It is more suitable than Time-Based Maintenance as it is scheduled based on the stress and deterioration that production activity places on equipment rather than just a period of time.</td>
</tr>
<tr>
<td><strong>Condition-Based Maintenance (CBM)</strong></td>
<td>This is again a form of preventive maintenance which is scheduled by actual variation or degradation that is measured on the equipment. This is extended version of the concept of Usage-Based Maintenance by scheduling maintenance based on measured wear, variation, or degradation on equipment as a result of production stresses.</td>
</tr>
<tr>
<td><strong>Predictive Maintenance (PM)</strong></td>
<td>This is a further extension of Condition-Based Maintenance to the next level by monitoring equipment performance and other parameters i.e. voltages, currents, clearances, flows and deviation etc.</td>
</tr>
<tr>
<td><strong>Corrective Maintenance (CM)</strong></td>
<td>This is planned maintenance that makes permanent continuous improvement changes to equipment. Within the TPM framework, identification of desirable corrective action activity occurs within the focused improvement, autonomous maintenance and planned maintenance TPM pillar activities. Corrective Maintenance may reduce / eliminate failure modes, improve variation/degradation identification (visual controls), or simplify scheduled or unscheduled maintenance activity.</td>
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</table>

The effective planned maintenance plan is based on the history and analysis of failure modes to determine preventive practices, it consists of five elements [Leflar, 1999] -

- A set of checklists for planned maintenance execution.
- A schedule for every planned maintenance cycle.
- Specifications and part numbers for every checklist item.
• Procedures for every checklist item.
• Maintenance and parts log (equipment maintenance history) for every machine.

2.4.4 Maintenance Prevention Pillar

Maintenance prevention is also known as early equipment management [Suzuki, 1994]. According to Shirose [1996], maintenance prevention is a set of design activities carried out during the planning and commissioning of new plant/equipment that impart to the plant/equipment high degrees of reliability, maintainability, economy, operability, safety, and flexibility, while considering maintenance information and new technologies. It is applied to equipment, layout, and facility of the plant as well as new processes and products (design for manufacturability is considered). The objective is to reduce the life cycle cost by minimizing maintenance expenses and deterioration losses.

Suzuki [1994] states that maintenance prevention design process improves equipment/plant reliability by identifying weaknesses in the existing equipment/plant and providing this feedback to the design engineers for their consideration. In TPM, the concept of maintenance prevention design is expanded to include design that aims at achieving not only reliability and maintainability but also prevention of all possible losses that may obstruct the effectiveness of the production system effectiveness and chase of overall system improvement. JIPM [1996] issues guideline for maintenance prevention that it should be exercised in a manner to satisfy reliability, maintainability, autonomous maintenance, operability, resource saving, safety, and flexibility. Effective Maintenance Prevention supports reduction of the vertical startup lead-time by improving the initial reliability and reducing variability of equipment and processes. Ideally, equipment designed with maintenance prevention plan must not break down or produce nonconforming products.

2.4.5 Education and Training Pillar

Education and training is an essential activity in the process of implementation of TPM, since, the effectiveness of whole programme depends on the degree to which the employees comprehend it and acquire desired operations and maintenance skills. According to Suzuki [1994] education and training pillar ensures success of the rest of
the pillars. Numerous methods of conducting training have been discussed in the literature. Some of them are on the job training (OJT), off the job training, one point lesson (OPL) etc. Robinson and Ginder [1995] find the OPL to be one of the most powerful tools for transferring skills. This is a very short duration self-study lesson prepared by team members focused on a single aspect of equipment or machine structure, its functioning, or method of inspection [JIPM, 1997]. It is obvious that in many cases sufficient time cannot be secured for the purpose of education at one time and also operators can acquire such learning practicing repeatedly. One-point lessons are, therefore, a learning method frequently used during daily work, such as during morning meetings or other time. Each individual member to think, study, and prepare genuine one-point lesson and to explain its content to all the other circle members, to hold free discussions on the spot and to make the issue more precise [JIPM, 1996]. This teaching technique helps people learn a specific skill or concept in a short period of time through the extensive use of visual images. One point lessons are really effective in transferring the technical skills required for a production operator even for minor maintenance responsibilities [Robinson and Ginder, 1995].

