TPM PRACTICES AND ITS EFFECT ON EQUIPMENT PERFORMANCE

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By

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TPM Practices and its effect on Equipment Performance

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Certificate

*This is to certify that the thesis entitled "**TPM practices and its Effect on Equipment Performance**" is the record of bonafide research work done by Mr. P.K.Suresh, under my supervision and guidance at the School of Management Studies, in partial fulfillment of the requirements for the Degree of Doctor of Philosophy under the Faculty of Social Sciences, Cochin University of Science and Technology . The thesis has not been submitted earlier, to any Institution or University for the award of any degree, diploma, fellowship or other similar title.*

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Declaration

I, P.K.Suresh,hereby declare that the thesis entitled ***' TPM practices and its Effect on Equipment Performance'*** *is a record of bonafide research work ,done by me under the supervision and guidance of Dr.Mary Joseph.T, Professor(Retd.), School of Management Studies for the award of the degree of Doctor of Philosophy under the faculty of Social Sciences, Cochin University of Science and Technology. I further declare that no part of this thesis has been presented before for the award of any degree, diploma , associateship, fellowship or any other title of any University or Board*

Kochi *P.K.Suresh*

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P.K.Suresh

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ABBREVIATIONS

AARS	Average Adjusted R Squared
AFVIF	Average Full collinearity Variance Inflation Factor
AM	Autonomous Maintenance
APC	Average Path Coefficient
ARS	Average R Squared
AVE	Average Variance Extracted
AVIF	Average Variance Inflation Factor
BM	Breakdown Maintenance
CBM	Condition Based Maintenance
CMMS	Computerized Maintenance Management System
CNC	Computer Numerical Control
CSF	Critical Success Factors
EI	Employee Involvement
EPM	Equipment & Process Management
FI	Focussed Improvement
FMEA	Failure Mode Effective Analysis
FMS	Flexible Manufacturing Systems
GOF	Goodness Of Fit
HR	Human Resources
HRM	Human Resource Management
IA	Information Architecture
IP	Innovation Performance
ISO	International Organisation for Standardisation
JIPM	Japan Institute of Plant Maintenance
JIT	Just In Time
KE	Kaizen Event
KPI	Key Performance Indicator

LV	Latent Variable
M	Management Commitment
MAI	Monitoring ,Analysis & Improvement
MIS	Management of Information Systems
MP	Manufacturing Performance
MTBF	Mean Time between Failures
MTTR	Mean Time To Repair
MV	Manifest Variable
NITIE	National Institute of industrial Engineering
NLBCDR	Nonlinear Bivariate Causality Direction Ratio
OCB	Organizational Citizenship Behaviours
OEE	Overall Equipment Effectiveness
OEEML	Overall equipment effectiveness of a manufacturing line
OEM	Original Equipment Manufacturer
O &M	Operation & Maintenance
PLS	Partial Least Square
PM	Planned Maintenance
QM	Quality Maintenance
RCM	Reliability Centered Maintenance
RSCR	R Squared Contribution Ratio
SEM	Structural Equation Modeling
SCQM	Strategic Collaborative Quality Management
SME	Small and Medium Enterprises
SMED	Single Minute Exchange of Dies
SPC	Statistical Process Control
SPR	Sympson's Paradox Ratio
SSR	Statistical Suppression Ratio
T&D	Training & Development
TPM	Total Productive Maintenance

TQM	Total Quality Management
UK	United Kingdom
USA	United States of America
VIF	Variance Inflation Factor
WIP	Work in Progress.

CHAPTER-1

INTRODUCTION

This chapter intends to provide a general introduction to the topic of this research. The chapter attempts to bring out the importance of total productive maintenance, in globalised competitive market which highlights the rationale of the study. The general concepts about total productive maintenance are discussed. The potential and expected contributions of the study are also included in the chapter. Finally the organisation of the thesis is done.

1.1. Introduction about TPM.

Total productive maintenance is known in Japanese Industry as productive maintenance, with all employees participating through small groups. The first organisation to introduce TPM was Nippondenso Co., a large manufacturer of automobile electrical parts, belonging to the Toyota group of companies.

Preventive maintenance was introduced in Japan in 1951 from USA. This led to the introduction of productive maintenance by Nippondenso in 1960, which meant operation personnel did production work, and maintenance remained responsible for maintenance, each group performing their designated functions. In 1969 Nippondenso introduced TPM. They had totally automated their manufacturing and assembly of parts by them. This made it impossible for the maintenance crew to maintain the very large number of automated facilities. Therefore, it was decided that, the operators of automated equipment were to be responsible for routine maintenance themselves. Based on this concept and their experience of quality control circle, it was decided to evolve PM with all employees participating in this small group.

To maximise the effectiveness of man-machine systems, TPM aims to eliminate three types of losses.:

a. Down time losses caused by unexpected breakdowns or set up and other adjustments.
b. Speed losses due to idling and minor stoppages, which arise from temporary blockage or stoppage; and those due to difference between designed speed and actual working speed of equipment.
c. Defect losses arising from rejects, defects, and rework. Also, reduced yield due to losses which result from the time gap between the start of production and stabilised production.

Total productive maintenance strives to produce overall equipment effectiveness, through a combination of availability, performance efficiency, and rate of quality products.

The concept being that

Overall equipment effectiveness. = Availability X Performance efficiency X Rate of products.

1.2. Relevance of the study.

Liberalization and opening of economy to the global competition, had brought new challenges to the industry in the realism of productivity, quality and total quality management. In today's industrial scenario, technological advancements have resulted in the introduction of sophisticated equipment, which supports for increased productivity, quality and delivery of products. It also considers the protection of the environment and safety. In those advanced equipment, the operations can be performed by even semi skilled or unskilled operators. Even though, the upkeep of equipment has its own importance since the condition and performance of the equipment have large role in providing the quality and output of the products. Total productive maintenance concept helps for the scientific upkeep of plant and equipment.

The performance of TPM is measured as the overall performance in productivity, quality, delivery, safety, morale and environment. TPM originated in Japan, and a number of companies in Japan and outside have achieved the prestigious Japan Institute of Plant Maintenance (JIPM) award. India stands for the first out side Japan , where large number of companies have attained this award. A large number of companies in India are engaged in practicing the TPM concepts, but several companies have not succeeded in effectively implementing TPM. So the study about the different factors influencing the success of TPM is important, as it provides more inputs to implement TPM effectively.

A study done by Dinesh Seth and Deepak Tripathi, National Institute of Industrial Engineering (NITIE), (2003) analyzed the 'Relationship between TQM and TPM implementation factors and business performance of manufacturing industry in Indian context'. This research study identified certain factors which are critical to the effectiveness of TPM as leadership, process management ,strategic planning, and equipment management. As per these researchers, their study had opened many research avenues on the interfacial aspects of TQM and TPM, where this area has largely remained under researched. Their study had considered manufacturing industry as a whole, and they recommended intensive case studies to be carried out on various modes of TQM and TPM implementation. The outcome of such studies will be valuable to both Indian and global practitioners, who want to focus attention on manufacturing centric improvement drives.

So as a total outset the study on the various factors of TPM have importance, as per the recommendations of the previous researchers .

1.3. Statement of the Problem.

Several number of studies are conducted in India and abroad about TPM . The conducted studies include the benefits achieved by the companies through TPM, and about various factors which is influencing the performance of TPM.

TPM concept is successfully implemented in various industry sectors in India. But a large number of companies have not succeeded in effective TPM implementation due to various reasons. A number of research studies have been done, based on the various factors influencing the success of TQM and TPM. Studies have also been done about the improvements achieved by companies through TQM and TPM. The conducted studies are mainly industry based and also company based .

The performance of TPM is measured based on the productivity, quality, delivery, safety , morale and environment. The improvements in productivity, quality and delivery are achieved mainly through the improvements in overall equipment effectiveness. The overall equipment effectiveness is achieved through the availability of equipment, performance of equipment (increase in quantity of production) and through the production of quality products. (reduction in defects of products from equipment).

The studies have been done so far about the various implementation factors and performance of TPM on industry basis, and there is research gap identified about the various implementation factors and performance of TPM on equipment basis. The overall results of TPM in industry is achieved basically from the performance of the equipment. So this research study aims to examine the relationship between factors influencing the successful implementation of TPM and the resulted performance from the equipment.

The identification of factors which directly influence the results of TPM through overall equipment effectiveness, will help the companies in realizing the factors, which have impact on getting the results of TPM through its various pillars.

1.4. Scope of the study.

The study is done for identifying the relationship between the various implementation factors and performance of TPM. The study is done on the selected critical equipment from selected TPM practicing engineering companies from Kerala and in Tamil Nadu. The various implementation factors are identified from literature review of the similar studies conducted so far. The performance of the equipment, on the basis of the results from the pillars of autonomous maintenance, planned maintenance, quality maintenance and focused improvement were selected for this study.

1.5. Scheme of the study.

This research thesis includes six chapters .

Chapter-1 includes the introduction about TPM ,relevance of the study, statement of the problem, scope of the study and the scheme of the study.

Chapter 2 mentions the importance of manufacturing excellence , detailed literature on maintenance and TPM as TPM objectives, the steps for the implementation of TPM and its benefits.

Chapter 3 includes the studies on the improvements achieved by the organisations through the application of TPM practices, the relationship between various factors and performance of TPM and TQM, the studies on the hurdles faced by the organisations while implementing TPM, the identified research gap, scope of the study,conceptual frame work,objectives of the study, and the definition of identified independent and dependent variables.

Chapter 4 consists of the research scope and frame work,hypothesis of the study,research design,sample design,analysis design,collection of data and the measures of constructs.

Chapter 5 includes the analysis and presentation of data for all the identified performance indicators from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillars

Chapter 6 presents the consolidated findings, conclusion and findings ,recommendations, the implications of the study ,limitations of the study and about the scope for further research.

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CHAPTER-2

AN OVERVIEW OF TOTAL PRODUCTIVE MAINTENANCE

2.1. Introduction.

This chapter describes about various concepts about total productive maintenance. The chapter begins with the manufacturing excellence, lean concepts, discussions about various types of maintenance systems and various terms associated with the plant and equipment. About TPM philosophy, TPM objectives,TPM targets and about various pillars of TPM are explained.The implementation of TPM and its benefits are also mentioned.

The various concepts briefed in this chapter are based on the reference from various books and publications on these topics.

2.2. Importance of manufacturing excellence

Liberalization and opening of economy to the global competition, has brought new challenges to the industry in the realm of productivity, reliability and total quality management. The globalization of the economy is putting terrific pressure on industries to have increased productivity and innovation.

Sahay et al. (2000) concluded, that globalization is characterized by

- Tightly linked global financial market
- Global sourcing of inputs
- Increased pressure for improved product quality and reduced product price due to the global competition
- Evolution of business toward more comprehensive and continuous global coordination and integration

Michael (2006) mentioned about productivity, as the ratio of output that an organisation obtains over the specific amount of inputs or resources that it takes to produce the output. Organisations have adopted the principles of six sigma and lean manufacturing in order to address the inefficiencies in production and supporting functions.

Manufacturing excellence:

Hall (1986) mentioned that manufacturing excellence is attained by 'value added manufacturing', which is based on the principle that 'purge anything that does not add value to the product or service', whether material, equipment, space, time, energy, systems, or human activity of any sort.

As per Shingo (2009) it is the summary of seven wastes , which does not add value to the product or service .These mentioned seven wastes and their methods of elimination are,

1. Waste of over production- Eliminate by reducing the setup time, synchronizing the quantities and timing between processes.
2. Waste of waiting- Eliminate by synchronizing work flows as much as possible, and by balancing uneven loads.
3. Waste of transportation - Eliminate by redesigning layouts to reduce the unnecessary transports and handlings.
4. Waste of over processing - Eliminate by proper assessment of product and process.
5. Waste of stocks- Eliminate by reducing the setup times, and lead times by synchronizing work flows.
6. Waste of motion- Eliminate by study the motion for economy and consistency.
7. Waste of making defective parts- Eliminate by preventing defects, to eliminate an inspection.

Balamathan (2011) mentioned that, in order to reduce or eliminate the wastes lean practitioners utilize many tools such as,

1.Pull system-The technique for producing parts at customer demand. Service organizations operate this way by their very nature. Manufacturers on the other hand, building products to stock (per sales forecast) as a 'push system', without firm customer orders.

2. Kanban – A method for maintaining an orderly flow of material. Kanban cards are used to indicate material order points, how much material is needed, from where the material is ordered, and to where it should be delivered.

3.Work Cells – The technique of arranging operations and/or people in a cell , rather than in a traditional straight assembly line. Among other things, the cellular concept allows for better utilization of people and it improves communication.

4.Total productive maintenance (TPM)– TPM capitalizes on proactive and progressive maintenance methodologies and calls upon the knowledge and cooperation of operators, equipment vendors, engineering and support personnel, to optimize machine performance.

The results of this optimized performance include; elimination of breakdowns, reduction of unscheduled and scheduled downtime, improved utilization, higher throughput, and better product quality. Bottom-line results include; lower operating costs, longer equipment life, and lower overall maintenance costs.

5.Total quality management – Total quality management is a management system used to continuously improve all areas of a company's operation. TQM is applicable to every operation in the company and recognizes the strength of employee involvement.

6. Quick changeover (Single minute exchange of dies) – It is the technique of reducing the amount of time, to change a process from running one specific type of product to another. The purpose for reducing changeover time is not for increasing production capacity, but to allow for more frequent changeovers, in order to increase production flexibility. Quicker changeovers allow for smaller batch sizes.