2.4.6 Quality maintenance pillar

Precisely, quality maintenance is establishment of conditions that will prohibit the occurrence of defects and control of such conditions to achieve zero defects [JIPM, 1996]. Quality maintenance is achieved by maintaining conditions within specified standards, inspecting and monitoring conditions to eliminate variation, and executing preventive actions before occurrence of defects or equipment/process failure. It is cause-oriented approach that focuses on preventive action ‘before it happens’ rather than reactive measures ‘after it happens’ [JIPM, 1996]. Like maintenance prevention, quality maintenance builds on the fundamental learning and structures developed within the focused improvement, autonomous maintenance, planned maintenance, and maintenance prevention pillars of TPM. According to Schonberger [1986] quality maintenance supports a key objective of TPM i.e. ensuring reliability of equipment and processes so as to function properly through their life cycle.

Shirose [1996] describes that the core concept of quality maintenance is integrating and executing the structures, practices, and methodologies established
within focused improvement, autonomous maintenance, planned maintenance, and maintenance prevention. The consideration of quality maintenance starts at the time of equipment / process planning and design and production technology development, and it is all about to put the equipment, jigs, and tools for ensuring high quality in the manufacturing process, as well as processing conditions, human skills, and working methods, into their productive states [Shirose, 1996].

2.4.7 Administrative TPM pillar

Administrative TPM applies TPM activities to continuously improve the efficiency and effectiveness of logistic and administrative functions, since, the logistic and support functions have significant impact on the performance of manufacturing operations. For its effective implementation TPM must embrace the entire company, including manufacturing support functions, administrative and support departments. As described in advanced manufacturing technology literatures, manufacturing is not a stand-alone activity, but is now fully integrated with its support functions. According to Suzuki [1994], they can help raise production-system effectiveness by reducing waste, loss and improving every type of organized activity that supports manufacturing. Administrative TPM focuses on identifying and eliminating effectiveness losses in administrative activities. Implementing administrative TPM is similar to equipment/process related TPM continuous improvement.

2.4.8 Safety, health and environmental pillar

Shirose [1996] depicts safety as “the maintenance of peace of mind”. Safety, health and environmental consideration is crucial in global manufacturing era of lean and green manufacturing and it has to be given due weight-age in TPM. No TPM program is meaningful without strict focus on safety, health and environmental concerns. Ensuring high equipment reliability, preventing human error, and eliminating accidents and pollution are the objectives of TPM [Suzuki, 1994]. Implementation of the safety, health and environmental pillar of TPM targets on zero safety, zero health and zero environmental incidents by identifying and eliminating them. Suzuki provides examples on how TPM improves safety and protects employee health & environment, are as described below.
Defective or unreliable equipment is a source of hazardous to the operator and the environment. The TPM objective of Zero-failure and Zero-defects directly supports Zero-accidents.

Exercising autonomous maintenance enables equipment operators to properly operate equipment and maintain a clean and organized workstation, and 5-S activities (described below) also help eliminating possibilities of accidents at shop floor.

TPM-trained operators have close understanding of their equipment and processes and are able to quickly detect and resolve abnormalities that might result in unsafe conditions.

Operators accept accountability for safety and environmental protection at their workplaces. Safety, health and environmental protection norms are proliferate and enforces as part of the TPM quality maintenance pillar.

2.5 5S - A BASE OF TPM

5S is a Japanese approach of establishing and maintaining an organized and effective workplace, is “a systematic method to organize, order, clean, and standardize a workplace – and keep it that way” [Productivity, 1999]. The 5S includes seiri (sort, organize), seiton (set in order), seiso (shine, cleaning), seiketsu (standardize the cleaning), and shitsuke (sustain, discipline) and are referred as the five keys to a total quality environment [Osada, 1991; Willmott, 1994]. It is a system to reduce waste and optimize productivity and quality through maintaining an orderly workplace and using visual signals to achieve more consistent operational results. It is aimed at to implant the values of organization, neatness, cleaning, standardization and discipline into the workplace basically in its existing configuration. In the daily work of a company, routines that maintain organization and orderliness are essential to a smooth and efficient flow of activities.

Osada [1991] considered 5S as a strategy for organizational development, learning and change, whereas Hirano [1995] took 5S to be an industrial formula that differentiates an organization from its competitors. Kobayashi et al. [2008] compared the frameworks provided by Osada [1991] and Hirano [1995] and made a division between 5S as a philosophy and 5S as a technique and concluded that 5S tends to be
recognized as a philosophy in Japan and as a technique or tool in the UK and USA. 5S is considered to be the first lean method implemented by firms.

The description of the steps of 5S is given below -

- Seiri (sort): Remove all items from the workplace that are not needed for current production operations or for records. Unnecessary material at the workplace can lead to errors and defects.
- Seiton (set in order): Arrange and label needed items so that they are easy to locate and use.
- Seiso (shine): Clean floors, equipment, and work stations, this step also includes identifying and preventing the sources of contamination or dirt.
- Seiketsu (standardize): Adopt methods and practices to maintain sort, set in order, and shine on an ongoing and continuously improving manner.
- Shitsuke (sustain): Make 5S standard practice.

2.5.1 Seiri

Meaning

Distinguish between the necessary and the unnecessary and get rid of the things which are not required.

Aims

- Establish criteria and stick to them in eliminating the unnecessary.
- Practice stratification management to set priorities.
- Be able to deal with the causes of filth.

Activities

1. Throw out the things which are not required.
2. Deal with the causes of dirt and leaks.
3. House cleaning.
4. Treat defects and breakage.
5. Inspect covers and troughs to prevent leakage and scatter.
6. Clean the grounds.
7. Organize the warehouse.
8. Eliminate grime and burrs.
2.5.2 Seiton

Meaning

Establishing a neat layout so you can always get just as much of what you need, when you need it.

Aims

- A neat looking work place.
- Efficient (including quality and safety) layout and placement.
- Raising productivity by eliminating the waste of looking for things.

Activities

1. Everything has a clearly designated place.
2. Thirty-second storage and retrieval.
3. Filing standards.
4. Zoning and making placement marks.
5. Eliminating lids and locks.
6. First in, first out.
8. Easy to read notices.
9. Straight lines and right angles.

2.5.3 Seiso

Meaning

Eliminating trash, filth and foreign matter for a cleaner workplace.

Aims

- A degree of cleanliness to your needs. Achieving zero grime and zero dirt.
- Finding minor problems with cleaning inspections.

Activities

1. Quick 5S drills.
2. Individual responsibilities.
3. Make cleaning and inspection easier.
4. Everybody is a caretaker (priority 5S).
5. Perform cleaning inspections and correct minor problems.
6. Clean even the places most people do not notice.
2.5.4 Seiketsu

Meaning

Keeping things standardized, neat and clean even in personal and pollution related aspects.

Aims

- Management standards for maintaining the 5S's.
- Establishing visible management so that abnormalities show up.

Activities

1. Okay marks
2. Danger zones marked on meters.
3. Thermal labels
4. Directional markings.
5. Belt size labels
6. Open-and-shut directional labels
7. Voltage labels
8. Colour coded pipes
9. Oil labels
10. Warning colours
11. Fire extinguisher signs
12. Error proofing
13. Responsibility labels
14. Inspection marks

2.5.5 Shitsuke

Meaning

Full participation in developing good habits and workshops that follow the rules.

Aims

- Doing the right thing as a matter of course.
- Communication and feedback as daily routine
Activities
1. Total cleaning
2. Exercise time
3. Pick-up practice
4. Wear your safety shoes
5. Public space management
6. Practice dealing with emergencies
7. Individual responsibility
8. Telephone and communication practice.

2.6. FOUR PHASES OF TPM PROGRAM

Once top management decides to support TPM, it can be implemented in four major phases [Nakajima, 1988]. Phase 1, preparation, consists of steps to overcome the initial resistance to change. Phase 2, preliminary implementation, is designed to involve operators in maintenance activities. Phase 3, TPM implementation, focuses on improving equipment effectiveness and overcoming resistance to TPM. Phase 4, TPM stabilization, involves perpetuating the TPM program. The changing role of top and midlevel managers in each phase of TPM is provided in Table 2.4 (on page no. 33).

In preparation phase, top management has the primary responsibility of preparing a suitable environment for TPM’s introduction. This is done by first announcing the decision to introduce TPM and beginning TPM education. Here, top management demonstrates its commitment by first educating the managers. This includes visiting other plants using TPM and conducting other activities to overcome resistance. Typically management uses a small central TPM committee to both promote and coordinate the TPM implementation. The committee ensures that autonomous small groups are established at every level. The committee also creates basic TPM policies and attainable, quantifiable goals for upper-level groups. After establishing these goals it ensures that each group below it develops consistent goals. As these groups are being established, the TPM committee helps top management formulate a master plan for TPM development. This includes a plan to reduce the six big equipment losses.
equipment failure, setup and adjustment, idling and minor stoppages, reduced speed, defects in process, reduced yield) and create an autonomous maintenance program, a plan for quality control, a plan for maintenance by the maintenance department and an education and training plan to improve maintenance skills.