7. Batch size reduction: Historically, manufacturing companies have operated with large batch sizes in order to maximize machine utilization, assuming that the changeover times were "fixed" and could not be reduced. Reducing batch sizes reduces the amount of work-in-process inventory, which reduces inventory carrying costs. Shorter production cycles allows the company to increase sales and market share.

8. Workplace organization or 5S – This tool is a systematic method for organizing and standardizing the workplace. It is one of the simplest lean tools to implement, provides

immediate return on investment, crosses all industry boundaries, and is applicable to every function with an organization.

9. Visual controls – These are the simple signals that provide an immediate and readily apparent understanding of a condition or situation. Visual controls enable someone to walk into the workplace and know within a short period of time what's happening with regards to production schedules, backlog, workflow, inventory levels, resource utilization, and quality.

According to Jay and Barry (1991), in order to attain global competitiveness the management have to take both strategic and tactical decisions.

Strategic decisions tend to have implications of long duration which take over a year to implement, which include the product strategy ,process strategy, location strategy, layout strategy ,human resource strategy ,procurement and just in time strategy.

Tactical decisions are those that can be substantially modified in one year or less which include, the inventory and just in time tactics, scheduling tactics, quality tactics, and reliability and maintenance tactics.

Both types of decisions support the production/operations management and company missions.

2.3. About Total Productive Maintenance:

2.3.1.Importance of maintenance:

Without having the plant and machinery in working condition, there is no use of an organization to implement modern techniques like FMEA, JIT, employee involvement, continuous improvement and SPC. So it becomes a prerequisite to go in for TPM before a company can talk about TQM.

Technical advancement throughout the world, has made the world today a border less society. Quality factors and cost depend upon the quality of the raw material, equipment precision, condition of the methods adopted and on the total involvement and capability of the people who carried out the work.

Today's competitive global market helps for availing the quality materials for processing and with the technological advantages helps for sensitive equipment, which can operate by a semi skilled operator which gives sensitive products. Now many precision equipment and devices help in monitoring and controlling raw material quality and consistency, functional efficiency and accuracy of equipment, auto operational systems to minimize and or to avoid variations in the methods used, and also the mistake proofing system to eliminate human errors.

The upkeep of equipment has become an additional responsibility. Maintenance still depends upon human beings. The concept of total productive maintenance meets this need.

TPM is a part of total quality management. Just as quality circle activities are carried out in small group, TPM also is carried out as small group activities on a company wide basis with equipment maintenance as its main aim. This guides the importance of management of equipment, to survive in the competitive market.

2.3.2.Maintenance systems :

Gopalakrishnn and Banerji (2002) detailed about various maintenance systems under various heads

a.Breakdown

b.Routine

c.Planned

d.Preventive

e.Predictive

f.Corrective

a.Breakdown Maintenance: Also termed as repair maintenance and the basic concept behind breakdown maintenance is not to do anything until and unless the machine ceases to function. Hence, no servicing is carried out excepting for a little bit of cleaning and lubrication which is done by the worker himself. The only attention the machine receives is at the time of failure. In most cases in a set up such as this, there is no maintenance man available, there is no spares kept even for immediate foreseeable needs, and no maintenance manuals or handbooks kept at hand to be referred by the personnel.

Such a system can continue for some time, but unfortunately once breakdowns begin to take place they have a tendency to recur at an ever increasing frequency. Hence, once the cycle of breakdown starts, they are prone to occurs over and over again at an alarming frequency.

Routine Maintenance: Routines are being established by defining the time available for each task and the number of units to be attended to within that time frame. A frequency is being established by estimating the time needed to do a particular job and the frequency that a particular unit will attain in a year, in half a year, or in a month is known.

Planned Maintenance: Planned maintenance is organised and carried out with for thoughts, control and records, to a predetermined plan. In the planned maintenance system the emphasis is on the machine's needs and the expected requirements from the machine. It has to be centred around the original recommendations made and prescribed by the original equipment manufacturer. The maintenance manager has to use all his experience and expertise to superimpose refinements and improvements on the manufacture's recommendations. In doing this the following factors have to be kept, as the extend of utilization , severity of utilization and operating conditions.

In the planned maintenance system, instructions are more detailed and thorough. The planned maintenance system requires the work to be planned in advance. The planning could be on the basis of three months roll on plan, in which the first month will be a fixed or a confirmed plan and the second and third month only be tentative plans. The first month's confirmed plan will then be broken down in to fortnightly plans, and there after daily plans.

This system has detailed instructions which have to be followed strictly. These include directions for inspection, repairs, rectification, and replacement of parts and so on. There has to be enough flexibility in this plan so that, changes in the plan can be accommodated to ensure reduced chances of failure during the intervening period, extending up to the next scheduled servicing date.

As experience is gained, the frequency between the checks/servicing can be progressively reduced, and certain elements of work found unnecessary can be eliminated. Initially the checklists and the detailed schedules of inspection and servicing are elaborate, as the maintenance personnel are not yet quite familiar at this stage with the newer equipment. As time goes by, and the maintenance personnel get experienced with the equipment and its servicing, reviews have to be carried out and the elapsed time between cycles increased, many items of checks/ work earlier considered essential are eliminated and some new ones introduced.

In the planned maintenance system, one important area which has to be taken care of is calibration. This function is so important that it has to be catered to separately and specifically because with out calibration checks, one is not sure of the output results.

Preventive Maintenance; Preventive maintenance system refers to those critical systems which have to reduce the likely hood of failures to the absolute minimum. To prevent breakdowns, preventive planned servicing is carried out with the specific objective of detecting/locating weak areas and ensuring perfect functioning by even replacing certain critical parts which could still be used, but for the assurance or reliability we demand. Thus after each servicing the equipment is considered to be as good as new and is expected to give a high level of reliable performance. In addition to this servicing, planned inspection and servicing will continue to be carried out in the interval between two planned preventive servicing which aimed at achieving the elimination of possible breakdowns. Thus at an added cost, a very high level of reliability of performance is assured or obtained.

Fredrik (2003) explained about the concept of reliability centred maintenance (RCM). RCM can be described as a systematic approach, to identify effective and efficient preventive maintenance tasks. The use of RCM can among other matters improve system availability and reliability, reduce the amount of preventive maintenance and unplanned corrective maintenance and increase safety.

Charles (1997) explained that reliability is defined to be the probability that a component or system will perform a required function for a given period of time, when used under stated operating conditions. Reliability may be viewed as the quality of the product's operational performance over time and as such extends quality into the time domain.

In the preventive maintenance system, we seek high reliability of operations and an accepted added cost. Reliability is there for an assurance that the equipment will function for the duration it is intended to, and will give failure free performance. It is the probability of successful operation of the component /equipment for a specified time or usage in a given environment. Successful performance may mean failure free operation or at operations with not more than a specified number of failures during that specified period.

Apart from accepting a low chance of failure as possible, the user department always wants a rapid return of the failed equipment to service. This needs a repair and its infrastructure ought to be so geared that the response time is minimal. This is the maintainability feature of the equipment.

Availability of any equipment for operational use and exploitation is a function of reliability and maintainability. Both these factors deeply affect availability. The highly reliable equipment will obviously be very expensive to design and produce, may have breakdown very rarely. But if it takes, too long to repair to be restored, then the availability will be poor.

Multiple trade offs in levels of reliability, maintainability, availability and cost has to be maintained.

Predictive Maintenance-Predictive maintenance can be defined as 'methods of surveillance' used to indicate as to how well the machine is, while performing its intended tasks.

When plants are put to continuous operations and to be able to get the maximum number of on stream days of operation, the system of maintenance operation to be such that it will be able to reduce down time to the absolute minimum. Hence continuous plant monitoring and diagnosing the actual condition of the equipment, by means of on stream non destructive testing methods are being increasingly used. The objective being the ability to predict an impending failure well in time, thus avoiding failures which could cause heavy penalty costs and even create health and safety hazards. There for an ability to forecast equipment behaviour by condition monitoring is a pre requisite for predictive maintenance. Condition monitoring is a method of extracting information from a plant/machinery and enables us to indicate its condition or health in quantitative terms.

Corrective Maintenance: Corrective maintenance is defined as maintenance (including adjustments and repairs on item) carried out to restore machinery which have ceased to meet an acceptable condition.

Design out Maintenance: Design out maintenance is a system that strives to eliminate, and if that is not possible then to minimise the need for maintenance to the lowest possible level. It is there for also known as eliminate maintenance. Hence it has to be thought of and applied to the product at the design stage itself so that machinery ,plant, and equipment are so designed as to need the least possible amount of attention or maintenance during their economical life span.

This concept has been applied to great advantage by the manufacturer, for by providing user convenience, safety, and reduction/elimination of maintenance.

Total Productive Maintenance:

The basic concept of TPM is change the attitude and improve the skill of all personnel by using quality equipment. Earlier as usual, the job of the operator and that of maintainer were separate, each was divided in to groups of operators and maintainers. The operators had thus no interest in the maintenance. Changing this attitude on the part of all employees was the first major task of TPM. That the operators maintain the equipment they use (self maintenance) .There for, training the operators in maintenance skills and knowledge was the next step. Improving the human beings is possible when both willingness and ability are present. This is achieved by driving home the need for eliminating losses in all forms and achieving optimal overall equipment effectiveness. All these activities improve the worker and equipment.

2.3.3.Other terms associated with plant and equipment:

Terotechnology: In 1970 UK introduced the new concept called terotechnology. Jacek (2008) explained terotechnology as the combination of management, financial, engineering, and other practices applied to physical assets in pursuit of economic life cycle costs. The practice of terotechnology is concerned with the specification, design for reliability and maintainability of plant, machinery, equipment, building and structure, in their installation, commissioning, maintenance, modification and replacement, with feedback of information, performance and cost.

TPM has an identical purpose to terotechnology, but in its approach is different. TPM is based on the assumption that, causes of equipment failure and poor quality are interdisciplinary and it is necessary to have a plant-orientated management organisation, and stresses the total participation of the workforce.

Flexible Manufacturing Systems : Al-Turki et al. (2004) mentioned that the most flexible and responsive to change manufacturing system is the flexible manufacturing system (FMS). It absorbs sudden large scale changes in production volume, capacity and capability. FMS has produced a product just like intermittent manufacturing and is continuous like continuous manufacturing. Flexibility is coming from either the ability to produce new products (machine flexibility) or from the ability to use multiple machines to perform the same operation (routing flexibility).

Usually, FMS consists of highly automated CNC machines connected by a sophisticated material handling system and a central computer that controls material movements and machine flow. The main advantage of FMS is its high flexibility in managing manufacturing resources. The resulting gains are numerous, including the reduced manufacturing cost, greater labour productivity, greater machine efficiency, improved quality, increased system reliability, and shorter lead times.

FMS implementation requires a large initial capital and substantial preplanning and high skilled labour.

2.3.4. Total Productive Maintenance (TPM) Philosophy:

TPM brings maintenance into focus as a necessary and vitally important part of the business. The TPM initiative is targeted to enhance competitiveness of organizations and it encompasses a powerful structured approach to change the mind-set of employees, thereby making a visible change in the work culture of an organization. TPM seeks to engage all levels and functions in an organization to maximize the overall effectiveness of production equipment.

TPM seeks to involve workers from all departments and levels, including the plant-floor to senior executives, to ensure effective equipment operation.

Ganapathy et al. (2004) explained that TPM is a methodology for maximizing equipment efficiency by

1. Establishing a total system for the productive maintenance for the entire life of the equipment.
2. Participation from all departments, including equipment planning, operating, and maintenance departments.
3. Involving all personnel, including top personnel to first line operators.
4. Promoting productive maintenance by motivation management, namely by autonomous small group activities.

2.3.5.TPM Objectives;

It includes

- Achieve zero defects, zero breakdown, and zero accidents in all functional areas of the organization.
- Involve people in all levels of organization.
- Form different teams to reduce defects and self maintenance.

Senthil and Praveen (2006) detailed about the performance measures used to achieve one or more of the following objectives:

1. Establish baseline measures and reveal trends.
2. Determine those processes to be improved.
3. Indicate process gains and losses.
4. Compare the organization /functional goals with actual performance
5. Provide information to make intelligent decisions.

6. Provide information for individual and team evaluation.
7. Determine the overall performance of the organization.

The objective of carrying out TPM is

1. Maintaining the equipment in condition till the life of the equipment.
2. Improving the capacity of the equipment.
3. Going in for continuous improvement.
4. Involving employees and forming teams so that they would give valuable inputs.

TPM Targets

P-Performance:

Obtain minimum 90% OEE (Overall Equipment Effectiveness)

OEE = Availability (A) X Performance Efficiency (P) X Rate of Quality (Q)

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

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

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

Q-Quality: Operate in a manner so that there are no customer complaints

C-Cost: Reduce the manufacturing cost by 30%.

D-Delivery: Achieve 100% success in delivering the goods as required by the customer.

S-Safety: Maintain an accident free environment.

M-Mastermind: Increase the suggestions by 3 times. Develop Multi-skilled and flexible workforce.

2.3.6..Defining the six big losses

One of the major goals of TPM and OEE programs is to reduce and or eliminate the six big losses as.

Breakdowns

Eliminating unplanned down time are critical to improving OEE. Other OEE factors cannot be addressed if the process is down. It is not only important to know how much down time the process is experiencing (and when), but also to be able to attribute the lost time to the specific source or reason for the loss .With down time and reason code data tabulated, root cause analysis is applied, starting with the most severe loss categories.

Setup and adjustments

Setup and adjustment time are generally measured as the time between the last good part produced before setup, to the first consistent good parts produced after setup. This often includes substantial adjustment and or warm-up time in order to consistently produce parts that meet quality standards.

Tracking setup time is critical to reducing this loss, together with an active program to reduce this time (such as single minute exchange of dies programme)

Many companies use creative methods for reducing setup time including assembling changeover carts, with all tools and supplies necessary for the changeover in one place, pinned or marked settings so that coarse adjustments are no longer necessary, and also the use of prefabricated setup gauges.

Small Stops and Reduced speed

It is the small stoppages, for any small maintenance activities as bolt tightening and for lubrication and the lack of capacity of the equipment to avail the designed speed which affects the quantity of production outputs.

Start up rejects and Production rejects

Start up rejects and production rejects are differentiated, since often the root causes are different between start up and steady-state production. Parts that require rework of any kind should be considered rejects. Tracking when rejects occur during a shift or job run, can help pinpoint potential causes, and in many cases patterns will be discovered.

2.3.7. TPM Pillars.

Japan Institute of Plant Maintenance (JIPM) have defined various pillars of TPM. Ganapathy et al. (2004), and Joel Levitt (2010) have explained about the various pillars of TPM as.

1. Autonomous Maintenance (Jishu hozen)
2. Planned Maintenance
3. Quality Maintenance
4. Focused Improvement (Kobetsu kaizen)

5. Development Management
6. Education and Training
7. Safety, Health and Environment
8. Office Improvement.

1. Autonomous Maintenance (Jishu hozen):

This pillar is geared towards, developing operators to be able to take care of small maintenance activities, thus freeing up the skilled maintenance persons.

The principal way in which the production department participates in TPM is through autonomous maintenance, that the cleaning, inspection, and simple adjustments performed by operators, who are systematically trained through a step-by-step programme.

The purpose of an autonomous maintenance program is three fold. First, it brings production and maintenance people together to accomplish a common goal, that to stabilize equipment conditions and halt accelerated deterioration. Operators learn to carry out important daily tasks that maintenance personnel rarely have time for. These tasks include cleaning and inspection, lubrication, precision checks, and other light maintenance tasks, including simple replacements and repairs in some environments.

Second, an autonomous maintenance program is designed to help operators to learn more about how their equipment functions, what common problems can occur and why, and how those problems can be prevented by the early detection and treatment of abnormal conditions. Third, the program prepares operators to be active partners with maintenance and engineering personnel,in improving the overall performance and reliability of equipment.

Traditionally, the general attitude on the shop floor has been “I run it, you fix it”. Operators were responsible only for setting up workplaces, operating the equipment, and checking the quality of processed work. All management of the equipment’s condition was the responsibility of maintenance staff. By now it should be clear that this way of thinking does not promote optimal equipment performance.

The alternatives are as operators can easily prevent many breakdowns and quality problems, by learning how to recognize abnormal conditions. A great deal of this learning can come about simply through physical contact with the equipment, that by taking a little time to tighten loose bolts, lubricating dry parts and cleaning away dirt, and by noticing dirt or grime on friction surfaces and on the switches, which are the conditions that can shorten equipment life.

While these tasks are easy enough to do, but in very few factories they have done well. Often clogged drains and empty oil supply equipment are neglected.

Autonomous maintenance teaches the equipment operator, to understand the equipment. Equipment knowledge is no longer limited to the operation; now it also includes a lot of things traditionally regarded as maintenance work. This approach is becoming increasingly important as factories introduce more robots and automated systems. Most importantly, the ability to look at the quality of the products and the performance of the equipment and notice when something is not right.

This depends on the following three skills:

1. Knowing how to distinguish between normal and abnormal conditions (the ability to establish equipment conditions).
2. Knowing how to ensure that normal equipment conditions are met (the ability to maintain equipment conditions).
3. Knowing how to respond quickly to abnormalities (the ability to restore equipment conditions).

When mastered all three skills, one can understand the equipment well enough to recognize the causes of future problems

The following list describes some of the skills operators' need.

a) The ability to detect, correct, and prevent equipment abnormalities and make improvements. This includes understanding the importance of

1. Proper lubrication, including correct lubrication methods and methods for checking lubrication.
2. Cleaning (inspection) and proper cleaning methods.
3. Improving equipment to reduce the amount of debris and prevent its accumulation and spread.
4. Improving operation and maintenance procedures to prevent abnormalities and facilitate their prompt detection.

b) The ability to understand equipment functions and mechanisms, and the ability to detect causes of abnormalities.

1. Knowing what to look for when checking mechanisms.

2. Applying the proper criteria for judging abnormalities
3. Understanding the relations between specific causes and abnormalities.
4. Knowing with confidence when the equipment needs to be shut off.
5. Being able to diagnose the causes of some types of failures.

   c) The ability to understand the relationship between equipment and quality, and the ability to predict problems in quality and detect their causes

1. Knowing how to conduct a physical analysis of the problem.
2. Understanding the relationship between product quality characteristics and equipment mechanisms and functions.
3. Understanding, tolerance ranges of static and dynamic precision, and how to measure such precision.
4. Understanding the causes of quality defects.

   d) The ability to make repairs.

   1. Ability to replace parts.
   2. Understanding of life expectancy of parts.
   3. Ability to reduce causes of breakdowns.
   4. Ability to take emergency measures.
   5. Ability to assist in overhaul repairs

Obviously, anyone who masters all these skills has achieved a very high level indeed, and no one is expected to do it quickly. Instead, each skill should be studied and practiced for whatever time it takes to acquire proficiency.

Implementation of Autonomous Maintenance in seven steps:

Below outlines the seven developmental stages of an autonomous maintenance program. These stages or steps are based on the experiences of many companies that have successfully implemented TPM. They represent an optimal division of responsibilities between production and maintenance departments in carrying out maintenance and improvement activities.

A Step -by -Step Approach

It is very difficult to do several things at the same time. That's why autonomous maintenance training takes a step-by-step approach, making sure that, each key skill is thoroughly learned before going on to the next. Autonomous maintenance is implemented in seven steps:

Step 1 : Conduct initial cleaning and inspection

Step 2 : Eliminate sources of contamination and inaccessible areas.

Step 3: Develop and test, provisional cleaning, inspection and lubrication standards.

Step 4: Conduct general inspection training and develop inspection procedures.

Step 5 : Conduct general inspections autonomously.

Step 6 : Organize and manage the workplace.

Step7: Ongoing autonomous maintenance and advanced improvement activities. People to spend time on more value added activity and technical repairs.

2. Planned Maintenance: It is aimed to have trouble free machines and equipment producing defect free products for total customer satisfaction. This breaks maintenance down into 4 "families" or groups

1. Preventive maintenance
2. Breakdown maintenance
3. Corrective maintenance
4. Maintenance prevention

With planned maintenance we evolve our efforts from a reactive to a proactive method and use trained maintenance staff to train the operators to better maintain their equipment.

Policy :

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

Steps in Planned Maintenance:

1. Equipment evaluation and recording present status.
2. Restore deterioration and improve weaknesses.
3. Building up information management system.
4. Prepare time based information system, select equipment, parts and members and map out a plan.
5. Prepare predictive maintenance system by introducing equipment diagnostic techniques

3. Quality Maintenance:

Quality maintenance activities are to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to maintain perfect quality products. It is aimed towards customer delight through the highest quality through defect free manufacturing. The 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. The transition is from reactive to proactive (Quality control to quality assurance).

In quality maintenance activity, the conditions are checked and measured in time series to verify that measured values are within standard values to prevent defects. The transition of measured values is watched to predict possibilities of defects occurring and to take counter measures beforehand.

Policy :

1. Defect free conditions and control of equipment.
2. QM activities to support quality assurance.
3. Focus on 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.

Data related to the 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. The occurrence trend in beginning and the end of each production/process/changes.
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.

4. Focused Improvement:

The target is to achieve and sustain zero losses with respect to minor stops, measurement and adjustments, defects and un avoided down times."Kai" means change, and "Zen" means good (for the better). Basically kaizen is for small improvements, but carried out on a continual basis and involve all people in the organization. Kaizen is opposite to big spectacular innovations. Kaizen requires no or little investment. The principle behind is that "a very large number of small improvements are more effective in an organizational environment than a few improvements of large value". This pillar is aimed at reducing losses in the workplace that affect the efficiencies. By using a detailed and thorough procedure, we eliminate losses in a systematic method using various kaizen tools. These activities are not limited to production areas and can be implemented in administrative areas as well.

Kaizen Policy:

1. Practice the concepts of zero losses in every sphere of activity.
2. Relentless pursuit to achieve cost reduction targets in all resources

3. Relentless pursuit to improve overall plant equipment effectiveness.
4. Extensive use of PM analysis as a tool for eliminating losses.
5. Focus of easy handling of operators.

Tools used in kaizen:

1. PM analysis
2. Why - why analysis
3. Summary of losses
4. Kaizen register
5. Kaizen summary sheet.

The objective of TPM is maximization of equipment effectiveness. TPM aims at maximization of machine utilization and not merely machine availability maximization. As one of the pillars of TPM activities, kaizen pursues efficient equipment, operator and material and energy utilization, that extremes productivity and aims at achieving substantial effects. Kaizen activities try to thoroughly eliminate 16 major losses.

16 Major losses in an organization:

Loss	**Category**
1. Failure losses - Breakdown loss 2. Setup / adjustment losses 3. Cutting blade loss 4. Start up loss 5. Minor stoppage / Idling loss. 6. Speed loss - operating at low speeds. 7. Defect / rework loss 8. Scheduled downtime loss	Losses that impede equipment efficiency

9. Management loss 10. Operating motion loss 11. Line organization loss 12. Logistic loss 13. Measurement and adjustment loss	Loses that impede human work efficiency
14. Energy loss 15. Die, jig and tool breakage loss 16. Yield loss.	Loses that impede effective use of production resources

5. Development Management:

Proper design, commissioning and testing will ensure that , equipment can reliably make products to specifications. The new equipment management involves, choosing systems based on lowest life cycle costs, design new products with customer focus and reduce lead time from design to production to market.

6. Education and Training:

It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skills. It is not sufficient to know only "know-how" but they should also learn "know-why". By experience they gain, "know-how" to overcome a problem and what to be done. This they do without knowing the root cause of the problem that 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 phases of skills are

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, conductive to employee revitalization
4. Training to remove employee fatigue and make work enjoyable.

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.

7. Safety, Health and Environment:

This focus on targets, the actual data and gaps in implementation of systems for ensuring safety, occupational health and clean environment through continuous training.

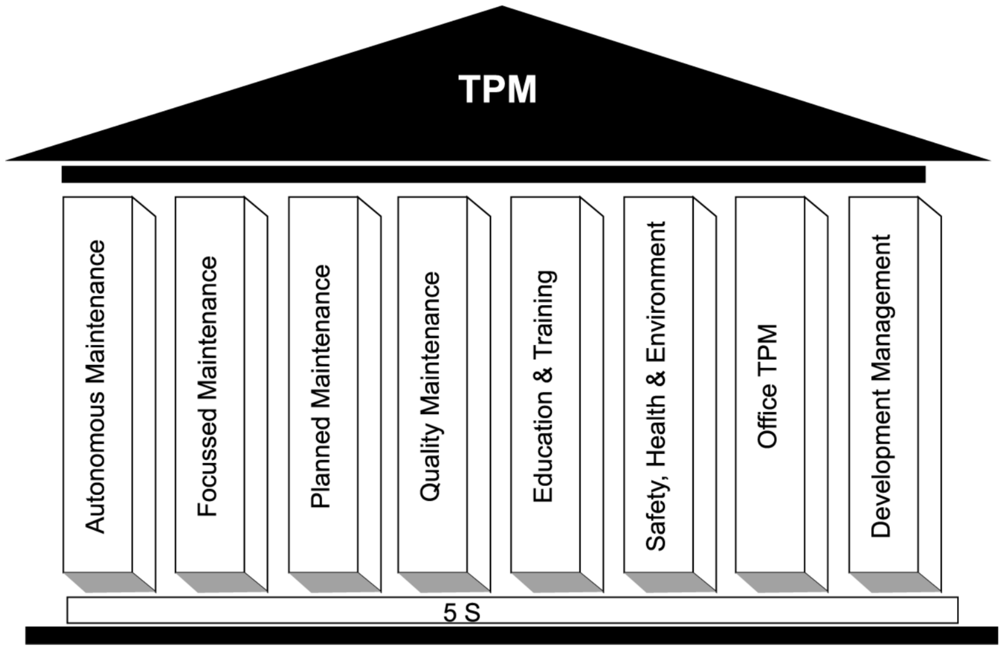
The aim is 1.Zero accident, 2.Zero health damage 3.Zero fires.

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

.**8. Office Improvement:**

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.

Figure-2.1



Eight pillars approach for TPM implementation (suggested by JIPM)

2.3.8.Similarities and difference between TQM &TPM:

The TPM programme closely resembles the popular total quality management (TQM) programme. Many of the tools such as employee empowerment, bench marking, and documentation used in TQM are used to implement and optimize TPM

Following are similarities between the two. The total commitment by upper levels of the management is required in both programme.

Employees must be empowered to initiate corrective action and a long range outlook must be accepted as TPM may take a year or more to implement and is an ongoing process. Changes in employee mind set toward their job responsibilities must take place as well.

The difference between TQM and TPM are summarized below.