Phase 2, preliminary implementation, is the “kick off” of the TPM program. In this phase, the individual worker begins to experience TPM through training activities aimed at eliminating the six big losses. To do this, the TPM committee identifies the initial tasks to be assigned to the operators and coordinates development of carefully detailed procedures. The actual writing of the procedures may be done by the maintenance technicians with oversight and support from management. This is an important phase of implementation that needs to be monitored carefully. Management needs to ensure that the operators receive training to learn the skills and that the maintenance technicians cooperate and support the operator’s efforts.

Phase 3 is full TPM implementation. It concentrates on improving equipment effectiveness by using a variety of common quality improvement techniques to focus efforts on the equipment that has chronic losses. Visible success eliminating chronic losses helps to overcome resistance to change and develops impetus for further change. Up to the point of starting autonomous maintenance many companies can implement TPM without any major changes in their maintenance practices. As soon as all the equipment operators are involved in the autonomous maintenance program, there may be some increased resistance to change since the traditional separation between the operators and maintenance is being reduced as operators become responsible for their own equipment. Active top management leadership may be required to successfully overcome resistance to change by operators and maintenance personnel. Management must carefully consider the skills required and the current capabilities of its operators. They must provide adequate training to the operators to enable them to work efficiently.

Phase 4, stabilizing and perpetuating TPM, is the phase where the TPM groups begin a cycle of continuously improving their TPM results. Managers at all levels focus on improving TPM skills by diagnosing each group’s performance in conducting the standardized maintenance program. In this phase,
maintenance considerations are incorporated into each of the company’s functions to change the interaction of people and equipment. This requires that the company include some maintenance goals in its business strategy to create an impetus to make the necessary culture changes and to focus the company on maximizing equipment availability and reliability. These goals help direct the company away from the old paradigm of minimizing maintenance costs toward the new paradigm of maximizing the benefits from maintenance investments.

Table 2.4 Roles during TPM implementation [Pomorski T. R. 2004]

<table>
<thead>
<tr>
<th>Phase</th>
<th>Top management</th>
<th>Middle management</th>
<th>Maintenance technicians</th>
<th>Operators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation phase</td>
<td>Educate and create a management structure</td>
<td>Educate and establish TPM groups</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Preliminary implementation phase</td>
<td>Serve on TPM committee and conduct management diagnosis</td>
<td>Assist in training and development, assessment and certification programs</td>
<td>Prepare assessment and certification programs</td>
<td>Begin training and certification</td>
</tr>
<tr>
<td>TPM implementation phase</td>
<td>Serve on TPM committee and conduct management diagnosis</td>
<td>Support training and certification programs, conduct diagnosis of chronic losses</td>
<td>Continue certification programs and attack chronic losses</td>
<td>Continue training and perform maintenance tasks</td>
</tr>
<tr>
<td>Stabilization</td>
<td>Serve on TPM committee and conduct management diagnosis, incorporate maintenance goals into business strategy</td>
<td>Support training and certification programs, conduct diagnosis of chronic losses</td>
<td>Conduct standardized maintenance</td>
<td>Improve autonomous maintenance</td>
</tr>
</tbody>
</table>
Fig 2.4 describes firm’s internal and external environment that affect TPM activities.

Objectives of TPM

- Most effective use of equipment.
- Building a comprehensive preventive maintenance system.
- Involves everyone that has some concern or interest with equipment.
- Everyone participate from top executives to shop floor employees.
- Promote and implement PM based on autonomous, small group activities

Business Performance

- Managerial Performance
- Operational Performance
- Financial Performance

Internal Environment

Management
- Corporate Planning
- Top Management
- Leadership
- Human Resource
- Focus

Operational
- Process Focus
- TQM Focus
- Information System Focus
- Contextual Focus

Productive Maintenance
- TPM Strategies
- TPM Teams
- TPM Process Focus

External Environment

Environment/Market Context
- Country and Industry
- Legal Environment
- Machine Maintenance due to legal requirements

Technological Environment
- New machinery made

Socio-Cultural Environment
- Educated consumers and Workforce
- More receptive to new ideas