Category	**TQM**	**TPM**
Object	Quality(Output and effects)	Equipment(input and cause)
Means of attaining goal	Systematize the management. It is software oriented	Employees participation and it is hardware oriented
Target	Quality for PPM	Elimination of losses and wastes

2.3.9. The implementation of TPM

Venkatesh (2009) explained about the steps in the introduction of TPM in a organization

Step A: Preparatory stage:

Step 1: Announcement by management to all about TPM introduction to the organisation

Proper understanding, commitment and active involvement of top management is needed for this step. Senior management need awareness programmes, after which announcement is made to all. Publish it in the house magazine and put it on the notice boards. Sends letter to all concerned individuals if required.

Step 2- Initial education and propaganda for TPM:

Training is to be made based on the need. Some need intensive training and some just an awareness. Take people who matters, to places where TPM already successfully implemented.

Step 3: Setting up TPM and departmental committees:

TPM includes improvement in autonomous maintenance, quality maintenance etc. as a part of it. When committees are set up it should take care of all those needs.

Step 4: Establishing the TPM working system and target:

Now each area is benchmarked and fix up a target for achievement.

Step 5-A master plan for institutionalizing;

The next step is implementation leading to institutionalized where in TPM becomes an organizational culture.

Step B-Introduction stage:

This is a ceremony and organisation should invite all. Suppliers as they should know that organisation want quality supply from them. Related companies and affiliated companies who can be customers or sister concerns that some may learn from organisation and someone can help organisation, and customers will get the communication that organisation care for quality output.

Stage-C –Implementation:

At this stage eight activities are carried out which are called eight pillars in the development of TPM activity. Of these four activities are for establishing the system for production efficiency, one for initial control system of new products and equipment ,one for improving the efficiency of administration and are for control of safety ,sanitation as work environment.

Stage-D –Institutionalizing stage:

By all these activities one would have reached maturity stage and it is the time for applying for TPM award

2.3.10. Benefits of Total Productive Maintenance:

The Newsletter of TPM club of India (2013) detailed about the benefits of Indian companies through TPM . TPM resulted for the companies for

1. Easy to clean, lubricate, inspection & tightening resulted the MTBF improvement, vessel cleaning time reduction, waste water generation reduction, preventive maintenance reduction, and in break down time reduction.
2. Easy to adjust -Some of the benefits included less operator fatigue ,reduced accident chances, life improvement with reduced stress and risk level of operators. The production increased with time saving and setup time reduction resulted in changeover time reduction.
3. Easy to operate or monitor resulted the increased production, product weight achievement and stoppage elimination, and also the reduction of inspection time, improvement in operations and safety levels.
4. Implementation of poka yoke is resulted with zero defects, line stoppage frequency reduction, elimination of defects , and in potential defect of grease missing prevention.

5. Elimination of minor stoppages benefits, included elimination of stoppage loss, improvement of performance rate, elimination of rework and reduction in WIP.
6. Tool change time reduction resulted the production loss decrease, with consistency in quality and improved quality with a reduction in minor stoppages.
7. In energy loss reduction.
8. Customer complaint elimination or the elimination of in-house rejection/rework resulted the elimination of customer complaints, zero customer rejections, improved machining efficiency and improved delivery adherence, zero warranty PPM with improved customer satisfaction, and in zero in house rejection achievement.

9. Logistics cost reduction through the improvement in production with zero inventory and reduction in transportation lead time and inventory reduction.
10. Operator's productivity improvement through layout changes (man-hour loss reduction/elimination) included floor space reduction, improvements in safety and time savings and reduction in WIP and savings in space.

11. Low cost automation- The accrued benefits included improvement of productivity by three times with set up time reduction.
12. Tools, jigs and consumables cost reduced

13.Breakdown elimination or Increasing MTBF -Some of the benefits included improved production and reduced breakdown; MTTR reduction ,reduction in manpower; motor winding heating phenomenon eliminated completely with savings in energy, and in MTBF increase.

14. Reduction in set/adjustment time included the increase in production time availability, and reduction in set up time and production with machine OEE increasing.
15. Start up time reduction or normal production loss reduction in process plant.
16. New technology introduction/process modification/ innovation resulted the elimination of machine investment; improvement in delivery and in capacity increase.

17. Equipment related design changes or lean machine building resulted reduction in capital cost

18. Lead time reduction resulted the fulfilment of increased demand by customer

2.4. Conclusion about this chapter.

This chapter discussed the importance of quality on the products and services in the era of liberalized economy. For the success in global competitiveness, the significance of attaining the manufacturing excellence and about various tools of total quality management were also discussed, which lead to the concept of total productive maintenance. The importance of maintenance, about various maintenance systems, the evolution of the concept of TPM, its objectives,the definition about various pillars of TPM, its implementation steps and the benefits were discussed. This brief discussion about these concepts are essential for this research study, and the following chapter detailed about the various research studies done on these concepts of TPM.

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CHAPTER 3

REVIEW OF LITERATURE

3.1 Studies on the improvements achieved by the organisations through the application of TPM practices

A number of studies are referred about the improvements achieved by the organisations, from different sectors, through the effective implementation of TPM practices. In general, the achievements includes the continual improvements in quality, reduction in costs, employee empowerments and the overall improvements in customer satisfaction.

The referred studies particularly on TPM, detailed its performance results on various sectors of industry. It includes the improvements in overall equipment effectiveness, improvements in productivity, quality, delivery and also in safety and environment performance.

Aizzat et al. (1994) mentioned that, in manufacturing companies in Malaysia the extent of employee's involvement in TPM practices is positively related to core job dimensions, as skill variety, task identity, task significance and in autonomy.

Ben –Daya and Duffuaa (1995) identified the links between maintenance and quality, using concepts from predictive maintenance and the measure of equipment effectiveness from total productive maintenance.

Blanchard (1997) mentioned that, average 28% of the total cost of finished goods attributed to maintenance activities, and the area of improving equipment design effectiveness through reliability and maintainability that offers a greatest potential of TPM.

Lim Cheng (1998) mentioned that total productive maintenance supports organization's survival, by meeting the diversified customer needs of small lot productions of various kinds of products and shortening of production lead time.
Bamber et al. (1999) mentioned about the TPM strategy to improve the performance of maintenance activities in the success of modern manufacturing.

Kevin and Vinod (2000) mentioned that, with TPM both less capital-intensive firms and more capital-intensive firms as well as more focused firms and more diversified firms do better, and also no significant differences between the performance of earlier and later implements of effective TQM.
Ben Daye (2000) mentioned that, reliability centered maintenance framework optimize the maintenance effort systematically, to get the maximum out of the resources committed to the preventive maintenance programme, for the competitiveness and profitability of any institution,.

Wang and Lee (2001) mentioned about the continuous improvement concepts and focussed on the application of total productive maintenance, and a time constant model was used to formulate a prediction model for checking the appropriate time for implementing of TPM.

Park and Han (2001) described TPM as a synergistic relationship between production and maintenance for continuous improvement of product quality, operational efficiency, capacity assurance, and safety through the investment in human resource development and management.

Vandelwal and Lynn (2002) concluded about the impact of reliability centred maintenance and TPM on availability, reliability, quality and also elimination of waste in a mill.

Hongyi et al. (2003) recorded the pilot implementation and evaluation of total productivity maintenance in a advanced manufacturing environment of a Hong Kong manufacturing company. The pilot test in an advanced model machine turned out to be very successful and that experience was useful for the company to apply TPM to all manufacturing.

James et al. (2004) mentioned about the overall cost management by increasing equipment efficiency, and reduce the cycle time by systematically identifying and reducing all sixteen types of losses under the categories of equipment, people, material and safety.

Nachiappan and Anantharaman (2005) mentioned that, the overall line effectiveness provide an appropriate solution for improving the effectiveness of a continuous product line manufacturing system, within a specific time period by identifying the problem exactly.

Ahuja and Khamba (2007) identified the maintenance related losses, and the improvements through the tangible and intangible benefits of the manufacturing performance, by strategic total productive maintenance initiatives in a steel manufacturing plant .

Halim et al. (2008) **i**dentified significant relationships between TPM practices and cost, and the moderating effect of technical complexity in the production process, on the relationship between TPM practices and manufacturing performance.

Ahuja and Khamba (2008) revealed the important issues in total productive maintenance ranging from maintenance techniques, framework of TPM, overall equipment effectiveness, TPM implementation practices and the barriers and success factors in TPM implementation. The study validated the relevance of strategic TPM initiatives into the manufacturing strategy, for realization of organizational objectives.

Jesse (2008) assessed and compared the maintenance optimization for wind turbines due to its impact on costs, risks, and performance. The technical feasibility and economic viability of the selected condition based maintenance strategy with time based maintenance strategy showed that, CBM is the most cost effective option.

Aditya and Uday (2009) identified that, different maintenance performance measurement frameworks as the measures of efficiency, effectiveness, quality, timeliness, safety, and productivity are the indicators to monitor, control and evaluate maintenance productivity performance. The different industries used as the indicators, best suited to their industry.

Kamran and Seyed (2009) analysed the relationships between training of employees, machine breakdowns, machine reliability and process quality and net throughput through a system dynamics model, and showed the effectiveness and usefulness of TPM in reducing breakdown down maintenance tasks, as well as enhancing machine reliability, process quality and product's net throughput.

Liu and Zhu (2009) indicated that in a 'connecter' manufacturer in China, TPM lead to the increase in efficiency and effectiveness of manufacturing equipment by reducing the failure, time loss and defects, and also significantly improved the morale of people and working environment.

Harsha et al. (2009) initially analysed the machine history to identify the bottleneck machine, and applied the TPM techniques as preventive maintenance, cleaning with meaning, poka yoke and kaizen effectively to the machine to improve the effectiveness.

Marcello et al. (2009) presented the overall equipment effectiveness of a manufacturing line, as an integrated approach to assess the performance of a line to improve the performance of the system as a whole, to overcome the limitation of overall equipment effectiveness. OEEML successfully highlighted the progressive degradation of the ideal cycle time, explaining it in terms of bottleneck in efficiency, quality rate, and synchronisation-transportation problems.

Osama and Almeanazel (2010) reviewed the overall equipment effectiveness in one of steel company in Jordan, and identified the three main techniques as CMMS, production planned, and SMED as have a very good impact to improve the production line and make the maintenance process more effective.

Farhana et al. (2010) identified the 16 losses in different sections of the tablet manufacturing facility of which some are attributed to human error. They proposed a simulation method in which worker allocation should be made by considering the skill level differences.

Ahmed et al. (2010) identified the factors contributing to the losses in a pharmaceutical industry as, equipment failure, set-up and adjustment, cutting blade change, start-up, minor stoppage and idling, speed, defect and rework and equipment shutdown. They suggested a planned maintenance program for TPM to make the production process quite smooth and proficient with increased efficiency.

Sivakumar and Saravanan (2011) after implementing TPM in a sick fabric industry, mentioned about the increase in the total productivity of the firm, by maximised equipment utilization ,product quality improvement via the quality rate of the equipment, improvement in the planned maintenance of the equipment, priorities in the equipment for corrective actions in the weak points , economy in natural resources and energy via the reduction in downtimes, and also in total process time.

Manu et al. (2011) discussed the results of TPM after a year's time of implementation in a cold rolling plant, as motivated employees, the improvement in overall equipment effectiveness,reduction in the number of accidents on the shop floor, increase in the team working spirit of the employees, healthy organizational environment and in kaizens.

Philipp and Jorn (2011) indicated about the significant potential of TQM and TPM supported with HR practices on total employee involvement.

Ohunakin. and Leramo (2012) examined the production performance of a beverage manufacturing plant, to gather data related to various losses associated with the functioning of the production line. The kobetzu kaizen technique showed increased overall equipment effectiveness by 50% more, with seven days' implementation of TPM than the seven-week adoption of the in-house maintenance practices. They observed a high tendency of achieving over 85% of overall equipment effectiveness with full implementation of TPM.

Tamer and Ayham (2012) explained the TPM implementation methodology, developed for increasing medical device utilization and for decreasing its failures at a hospital in Jordan. They investigated the applicability of manufacturing, maintenance systems that can generate significant operational benefits, and suggested the development of TPM implementation methodology using the 5S modelling technique. Through TPM, the employees can develop their working skills, by handling a wide range of challenging demands on a daily basis. The ability of the employees to control the work and to decide about the way they handle, improve the productivity and service quality.

Parastoo et al. (2012) investigated about the influence of TQM and TPM on productivity, and mentioned that TQM influences the effectiveness by improving the outcome by increased customer satisfaction, and also increasing the efficiency by increasing the quality of output. TPM influences by improving the performance of equipment, and also increasing the involvement of employees with improved job satisfaction.

Ashok Kumar et al. (2012) in the extensive literature review, indicated the positive impact of TPM on multiple dimensions of manufacturing performance, and OEE as a valuable measure that provides information on the sources of lost time and lost production. OEE is a valuable tool that can help management to unleash hidden capacity and therefore reduce overtime expenditures incurred due to reduced capacity.

Shiv Kumar et al. (2012) mentioned about the improvements in overall equipment effectiveness of a steam power plant, by increasing the power output and thermal efficiency with TPM implementation. The proper implementation of TPM, expenditure is justified by the gain in output and efficiency, and the training of workers on a regular basis lead to learn new skills and a positive inclination in their morale.

Hemlata Sahu et al. (2012) compared the previous month data before implementing TPM with data after implementing TPM in an auto industry, and found out the reduction in the maintenance cost and improved quality performance of the product.

Bimal and Jayanta (2013) concluded that in a mine industry, a systematic and long-term work with TPM, influenced on the cost positively as the losses are reduced. TPM progress was measured by the stages of autonomous maintenance completed and seen the higher reliability of equipment, reduction of waste and improvements in safety.

Abhishek et al. (2013) mentioned that, for customer satisfaction many of the Indian SMEs continually increased their productivity and quality standards, and TPM only is the significant business strategies that impact directly on manufacturing performance and continuous improvement of firms.

Halim et al. (2013) focused on two main practices of TPM as autonomous maintenance and planned maintenance in a Malaysian SME. The equipment deterioration eliminated as the equipment operated efficiently. The autonomous maintenance activities with total employee participation, and the investment in training and education, increased the operators' morale and the commitment towards company's goals.

Ratapol (2013) proposed an analytic network process with OEE, for improving the weaknesses of original OEE, since the significance of every single OEE's element is completely dissimilar to the others. The intensity of incurring losses is different in the matter of machine type, capacity and also operating cost.

Abhay and Dabade (2013) mentioned that, TPM is based on enhancing, exploring, and using of the capabilities of people, and it recognizes and attempts to realize needs of people, such as self-esteem, morale, safety, and in job satisfaction.

Suzaituladwini et al. (2013) mentioned about the impact of TPM on innovation performance, and it will be more effective if supported by other practices, such as kaizen event .They used a conceptual model to study the structural relationship between TPM, KE practices, and IP for Malaysian automotive industry.

Iftekhar et al. (2013) discussed the important key performance indicators of TPM, as machine breakdown time, mean time between failure (MTBF), mean time to repair (MTTR) and breakdown time percentage of available time. A transformation of work environment and employee mind set are also seen, as a change in culture which happen slowly.

Wasim and Sanjay (2013) advocated the concept of TPM for Indian approach, as its successful implementation can achieve better and lasting result, because there is an ultimate change in people (knowledge, skills, and behavior) during the progress.

Damjan et al. (2014) examined the role of maintenance in improving competitiveness and profitability, and the condition-based maintenance approach represented the highest opportunity for improvement in a Slovenian textile company maintenance practices.

Senthil and Samuel (2014) selected a production layout in a clothing factory, to study 5 different sewing machines for TPM implementation. Performance efficiency levels of these sewing machines before and after the TPM implementation found improved, and also found the lead time improvement as an interaction effect with kaizen tool.

3.2 Studies on the relationship between various factors and performance of TPM

A number of studies mentioning the various implementation factors and performance of TPM were referred. The common factors proved by the researchers which influence the success of TPM are the leadership, management commitment, education and training, information management, process management, and analysis and improvement practices.

Bailey et al. (1989) defined TPM as composed of six concepts as, utilization of operators to perform specified routine maintenance tasks on their equipment; utilization of operators to assist mechanics in the repair of equipment when it is down; utilization of mechanics to assist operators in the shutdown and start-up of equipment; utilization of lower-skilled personnel to perform routine jobs not requiring skilled craftsman; utilization of computerized technology to enable operators to calibrate selected instruments; and transfer of tasks between operating groups .

Bohoris (1995) concluded that, total productive maintenance increase the availability of existing equipment in a given situation, which reduce the need for further capital investment. The investment in human resources results in better hardware utilization, higher product quality and reduced labour costs. The computerized maintenance management system assist for the successful introduction of TPM

Eugene (1996) mentioned that, manufacturing organizations need meaningful and reliable data on their equipment performance, and based on the data future TPM projects can be prioritized. Incentives and rewards need to be revised to encourage TPM implementation.

Patrik (1997) analysed five linked maintenance management components in Swedish manufacturing, as strategy, human aspects, support mechanisms, tools/techniques and organization components, and the integration of maintenance into production planning and control for a complete market oriented system. It needs committed management, training at every level, and feed back system to designers about detailed reliability data and running condition of machinery, for the rapid development of reliability in successive evolutionary design. MIS for the data needed, for the true reliability based maintenance schedule optimization, and for the PM scheduling for improved preventive maintenance schedules based on the facts.

Roberto and Francesco (1997) mentioned that, TPM is widely recognized as a strategic weapon to superior performance even in small and mid sized business in Italy and in other European countries. Each industry and within each industry each company, tailors a specific TPM implementation pattern to fit its particular needs, and subject to the specific environment competitive constraints.

Muthu et al. (2000) combined the principles of total quality control and maintenance engineering, and proposed a model called ‘strategic maintenance quality engineering’ model. The maintenance quality strategy is through human knowledge nourishment, information system, continuous monitoring of maintenance quality system, approach towards maintenance quality target, transfer of customer feedback, training and education on maintenance quality, failure analysis, maintenance quality costs, maintenance quality auditing and also maintenance quality through counseling.

Ireland and Dale (2001) adopted the TPM pillars, as education and training, safety, quality maintenance, and used the cost deployment to the potential greatest benefits areas, to help the focus improvement activities in three companies .

Rambabu and Subash (2001) mentioned about the analytical hierarchy process model, as a multi attribute decision model for justification of TPM in Indian industries, and priorities can be very useful for strategic and operational decisions in reallocating resources.

Ramayah et al. (2002) examined the effects of change management towards the implementation of productivity and quality improvement programs, through the concept of total productive maintenance in manufacturing firms in Malaysia. With the autonomous maintenance and planned maintenance, the factors as management commitment, training and education, team culture, employee empowerment and setting up of new company policies and goals, can lead to better TPM implementation.

Dinesh and Deepak (2003) examined the relationship between factors influencing the implementation of TQM and TPM, and business performance. The three approaches selected in Indian context as TQM alone, TPM alone, both TQM and TPM together. The identified factors significant for performance in Indian context include the leadership for improvement, strategic planning, process management and education and training. Also the approach specific factors as equipment management for TPM, and focus on customer satisfaction,employee involvement and empowerment for TQM. The performance management system found significant for combined approach and information architecture found critical for both TPM and combined approach.

Samir (2004) mentioned that top management commitment is the top driven factor for success of TPM, with a realistic practical plan based on the project management principles. The participation of all the employees, their attitudinal changes to adopt the changes in job responsibilities , continuous training, and to develop a network of TPM coordinators , senior level support with time and resources, and the relevant measures of performance, are to be established and continually monitored.

Brah and Chong (2004) mentioned about the positive correlation between TPM and business performance, and it constructs as corporate planning, top management leadership, human resource focus, process focus, total quality management focus and information system focus.

One Yoon et al. (2005) identified both human-oriented and process-oriented strategy, as the critical success factors in the implementation of TPM in a manufacturing organization. The impact of the human oriented strategy is fostering higher extent of TPM implementation, as the human issues much more related to the changes and adoption in the organisation.

Ahuja et al. (2006) revealed about the success of TPM in a typical Indian manufacturing organization, that it depends upon the organisations endeavour to holistically implement TPM initiatives, by top management commitment support and involvement, and developing a realistic TPM implementation plan by employing the project management principles . Also the organisation to provide empowerment and incentives for employees, reward mechanisms, eliminate the reactive maintenance culture, inculcate self belief in the work force, ensure the motivation of work force by participative management, provide cross functionality, install skills and knowledge related to autonomous maintenance and equipment improvement ,put in place the relevant measures of performance, and to continually monitor and publicize the benefits achieved in financial terms.

Mfowabo (2006) recommended the need of support from top management for TPM activities, by providing the necessary planning, commitment, direction, create and establish clear measures and performance including achievable milestones and objectives, using the project management techniques. Also needed the incentives and rewards in order to encourage continuance of TPM activities, financial supports, training and educational supports, regular communication between the operation and maintenance departments, and also the regular review audits to provide meaningful management information relating to the TPM policies and practices.

Jamel and Hashmi (2006) concluded that, in automated manufacturing industries the maintenance function to be regarded as a sufficiently important function to the business strategy, and need full commitment from the top management. The use of computerised maintenance management system, conducting an appropriate training needs analysis and good training implementation, and a better of performance improvement in equipment availability were recommended.

Eti et al. (2006) suggested for self-auditing and benchmarking as desirable prerequisites before TPM implementation. For the essential prerequisite for success of TPM, need the willingness of employees within an organisation to accept changes for the better, and management commitment to provide the necessary training and time to monitor the success or failure of the improvement initiatives.

Yon-Woo et al. (2008) revealed that, the individual's improvement,education and training as well as the organizational and personnel management, significantly influence the management results of productivity and increase in quality.

Zora et al. (2008) mentioned that the quality of the entire process is dependent on the maintenance process, and it must be carefully designed and effectively implemented. The information system for managing maintenance must include strategic, tactical and operational aspects of decision-making within the domain of equipment maintenance.

Jesu´s and Carlos (2008) recommended for a Spanish group of timber companies, a participative approach and a suitable methodology to design and implement a satisfactory preventive maintenance program, in accordance with continuous improvement.

Christie (2008) proposed an appropriate strategy for the implementation of total productive maintenance at Continental Tyre, South Africa, and to overcome the barriers of implementation proposed for, proper understanding of the total effort required, sufficient management support, sufficient TPM staff, no union resistance, enough training carried out, change of priorities, no failure to develop a good installation strategy, and the possibility of right wrong approach

Ahuja and Khamba (2008) surveyed a large number Indian manufacturing industries to ascertain the contributions made by TPM initiatives. The study revealed that, organizational leadership and involvement, traditional maintenance practices, successful adaptation of effective TPM initiatives, can significantly contribute towards accruing core competencies in the organization. The focused TPM implementation over a reasonable time period varying between three and five years, can significantly contribute towards the realization of core competencies in MP, thereby providing a sound platform to compete effectively in the dynamic environment.

Albert (2009) mentioned about maintenance performance management as, people shared objectives aligned with those of the organization, action plans are clearly communicated to those responsible for implementation, work is structured to achieve fast response and minimize loss, and efforts are reinforced by support systems. The performance to be linked to the maintenance strategy for guiding management decisions.

Vasile et al. (2010) mentioned that, with detailed information possessing by maintenance's operational computerization, offer the necessary and sufficient information to the maintenance department. It covered the knowledge, analyzed the equipment that must be conserved, the materials stocks and replacements, cooperation activity, and equipment maintenance's costs.

Pamintas (2010) mentioned that total productive maintenance is to be applied in accordance with the specific organization structure and culture. It needed detailed analyses of entire machining process, hardware and software integration, maintenance planning and scheduling based on predictive methodologies, and a new approach of the system architecture. Also needed the proper understanding of terms and goals, commitment and active involvement of the employees, and employees must be educated and convinced that TPM needs extended time frame necessary for its full implementation.

Fore and Zuze (2010) concluded that, a manufacturing company can only benefit from TPM if it ensured management commitment through activities such as, permitting, supporting, managing, and leading by example. The process of recording information to be simple and effective for future data analysis .The problems such as, breakdowns and rework, and possible causes lead to the correction of common problems, are to be highlighted. The employees must be appropriately trained, empowered and convinced, that TPM is a sustainable program and management is totally committed to the program.

Mohammad et al. (2010) mentioned about the training requirements to raise employees' responsibility and enthusiasm to their jobs, for the success of lean and TPM implementation. To highlight the mistake-proofing and problem solving during the training program, the message to be transfer that everyone's roles are important, and all employees should obtain a common view and can share in the success of the company, and they should understand the targets and goals of the company. All the employees should feel free to suggest improvements, make decisions, and be productive, and discover work shortcomings and ask for techniques for improvements. The lean tools like 5S, JIT, kanban, and TPM to be deployed with employee participation, and the results to be periodically evaluated by reviews, modifications, or further implementation of methods .

Kumar et al. (2011) provided an overview of research and developments in the measurement of maintenance performance, looking at the maintenance strategies as condition based maintenance and reliability centered maintenance. Quantitative approaches included economic and technical ratios, value-based and balanced scorecards, system audits and human factors, amongst others.

Fatemeh and Sha'ri (2011) derived the critical success factors for continuous improvement through TPM and six sigma integrated models as, management commitment, employee involvement, education and training, organization structure, manufacturing strategy, responsibility and teamwork.

William et al. (2011) done a case study of the application of TPM principles in a pharmaceutical company in Zimbabwe, and training and education through short course training lead to the improvement of company employees.

Rohit and Trikha (2011) recommended for employee empowerment in a piston manufacturing company, to enhance responsibility and authority to improve and totally eliminate the big losses. If the maintenance department realizes its proper function in a progressive, innovative industrial society, then its personnel must be continuously trained to meet current needs as well as future requirements. To make the maintenance planning system effective, it is essential to keep track of all the corrective maintenance jobs and preventive maintenance inspections, by implementing CMMS.

Abhijit et al. (2011) mentioned that scheduling planned maintenance activities is the key to the success of total productive maintenance, in reducing the mean and variability of production lead time.

Ng, (2011) identified the critical success factors of TPM implementation as, a commitment from top management, cultural change, education and training, clear vision and mission, effective communication, language problems and measurable definition for TPM.

Burhanuddin, et al. (2011) mentioned that, the maintenance decision support system is essential to ensure maintainability and reliability of equipment in the industry. Decision making grid to be embedded with computerized maintenance management system, to aid maintenance strategies for the machines in small and medium enterprises.

Narender and Guptha (2012) discussed that, for developing the autonomous maintenance teams, better teamwork with communication are required. An efficient data processing system for accurate and updated information to the management is required, for future data analysis for correction, and to eliminate common problems of breakdown and reworks.

Melesse and Ajit (2012) evaluated the correlation between various TPM implementation dimensions and manufacturing performance improvements in a boiler plant. The study focussed on the contributions of top management leadership and involvement, and holistic TPM implementation initiatives, as the TPM implementation success factors.The focused TPM implementation over a reasonable time period can contribute towards the realization of significant manufacturing performance.