International Environment
- JIPM Awards
- Foreign Environment
- TPM excellence Award

Figure 2.4 Macro views of factors affecting TPM [Brah and Chong, 2004]

2.7 PERFORMANCE MEASUREMENT IN TPM

Management needs information of maintenance performance for planning and controlling the maintenance process. This information is related with effectiveness and efficiency of the maintenance process, its tricks, organization, cooperation and coordination with other units of the organization. Measuring the performance of a
process provides information both for management and employees concerning the status of the process and enables decisions to be made concerning the adjustment of settings or actions to improve performance. Parida [2006] viewed maintenance performance measurement as the multidisciplinary process of measuring and justifying the value created by maintenance investment, and taking care of the overall business requirements. A performance measurement system is defined as the set of metrics used to quantify the efficiency and effectiveness of actions [Neely et al. 1995]. Performance measurement is examined from three different levels, (1) from the individual performance measures, (2) from performance measurement of the system and (3) relationship between the performance measurement system and its environment. Neely et al. [1995] also highlighted three concepts of performance measurement, as (1) classifications of performance measures as per their financial and non-financial perspectives, (2) positioning the performance measures from the strategic context and (3) support of the organizational infrastructure, like resource allocation, work structuring, information system amongst others. Maintenance performance measurement aligns the strategic objectives within the hierarchical levels of the whole organization allowing the visibility of the company’s goals and objectives from the top management level to the middle management at tactical level and throughout the organization.

Maintenance performance indicators measure the utilization of resources, like labor, materials, contractors, tools and equipment, using various cost indicators, such as man power utilization and efficiency, material usage, equipment efficiency and tool life etc. Kelly [1997] states that tracking maintenance productivity ensures that the targeted levels of maintenance efforts are being continued and that required plant output is achieved.

Kaydos [1999] identifies five major outcomes of performance measurement –
1. Improved control, since feedback is essential for any system.
2. Clear responsibilities and objectives, because good performance measures clarify who is responsible for specific results or problems.
3. Strategic alignment of objectives, because performance measures have proven to be a good means of communicating a company’s strategy throughout the organization.
4. Understanding business processes, since measuring data requires an understanding of the manufacturing process.

5. Determining process capability, because understanding a process also means knowing its capacity.

2.7.1 Overall equipment effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is viewed as key performance measure in mass-production environments applied to any kind of product. It was introduced by Nakajima [1988] in the context of Total Productivity Maintenance (TPM) and is focused at equipment / machines. Being aggregated metric instead of many detailed metrics, OEE is experienced as user friendly and clear overall metric and appreciated by professionals. According to Huang et al. [2003] the concept of OEE is becoming increasingly popular and that it has been widely used as a quantitative tool essential for the measurement of productivity in semiconductor manufacturing operations, because of extreme capacity constrained facility investment. They state that traditional metrics for measuring productivity, throughput and utilization, are insufficient for identifying the problems and underlying improvements needed to increase productivity.

OEE is defined as a measure of total equipment performance, that is, the degree to which the equipment is doing what it is supposed to do [Williamson, 2006]. The OEE metric helps maintenance management in the measurement of equipment availability and planning rate [Muchiri et al. 2010]. Ljundberg [1998] states that the definition of OEE does not take into account all factors that reduce the capacity utilization e.g. planned downtime, lack of material input, lack of labour. Moreover, the available time for operation would be a more appropriate basis for time measurement than the loading time as it was originally used. Similarly, De Groote [1995] utilizes a fixed planned production time and calculates the difference between the actual and planned production time. Sattler and Schlueter [1998], Jonsson and Lesshammar [1999] and Jeong and Phillips [2001] advocate for a more appropriate time basis. Furthermore, it is obvious that the accuracy of OEE is mainly dependent on the quality of the data collected.
Nakajima [1988] defines six large equipment losses which contribute to reduced OEE and the same analyzed by Pintelon et al. [2000] for palletizing plant are –

(i) Losses responsible for reduced availability index:
   a. Equipment failure/breakdown losses are categorized as time losses when productivity is reduced, and quality losses caused by defective products.
   b. Setup/adjustment time losses result from downtime and defective products that occur when the production of one item ends and the equipment is adjusted to meet the requirements of another item.

(ii) Losses responsible for reduced performance index:
   a. Idling and minor stop losses occur when production is interrupted by a temporary malfunction or when a machine is idling.
   b. Reduced speed losses refer to the difference between the equipment design speed and the actual operating speed.