Aaditya (2012) mentioned that, employee empowerment in the manufacturing industry will enhance responsibility and authority to improve and totally eliminate the six big losses. The personnel must be continually trained to meet current needs as well as future requirements. It is essential to keep track of all the corrective maintenance jobs and preventive maintenance inspections,with the implementation of computerized maintenance management system, to make the maintenance planning system effective. The successful TPM implementation can achieve better and lasting result through the ultimate change in people (knowledge, skills, and behavior) during the progress.

Gautam et al.(2012) revealed that, for successful implementation of TPM top management commitment and support is needed, and also need a greater sense of ownership and responsibility of operators, cooperation and involvement of both operators and maintenance workers, and also an attitude change. The study mentioned about the need for a more proactive approach to maintenance management, and greater integration between maintenance and production departments.

Adnan et al. (2012) made an attempt to critically discuss the previous literature related to the management commitment. Management commitment is the main issue in TPM implementation that discussed in most of the literature related to CSFs. This literature review-based research highlighted significant research gaps that need further assessment, particularly related to the intangible factors and hierarchical context.

Hemant and Pratesh (2012) mentioned about the process of recording the information associated with a machine, which must remain simple but effective for future data analysis. The highlight of problems and possible causes lead to the correction of common problem such as breakdowns and rework, and the aim is to eliminate such causes. Information with trend analysis can provide a basis for forming long-term plans. In order to establish autonomous maintenance teams, better communication and team- work must be promoted.

Pradeep Kumar et al. (2012) done an empirical study about the high end printing press machines and packaging machines, based on real time data and analysis, to assess information on successful implementation of TPM in the industry. The results revealed the varying trends in the overall equipment effectiveness. A comparative study identified various problems leading to decrease in the overall efficiency of the industry, between world class industries where TPM has been implemented and industries which do not follow TPM

Khairul and Muhamad (2012) developed a framework of maintenance strategy, for effective maintenance management systems in Malaysian NPK Fertilizer company, and to demonstrate the validity the elements tested by implementing it on actual equipment. The identified 5 disciplines in basic maintenance strategies are: i. Training and education ii. Maintenance indices and KPI iii. Autonomous maintenance (AM) iv. Basic equipment condition v. Understanding of preventive maintenance .

The 5 disciplines in intermediate maintenance strategies that to be implemented after the establishment of basic strategy are: i. Root cause failure analysis ii. Lubrication strategy iii. Reliability initiatives iv. Life cycle management and v. Spare parts management .

The advanced maintenance strategies include: i. Condition-based monitoring and ii. Computerized maintenance management systems.

Badli Shah (2012) identified the critical success factors as, top management commitment, resource management, performance measurement system , continuous improvement system , education and training , work culture and involvement of TPM, as important in ensuring the success of TPM program in Malaysian automotive SMEs.

Amit Kumar and Garg (2012) mentioned that, TPM can be adapted to work in industrial plants as well as in construction, building maintenance, transportation, and in a variety of other situations. TPM success require strong and active support from management, clear organizational goals and objectives for implementation, and need the extended time frame for full implementation.

Ayman (2013) examined the influence of soft and hard TQM practices on TPM implementation level in manufacturing companies in Jordan, and the results indicated that four soft TQM practices, as top management leadership, training, workforce management, and customer focus and three hard TQM practices, as continuous improvement, information feedback, and process management, which significantly and positively affected the TPM implementation level. Manufacturing companies are strongly recommended to initiate a TQM program prior to TPM introduction.

Prabir (2013) studied about TPM in two companies that, a large company implemented with a 'text book approach' with a clear hierarchical structure and gone for JIPM award, and the other with company implemented with immediate problem focused approach and a simple structure. The commonality between these two approaches is the involvement of people, education and training, involvement of top management and commitment towards continuous improvement.

Ranteshwar et al. (2013) mentioned that, with the implementation of TPM the utilization of CNC machines is improved, by eliminating all the losses associated with equipment effectiveness. The success of TPM depends on the various pillars, and top management support and workers involvement are the key factors for its implementation.

Shamsuddin and Masjuki (2013) briefed that, for implementation of TPM a firm can generate its own working plans and programs according to its suitability, with active participation of the knowledge of workers developed through visionary training programs. The structure of the organization is to be updated, to accommodate those knowledge workers to apply their wisdom in exercising decision-making, and to play roles in decision implementations.

Naran et al. (2013) proposed a solution to improve the machine availability at the Weir Minerals Africa Isando plant, through the reactive maintenance with a maintenance report card for each critical machine. It include a machine diagram, the frequency of breakdowns, a root cause analysis, a list of critical spares and a planned maintenance schedule. That is a starting point for a comprehensive preventative maintenance programme for the plant.

Kun-Huang et al. (2013) extracted four constructs named as, top management commitment and kaizen, field maintenance and process control, modular production and process integration, and supply chain management, as four practices which have a positive and significant impact on manufacture performance in electric and electronic firms in Taiwan. They suggested that firms can promote management involvement in program activities, use team to solve problems, managers to provide programs with the required resources, do kaizen activities actively, using cross-functional team to promote kaizen program, and also continuous employee training.

Prasanth et al. (2013) with the experience in TPM and in the refinery industry, attempted to understand the factors that hinder implementation of TPM. There should be free flow of communication and information, both horizontally and vertically transcending all levels within an organization. Processes need to standardized and maintenance need to be planned. Routine maintenance activities require to be carried out by operators, to allow maintenance personnel for schedule modification and maintenance programs. Extensive training has to be given throughout the organization on TPM and its benefits.

Sarang et al. (2013) studied the implementation of the TPM program in the spinning industry using, a H-Check sheet, PM-check sheet, one point lessons, empirical and comprehensive approach toward the methodology, which result proper implementation of TPM. After implementation of TPM on model machine, both direct and indirect benefits obtained for equipment and employees respectively.

Jagtar et al. (2013) evaluated the relationship between various TPM implementation dimensions and manufacturing performance improvements, by applying OEE in one of the two wheeler automobile Industry in India. The study established that, focused TPM implementation over a reasonable time period, strategically contribute towards the realization of significant manufacturing performance enhancements. Also suggested a set of various techniques like single minute exchange die, computerised maintenance management system and production planning to the industry, to improve their maintenance procedures, and improve the productivity after calculating the overall equipment effectiveness.

Mohamed and Ali (2014) studied the critical success factors for deploying total productive maintenance programs in the Egyptian fast moving consumer goods companies. The research identified nine factors affecting the success of TPM deployment as, leadership style and influence, management commitment, clear vision and integrated strategy, existence of strong motive, availability of financial resources, level of knowledge and experience, organization culture, the role of consultant, benchmarking and also the sharing of best practices.

Suchisnata and Ajit (2014) concluded that, TPM in manufacturing industry necessitates a change in both the company's and employee's attitude and their values, which takes time to bring about, and need long-term planning. Holistic TPM implementation can lead to the establishment of strategic, proactive maintenance practices in the organization, for avoiding future system and equipment related losses, and marshal the organizations towards capability building for sustained competitiveness.

3.3. Studies on the interrelation between TPM and TQM

A number of studies were referred which mention about the relationship between the various factors and performance of TPM. There are various common factors which influence TQM and TPM, and so these reference also have importance.

Wilkinson et al. (1994) examined the growing development of TQM in United Kingdom and its linkages to the management of human resources, and suggested that HR practitioners firstly play a creative role at the shaping stage of TQM. Secondly HR can publicize the launch of TQM at the introduction phase by designing communications events. Thirdly assistance can be provided to maintain and reinforce TQM by identifying ways to recognize and reward achievements, or redesigning suggestion schemes. Fourth, HR practitioners have a role to play in reviewing TQM by designing the attitude surveys and analyzing their results**.**

Phillip and Uday (1997) provided the quality management model implementation, as visionary leadership, education, training, empowerment, and teamwork, as which effect TQM by employee practices and enhance employees' job satisfaction

Sharp et al. (1997) showed that the results of implementing TQM in maintenance, contribute the manufacturing performance, and the requirement of top management commitment, improvement of quality in work life and involvement, teamwork and people empowerment, as its success

Shari and Elaine (1999) proposed a set of critical success factors for TQM implementation in SME's, as 1.Management Leadership, 2. Continuous improvement system 3.Eductaion and training 4.Supplier's quality management 5. Systems and processes 6. Measurement and feedback 7.Human resource management, 8.Improvement tools and techniques 9.Resources and 10. Work environment and culture.

Danny and Mile (1999) identified in manufacturing companies, the categories of leadership, management of people and customer focus as the strongest significant predictors of operational performance, than the other TQM tools as, process improvement, benchmarking, and information.

Vidhu and Joshi (2002) showed the influence of effective management leadership, on human resource management, supplier management, and design management, as the effects of TQM on the firm's performance in Taiwan information-related industries.

Teddy & Hal (2003) assessed the implementation of TQM processes in government agencies in Malaysia, and the leadership commitment figured importantly as an influence on perceptions about TQM implementation, along with cultural and structural factors.

Sha'ri (2003) revealed as the results of a survey conducted among a sample of local SMEs in Malaysia that, the top management's support and involvement is crucial in communicating its vision, setting the direction, and arranging adequate resources for employee education and training. The recognition of quality management holds the key to competitiveness in the global market irrespective of the size of the company.

Irani et al. (2004) stressed as the key element for improving organisational competitiveness and performance, as the importance of a strong total quality culture, as the customer focus linked with a continuous improvement plan, supported by innovation.

Gunasekaran and Ngai (2004) demonstrated that, information technology is an essential ingredient for business survival and improves the competitiveness of firms.

Deepak (2005) mentioned about the initial investments that TQM and TPM require, in terms of employee training, documentation, mobilization and investment in infrastructure. The marginal performance improvement is owing to country specific factors, like initial orientation resistance of employees and executives, relatively lower literacy levels to understand TQM, lack of availability of quality data and measurement systems, and the very basic Indian culture tuned for slow and steady changes.

Benjamin and Elizabeth (2005) mentioned about the improved quality and costs reduction, when TQM is correctly applied with consideration on organizational type and climate, cultural differences, and the demographic and psychological diversity of personnel.

Fotis and Katerina (2005) mentioned about the important factors evaluated by the European quality award, such as competitiveness, customer focus, continuous improvement, benchmarking, fact-based management, people participation and partnership, strategic quality planning, and advance their quality management systems, which are as well beyond ISO-9000 certification

Fang and Peter (2006) mentioned that the knowledge based TQM approach will, inform, guide, and facilitate continuous improvement, and learning assist the organisation to meet the changing needs and expectations of customers in better. The management understanding and commitment to be flow from top management through to all levels, and sufficient resources are to be allocated to ensure success. The new learning to be accessible to all, encourage individual and collective learning by supporting training and development, and by sharing of the experiences associated with new learning and application.

Noorliza and Muhammad (2006) examined the significant positive effect of training and education on job involvement, job satisfaction, and organizational commitment.

Fang et al. (2006) examined the relationship among TQM practices and various levels of firm performance in Taiwan information-related industries, and showed that an effective management leadership positively influence on human resource management, supplier management, and design management.

Therese (2007) explored a strong positive relationship between the extent of implementation of TQM practices and organizational performance, and the moderating effect of co-worker support and organization support on the TQM/performance relationship.

Cheng and Petrus (2007) identified four success factors of quality management, as top management commitment and participation, quality information and performance measurement, employee training and empowerment, and customer focus, and developed a functional instrument to measure quality management in the shipping industry.

James (2008) assessed the implementation of total quality management in Florida's municipal police agencies, and recommended that more effective education in TQM would facilitate in recognizing its values, and it provide techniques to make successful TQM implementation easier.

Kanagikanapathy (2008) identified eight critical most commonly used factors of quality management by researchers, as top management support, quality information availability, quality information usage, employee training, employee involvement, product/process design, supplier quality and customer orientation.

Baba Md et al. (2009) concluded about the most significant TQM implementation critical success factors in Malaysian SMEs, as the senior management perception and practice in setting a realistic TQM objectives, providing TQM related trainings to their employees, making decisions based on fact, enhancing teamwork effort, and giving priority and attention to the internal and external customer.

Dinh et al. (2010) identified that, in TQM implementation the Vietnamese manufacturing and service companies implemented customer focus and top management commitment at a quite high rate, and information and analysis system, education and training, employee empowerment, and process management found to be just average .

Rallabandi et al. (2010) explored the contribution of TQM and six sigma in the organizations, and mentioned that TQM takes a long time to implement as it requires major organizational changes in culture, and employee mindset and six sigma quality control program mandates training in all aspects of organizational processes.

Gbadeyan and Adeoti (2010) mentioned about the TQM approach's contribution to business organization in a downturn economy such as Nigeria, that the application of total quality management in organization involves every department and section of the organization, and the complete involvement of the entire workforce in the organization as chief executive to the least subordinates

Arash and Reza (2011) proposed a comprehensive framework of TQM soft factors,with more relationship with factors as committed leadership, closer customer relationship, benchmarking and process improvement.

Fazli (2011) developed an instrument to measure the related TQM constructs in six factors, as leadership, best practices, customer focus, employee focus, community focus and productivity focus. Transformational style of leadership emphasize leaders, who could inspire and nurture individuals' competencies in line of the TQM principle, and also found that employee focus is positively related to company performance

Faisal et al.(2011) concluded that total quality management is a major business strategy to achieve sustainable competitive advantage in the service industry . The strategic factors in TQM implementation require, continuous top-management commitment and support for the effectiveness of TQM, and set and communicate clear quality objectives and performance expectations to all levels. Second the tactical factors as to train and educate people at all levels, so that an environment of TQM awareness, interest, desire, and action could be developed. Management should set operational factors in implementing TQM for better results, and allocate resources to these factors.

Andre (2012) analyzed the differences of TQM practices between TQM firms and non TQM firms. The variables forming the critical factors of TQM implementation practices are, 1. Top management commitment 2. Customer focus 3. Supplier quality management 4. Employee empowerment 5. Employee training 6. Process management and 7. Award for quality improvement.

Muhammed and Anwarul (2012) implied the creation of a quality management environment as, development of teamwork, practice of quality control tools and techniques, closer supplier relationship, and customer focus as the main pillar of TQM implementation. The investigation identified the important factors as, training of employees in TQM, long term contract with suppliers, formal customer feedback, recognition and rewards for employees, training and development of employees, information sharing, the introduction of quality tools and techniques, arrangement of seminar and symposium on quality management, quality slogans and displays at different locations, and development of cross functional teams.

Abbas and Mansooreh (2012) investigated the relationship between national culture and total quality management implementation in Iranian multinational electrical manufacturing companies, and showed that some national culture dimensions and the dimensions of TQM implementation are correlated. Long-term orientation significantly affects three TQM elements as strategic planning, process management and business performance in positive ways.

Neelam Devi (2012) concluded that, in TQM everyone is involved in the process and everyone in the company is responsible for producing quality goods and services, and performance feedback and appropriate system of recognition and reward is vital, to enable managers at all levels to improve their contributions to the business.

Esam and Abdul (2012) mentioned about the criticality and the vitality role of top management leadership and commitment, in setting up and deploying the TQM system and philosophy, and to link the role of top management to other common TQM practices such as employee empowerment and communication.

José et al. (2012) suggested that, for TQM programme organisations should focus on their efforts on generating a more advanced culture as creative culture. The organisations to focus on both exceeding the performance of expected standards, and to emphasise surprising and delighting customers.

Lilian (2012) confirmed that, job satisfaction is positively associated with desired workplace outcomes, as organizational commitment, productivity and quality.

Faisal (2013) concluded that, TQM takes a long time to get implemented to have fruitful results, and it require major changes in cultural aspects as well as an employee mindset in an organization.

Darrell (2013) concluded that total quality management program require, managers to assess customer requirements to understand present and future customer needs, and to design products and services that cost-effectively meet or exceed those needs. It is by, deliver quality by identifying the key problem areas in the process, and work on them until they approach zero-defect levels, train employees to use the new processes, develop effective measures of product and service quality, create incentives linked to quality goals, promote a zero-defect philosophy across all activities, encourage management to lead by example, and develop feedback mechanisms to ensure continuous improvement.

Abla et al. (2013) identified significant statistical evidences, to show the differences between factors that affected total quality management implementation in Jordanian commercial banks, and recommended to develop recruitment and employment methods to place the appropriate person for the appropriate job, to conduct training courses based on identification of training needs, to provide employees with the required information, and to develop their abilities, skills, and attitudes.

Neha and Anoop (2013) showed that, in Indian automotive industry the policy and strategic plan, quality leadership, customer focus and satisfaction are the critical success factors in total quality management

Ghnaim (2013) recommended for holding training courses and workshops and continuous improvement and self-assessment, for the TQM application in the higher education institutions of Kuwait.

Ali and Abedalfattah (2013) showed a significant relationship between quality management dimensions as leadership, strategic planning, customer focus, and employee relation, and organisational performance, and the managers to be concerned about these dimensions to enhance the organisational performance.

Fred et al. (2013) utilized the total quality management variables, as top management commitment, training for TQM, customer driven information, process control and improvement, employee empowerment, supplier involvement and communications, to identify the linkages between total quality management and organizational survival in manufacturing companies in Ghana, and presented a positive correlation between the TQM variables and performance.

Talib et al. (2013) developed a model, based on the total quality management in the SMEs in the food processing industry in Malaysia, with leadership, corporate planning, human resource management, customer focus, supplier focus, information management, process management and quality assurance as critical success factors.

Ola (2013) concluded that, total quality management Baldrige model , the TQM frame work for e-learning based on Kirkpatrick models claims different approach, and to achieve excellence top management to be involved in the application of quality. All functions, and all employees to be ` participate in the improvement process and to reveal the importance of evaluation to achieve continuous improvement.

Ramreddy and Choudhary (2013) used the real experimental results of four machines, in which output values such as availability, performance, quality and overall equipment effectiveness are very low compared with the world class industry. The effort is to apply two important basic concepts of TQM as continuous improvement of production processes by applying new and innovative methods, and for establishing performance measures for the processes.

Abdullah (2013) suggested that, in a Saudi Arabian public sector organization, top management to be committed to the employee involvement and to the provision of adequate training programmes to develop skills and capabilities for facilitating TQM. The organisation employees differ in terms of job satisfaction, their view of co-operation by management, trust, satisfaction with management style, and satisfaction with the work environment.

Massoud and Syed (2013) revealed the critical success factors for implementing total quality management in Libyan iron and steel company, as education and training, supplier quality management, employee empowerment, vision and plan statement, recognition and reward and customer focus. The government influence, poor vision statement, lack of a detailed plan towards implementation of TQM, lack of top management commitment, as that prevent the company from implementing TQM successfully **.**

Eyad et al. (2014) examined the job enrichment, worker safety, giving workers more planning responsibility, giving workers a broader range of tasks, changing management/labour relation, management training, supervisor training, and worker training as the HRM practices, and identified the significant differences in the degree of emphasis on these among firms with varying TQM intensity.

Ali Mohammad (2014) examined the strategic collaborative quality management practices, such as visionary leadership, education, training, strategic quality planning, effective communication, employee empowerment, teamwork, reward, and recognition, theoretically contribute positively to employees' satisfaction, and the SCQM initiative needs employee's knowledge, skills, abilities, passion, motivation, persistence, responsibility, accountability, and a quality-oriented attitude.

3.4. Studies on the hurdles faced by the organisations while implementing TPM

Various hurdles in the successful implementation of quality management practices are analysed by researchers .

Ashraf (1998) emphasized that, to develop and implement a maintenance programme, the maintenance managers have to achieve conflicting objectives of different interested parties in maintenance, that for maximise throughput, availability and quality of equipment, subject to constraints in production plan, available spares, manpower, and skills.

Lawrence (1999) mentioned that, the TPM programme fail due to the resistance from the part of maintenance personnel and or from the production personnel, to the new way of getting the job done. That is due to the lack of understanding that how it will affect the individual jobs and how it will affect the organisation's overall performance. With top management support and training of resources, mathematical modelling make the potential benefits of TPM more tangible, and improves every one's understanding about the work processes they involved, and about how their work affects the overall organisation and customers.

Tsang and Chan (2000) concluded that, in developing countries as in a high precision machining factory in China, the organisational environment is typically traditional and unfavourable for change of culture, for an innovative approach to maintenance through TPM.

Hale (2003) mentioned about the lack of top management commitment in implementation, as a possible reason for TQM failure, based on the effectiveness criteria of organizational learning, employee satisfaction, decentralized structure, and resource acquisition

Sorabh et al. (2006) concluded that, the implementation of TPM is not an easy task and considerably burdened by organizational, behavioral and other barriers, and necessitates the difficult mission to change peoples' mindsets from a traditional maintenance approach.

Pramod and Jagathy (2007) in their research work, mentioned about the proposition of quality function deployment principles integrated in TPM, and designed a maintenance quality function deployment model which can overcome the lacunas of TPM.

Ahuja and Khamba (2008) critically examined the factors influencing the implementation of TPM in Indian manufacturing industry, and revealed that implementation of TPM is heavily burdened by organizational, cultural, behavioural, technological, operational, financial, and departmental barriers . For Maintenance to be a competitive strategy, need the synergy between the maintenance function and other organizational quality improvement initiatives.

Mustafa and Amin (2011) investigated the maintenance and production problems in the cement industry in Libya, as an initiative for TPM implementation, and identified low productivity and production levels when compared with the design values. The four factories under investigation have, no clear TPM strategy, and lack in training and personal development, and no motivation to employees, as a result of the lack of a management strategy and reward structure.

Guptha and Narender (2012) observed from the literature review that, there is no focus to implement TPM in small scale industries in the Indian industrial scenario, and only few studies till date that devoted to the analysis of total productive maintenance adopted by Indian manufacturing companies. Qualitative studies reported on total productive maintenance in sectors of process industries, mechanical industries and only few studies on electronics manufacturing industries and in service sector.

Murugadoss (2012) mentioned that, TPM implementation is heavily hampered by behavioural, organisational, cultural, technological, departmental, operational and financial obstacles. TPM need a change in both the company's and employee's attitude, and their values, which takes time to bring about, and require long-term planning. For the success of TPM, top management must know how to utilise TPM initiatives in varying circumstances, as to promote employee involvement in every stage of the production and maintenance processes.

Jyothi Pakash and Murali (2012) mentioned that understanding and awareness of the various possible causes behind the failure of TPM, is essential for its successful and effective implementation in manufacturing industries in India. The various causes of failure of TPM is classified into three major categories at three different stages as, organizational issues during the foundation stage; TPM implementation issues during the formation stage; and operational issues during the TPM running stage.

Kapil et al. (2012) mentioned about the barriers observed in effective implementation of TPM,as lack of management exposure, difficulty in understanding TPM methodology and philosophy by middle management, and long time taken for implementation. They recommended to use the O.E.E. as the tool to assess the current situation, and to find out the starting point for the improvement process. The current preventive maintenance plan to be modified for the all machines to decrease the failures and short stoppages, and for keeping the machines in the best conditions for production. The frequently problem creative parts to be kept in the store, and the operators need the good skills according to their job, and to provide training for them time to time to keep them updated and motivated.

Ranjeet et al. (2013) mentioned that, in a Indian manufacturing industry some barriers for effective implementation of TPM include, the lack of management exposure, difficulty in understanding TPM methodology and philosophy by middle management, and long time taken for implementation, so people show strong resistantance to it. They suggested that in Indian context, the main objective is to understand the TPM concept, and to generate awareness among the budding technocrats and budding enterprises about TPM philosophy.

Elaine and Maged (2013) highlighted culture as the main obstacle to successfully implement TPM in large and medium size UK manufacturing companies, and lack of awareness about the advantages of the programme, low employee skills and high cost as other factors. Two benefits gained by the four companies were the significant improvement in the availability and performance of the equipment within the plant, and improved communication between employees. The findings indicated the urgent need for ensuring regular training and education programmes on TPM to all the employees including management, and to recognise people's achievements in the programme through awards such as money and promotions.

Ravikant and Rajeshkumar (2013) analysed the practical problems at cotton spinning plant accomplishing TPM program, by considering the values of production quantity, breakdown time, productive time, and wastage and recycles cotton quantity,

Prasanth and Jagathy (2014) mentioned that, industries found it very hard to implement TPM due to the inability to grasp its concepts fully. A long term commitment required on part of the management for its successful implementation. Resources have to be committed, and needs a radical change in the outlook of the organization to view the expenses spend on TPM as an investment, which will yield profits in a couple of years.

3.5. Identified research gap.

The referred papers give an insight on the various areas of studies on the topics of TPM. It had given a direction to the potential areas for further studies. From this the scope of this research work is identified.

The referred studies are mainly on the performance of TPM, as well the factors which resulted in the success of TPM. The attainment of the overall equipment effectiveness is one of the core aim of TPM . The OEE is the achievement on availability,performance and quality. Previous researchers have recommended sectorwise studies on TPM implemantation in Indian scenario. So this study focuses on TPM implementation in engineering sector of industries with equipment performance as the dependent variable.