(iii) Losses responsible for reduced quality index:
   a. Reduced yield occurs during the early stage of production from machine startup stabilization.
   b. Quality defects and rework are losses in quality caused by malfunctioning of production equipment.

The losses under first category are known as downtime losses and are used to calculate the availability index (AI) of equipment. Losses under second category are known as speed losses which occur due to operating equipment lower than the designed speed. These are used to calculate the performance index (PI). The third category of losses due to defective production, and are used to measure the quality index (QI).

The availability index (AI) can be calculated as –

\[ AI = \frac{\text{loading time} - \text{down time}}{\text{loading time}} \]

Where as availability efficiency (\( \eta_a \)) can be expressed as –

\[ \eta_a = \frac{\text{loading time} - \text{down time}}{\text{loading time}} \times 100 \] (2.1)

Loading time is the working time minus planned downtime, where downtime is the stoppage time loss due to breakdowns, setup and adjustments also termed as
unplanned downtime. Hence, it is a function of the number of breakdowns within a specified time period and related measures such as mean time between failures (MTBF) and mean time to repair (MTTR) [Pintelon et al. 2000]. MTBF and MTTR are claimed to be measures of equipment health & achievement and are related to objectives such as functional performance and process capability [Wilson 1999; Sharma et al. 2011].

The performance index (PI) can be calculated as –

\[
PI = \frac{\text{theoretical cycle time \times processed amount}}{\text{operating time}}
\]

Where as Performance efficiency (\(\eta_p\)) related to rate of production can be expressed as –

\[
\eta_p = \frac{\text{theoretical cycle time \times processed amount}}{\text{operating time}} \times 100 \quad (2.2)
\]

The quality index (QI) can be calculated as –

\[
QI = \frac{\text{processed amount - defective amount}}{\text{processed amount}}
\]

Where as quality efficiency (\(\eta_q\)) can be expressed as –

\[
\eta_q = \frac{\text{processed amount - defective amount}}{\text{processed amount}} \times 100 \quad (2.3)
\]

Using equations (2.1), (2.2), and (2.3) overall equipment effectiveness can be calculated as –

\[
\text{OEE} = \eta_a \times \eta_p \times \eta_q \quad (2.4)
\]

SEMI [2000] expresses OEE entirely in terms of time units in which the losses are expressed in time. SEMI [2001] defines six main states of manufacturing equipment, which are again related to the types of losses as discussed earlier. The idea behind OEE is to have a metric indicating the performance of equipment. However, OEE is not directed towards the equipment itself, but also includes the effects of the environment of the equipment. This is caused by viewing time losses, because of a lack of input items or no buffer space for items in the time base, although this no-input or no-output situation cannot be put on the account of the equipment [De Ron and Rooda; 2006]. Huang et al. [2003] find the concept of OEE becoming increasingly popular and widely used quantitative tool for performance measurement.
The manufacturers have used many performance measurement indices derived originally from the concept of OEE and customized to fit their particular industrial requirements. These are overall factory effectiveness (OFE), overall plant effectiveness (OPE), overall throughput effectiveness (OTE), production equipment effectiveness (PEE), overall asset effectiveness (OAE), and total equipment effectiveness performance (TEEP).

2.8. RESEARCH GAPS

The extensive review of the literature discussed above covered various aspects of TPM including implementation of TPM and performance measurement. But, the following research gaps were found -

- The effects of individual pillar of TPM have not been measured yet.
- The methods to quantify the effects of these pillars have also not been discussed.
- The positive and negative impacts of the various pillars were missing.
- The impacts of implementations of these pillars have not been anchored individually with the manufacturing performance.
- The frameworks need to be developed to apply these pillars to various sectors.

In this research, it has been decided to measure the effectiveness of education and training pillar of TPM, since, manufacturing performance and success of all the activities of TPM depends upon the skills of the employees of the firm. Various performance measurement metrics were identified to measure the performance of the pillar (discussed in chapter 3).

2.9 PROBLEM DEFINITION

As discussed in the previous section, effective exercise of education and training pillar of TPM is vital for the successful implementation of TPM in order to improve the manufacturing performance of the firm, so, it is essential to measure and verify the effectiveness of such an important pillar. The problem statement for the research is “verification of effectiveness of education and training pillar of Total Productive Maintenance”.