3.6. Scope of the study

The scope of the study is to identify the relationship between the various implementation factors and performance of TPM. The study is planned to be conducted on selected critical equipment from the identified TPM practicing engineering companies in Kerala and in Tamil Nadu. The various implementation factors, as independent variables are identified from literature review of the similar studies conducted. The performance of the equipment, on the basis of the results from the pillars of autonomous maintenance, planned maintenance, quality maintenance and focused improvement were selected for this study

3.7. Conceptual frame work

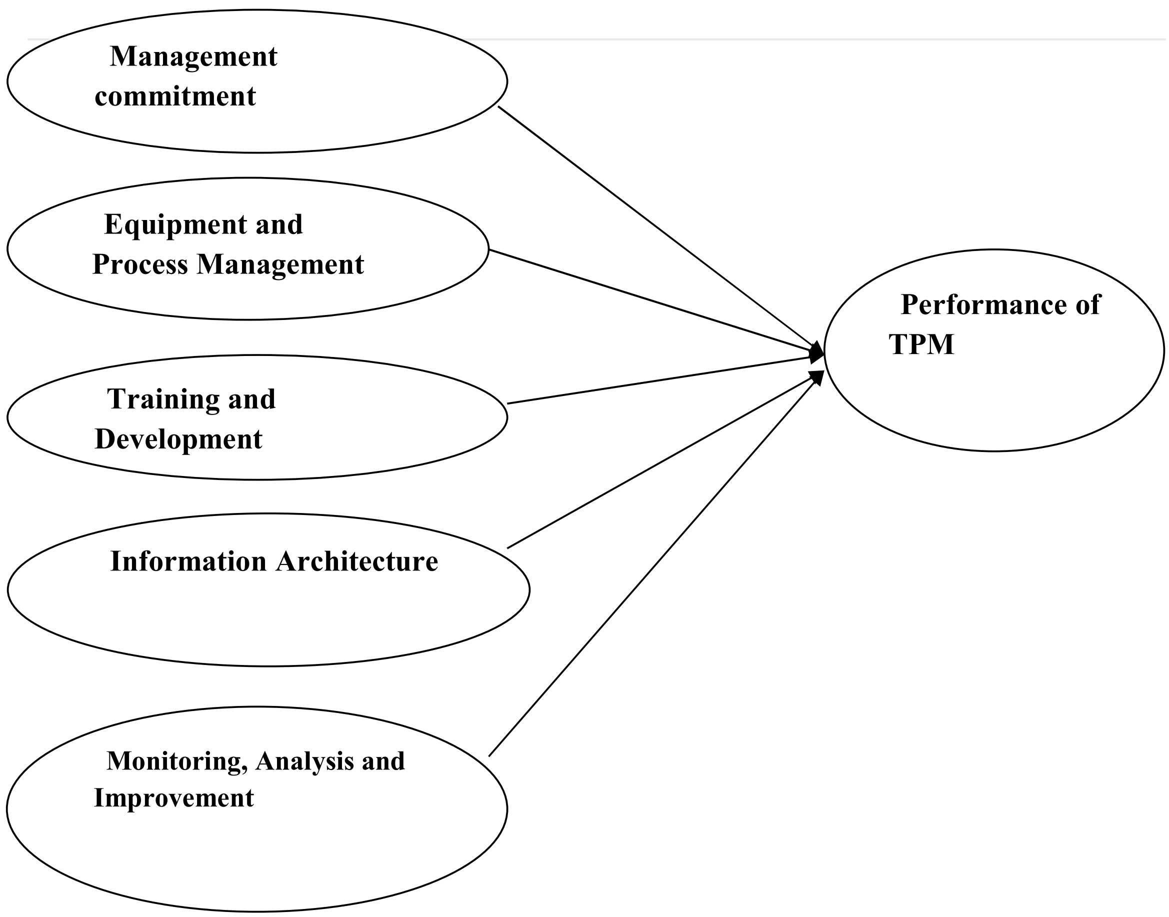

Figure 3.1. Conceptual frame work

In this conceptual frame work the independent variables as management commitment , equipment/process management, training and development, information architecture, and monitoring analysis and improvement, which have the impact on the performance of TPM by improving the availability, performance and quality through the various performance indicators.

3.8. Objectives of the study

Main objective: To study the TPM practices and their effect on overall equipment performance

Sub objectives:

1. To assess the effect of Management commitment individually or combined with other factors, on the performance of equipment in various TPM practicing engineering companies..
2. To assess the effect of Equipment and Process management practices individually or combined with other factors, on the performance of equipment in various TPM practicing engineering companies.
3. To assess the effect of Training and Development practices individually or combined with other factors on the performance of equipment in various TPM practicing engineering companies.
4. To assess the effect of Information Architecture practices individually or combined with other factors on the performance of equipment in various TPM practicing engineering companies.
5. To assess the effect of Monitoring, Analysis and Improvement practices individually or combined with other factors on the performance of the equipment in various TPM practicing engineering companies.

3.9. Definition of identified independent variables

The researchers in the field of quality management have already proved the relationship between the various implementation factors of TPM and its effects on performance. The review of literature mentioned about the various factors identified by the researchers, which have effect on the performance of TPM..

The independent variables identified in this research,based on the review of various studies are:

1.Management Commitment 2. Equipment and Process management 3. Training and Development 4. Information Architecture 5.Monitoring, Analysis and Improvement system

1. **Management commitment**

The quality management system standard of International organisation for standardisation (ISO 9001) defined management commitment as, the top management shall provide evidence of its commitment to the development and implementation of the quality management system and continually improve its effectiveness by establishing policy and through the establishment of quality objectives. The management to review the effectiveness of implementation periodically and to ensure the availability of resources.

The researchers in the areas of quality management, including total productive maintenance, mentioned about the factor of management commitment, which have effect on attaining the improvement results.

Muthu et al. (2000) mentioned about the maintenance quality target approach, which focused on the importance of particular target, in improving the maintenance quality.

Ramayah, et.al (2002) evaluated the effect of the factor of management commitment, on change management towards the implementation of productivity and quality improvement programs, through the concept of total productive maintenance.

Dinesh and Deepak (2003) mentioned about the universally significant factors for performance of TPM as leadership for improvement and strategic planning

One Yoon Seng et al.,(2005) identified the core of human-oriented strategy as top management commitment and leadership

Zahid Habib, (2008) mentioned about top management commitment, to make all the employees aware of the change of shifting towards the new culture of TPM.

Based on the inputs from the above mentioned papers, the various indicators of management commitment identified are as, the fixing of particular objectives for performance, assigning responsibility to attain these objectives, clear assigning of duties and responsibilities at all levels,providing the necessary resources including training for attaining the objectives, doing the periodic review of the progress of activities , and the continuation of activities even with the change in leaderships.

2. Equipment and Process Management:

Equipment management practices is proved by the researchers as a significant factor in success of total productive maintenance.

Dinesh & Deepak (2003) mentioned about the equipment management practices, as the effective implementation of preventive and predictive maintenance programs, continuous improvement in maintenance quality and efficiency for improved reliability and cost effective maintenance, and the in-depth analysis of equipment performance, and its use in developing maintenance programs. Also the process management practices as identification of key processes, for managing and improving and for ensuring continuous improvement .

Nakajima(1988) concluded that, process-oriented strategy plays an important role in the next part to achieve a successful TPM implementation in the organization. Process-oriented strategy includes, all kinds of technical approaches to maximize the overall equipment efficiency through quantitatively increasing the equipment availability and qualitatively eliminating all production losses, that resulted from inefficient equipment. The primary goal of TPM is to achieve the ultimate target of zero loss and zero breakdown, so that all equipments are performing at its optimal condition.

Various indicators are identified for the implementation of equipment and process management practices for various TPM pillars. The identified indicators are based on the inputs from the questionnaire developed by Dinesh and Deepak (2005) and the inputs from Joel (2010) and Japan institute of plant maintenance questionnaire.

In autonomous maintenance the equipment management process includes, the operator level actions to remove dirt, scattered materials, oil leakages, and the bolt tightening on the equipment, cleaning materials , tools , and spares are to be kept near to the equipment, storage procedures for tools, jigs, with routine cleaning, and the lubrication is to be standardised ,monitored and automated in equipment.

In planned maintenance the equipment management process includes, maintenance time cycle is to be established for effective weakness improvement of the equipment, major parts of the equipment prone to wear and tear are to be put to predictive maintenance, equipment diagnostic technologies as vibration analysis, and time based and condition based maintenance practices are to be used, equipment analysis to be done by instruments and sensors and maintenance cycle are to be determined, equipment to be improved for ease of autonomous maintenance, and failure analysis done on the equipment to enhance improvement.

In quality maintenance the process management includes, monitoring of inward material for identifying the defects , equipment is to be monitored regularly for its performance level on quality, monitoring of production are to be done at frequent periods by sensors for identifying the defects, and analytical tools as pareto analysis, why-why analysis are to be effectively used in defect analysis.

For the results from focused improvement pillar, this factor is not considered, since the focused improvement pillar, the performance indicator is implementation of improvement projects , and not a routine equipment and process management activity .

3. **Training and Development:**

Gary and Biju (2010) mentioned about training and development, as giving new or current employees the skills they need to perform their jobs, and managers can create their training programme using the procedures as to set the training objectives, and to use a detailed job description.

Muthu et al. (2000) proposed the maintenance quality strategy through, human knowledge nourishment, training and education on maintenance quality, and maintenance quality through counseling

Ramayah, et.al (2002) examined the productivity and quality improvement programs through autonomous maintenance and planned maintenance, and mentioned about the influencing factors of training and education, employee empowerment, and team culture.

Maggard and Rhynen (1992) stated that, training and education is necessary to create a clear understanding of the changes required and the purpose of the change as well as the benefits to be gained out of it. In training and education ,the maintenance personnel can train operators to perform routine preventive maintenance tasks, operators training on the mechanics of their equipment, problem skills, and team building. About the factor employee empowerment, the management has to get employees to accept this responsibility by giving the employees the authority to act. Empowering the employees is one of the elements necessary to ensure success in TPM implementation.

Dinesh and Deepak (2003) mentioned about the factor of education and training on the performance of TPM in Indian context. They proposed for the coverage of training on most managers and employees, and the training system to accommodate changing requirements based on the regular reviews.

Samir (2004) revealed that motivation of management and workforce is a key success factor in the implementation of TPM, and reward and recognition should be used to encourage and motivate in the required direction.

Various indicators are identified for the implementation of training & development practices for various TPM pillars based on the questionnaire developed by Dinesh and Deepak (2005) ,and with the input from Joel (2010) and from Japan institute of plant maintenance questionnaire,

In the variable of training & development the indicators include, necessary skill requirements identified for the equipment, on job training programmes on the equipment operation for upgradation of the skill of staff members, developing internal trainers on the equipment, retired staff is to be engaged with training activity to share their experience on the equipment, training to be conducted by lubricant vendors to solve the problems on the equipment, video technology supported training to be done on the equipment, each employee need their own schedule on the equipment operation and maintenance, training by cooperate companies to lead the level of assessment of the equipment, own research and by outside consultants like OEM's for better cleaning and lubrication on the equipment, increase in employee suggestions/quality circle participation for the improvement of the equipment, and multi skill training on the equipment for operation and maintenance.

4. **Information Architecture:**

Dinesh and Deepak (2003) mentioned about information architecture, as the company's selection, management and use of internal and external information and data needed to support key processes, action plans, and performance improvement. According to them, the information architecture provide necessary infrastructure to facilitate decisions in right direction. The reliability and availability of the equipment need adequate information system. They mentioned that the significance of information architecture for implementation of TPM in Indian industry was rightly emphasized and to ensure that, information to be made available to people at point of use. Tracking of continuous improvement in through collection and use of relevant data, make effective use of data and information, for comparison and benchmarking.

Muthu et al. (2000) proposed the maintenance quality strategy by information system for maintenance quality

Ahuja and Khamba, (2007) from the reference from Wakaru (1988) and Bhadury (1988) mentioned that computerized maintenance management systems (CMMS) assist in managing a wide range of information.

Various indicators are identified for the implementation of information architecture for various TPM pillars based on the inputs from the questionnaire developed by Dinesh and Deepak (2005) ,Joel (2010) as well as the questionnaire from Japan Institute of Plant Maintenance.

In autonomous maintenance it includes the speedy information processing and efficient distribution about the performance status of the equipment, operators mini manual with description of production system and machine abnormalities about the equipment, one point lessons with plant description of the equipment, and review of operation and maintenance manuals about the equipment with updated field conditions. Tags to be kept on the equipment in problem areas and the contents are to be transferred to log books.

In planned maintenance pillar the questionnaire includes the communication of problems of the equipment with other users and vendors, CMMS used in recording the equipment deterioration, breakdown, and spares management and the maintenance requirements of the equipment are to be published well in advance.

In quality maintenance pillar the information architecture includes, speedy information processing and efficient distribution about the performance status of the equipment ,system is to be established for information on defective products from the equipment and for further tracking, and the mistake proofing systems to be in progress in the equipment.

In focussed improvement pillar, the information architecture includes the speedy information processing and efficient distribution about the performance status of the equipment, information on improvements on similar equipments, and the review of loss from the equipment is to be performed regularly for zero loss activity.

5. **Monitoring, Analysis and Improvement:**

The quality management system standards of International organisation for standardisation (ISO 9001) defined that the organization shall plan and implement the monitoring, measurement, analysis and improvement processes needed to, demonstrate conformity to product requirements, to ensure conformity of the quality management system, and to continually improve the effectiveness of the quality management system.

Muthu et al. (2000) in the 'Strategic maintenance Quality Engineering' model mentioned about the continuous monitoring of maintenance quality system and about maintenance quality auditing.

Dinesh and Deepak (2003) identified the performance measurement system, as to modify accounting system to reinforce improvement program, and to designing performance indicators to develop clear linkage between improvement programs and the results and to clear identification of all current and potential problems.

Various indicators are identified for the implementation of Monitoring, Analysis and Improvement practices for various TPM pillars based on the inputs from the questionnaire developed by Dinesh and Deepak (2005) , and with the input from the research papers of Muthu et al. (2000).

In all the pillars as autonomous maintenance, planned maintenance, quality maintenance and focussed improvement pillar , the factor monitoring, analysis and improvement process include that, the results are to be reviewed against the targets at frequent period, feed back from the stake holders are to be received, the real problems are to be analysed and the reasons are to be identified, and corrective actions to be done on all the problems.

3.10. Identified dependant variables

The dependent variable are the results of TPM through the improvement in overall equipment effectiveness by the multiplication of availability , performance and quality.

The availability of the equipment can be achieved by the reduction in the scheduled down time as well as by eliminating the breakdowns.

The performance of the equipment can be achieved by the attaining the designed speed or out put from the equipment

The quality of the equipment can be achieved by eliminating the defects and reworks .

Joel (2010) identified various dependent variables from various TPM pillars which improve the availability, performance and quality.

From Autonomous Maintenance pillar:

1.Reduction in scheduled down time –The achievements in reducing the planned maintennace time which increases the availability for operation of the equipment.

2.Increase in speed/ output from the equipment –It is the improvements achieved in the process speed with increase in the feed rate of operation.It improve the performance of the equipment.

3. Increase in accuracy level of the equipment –It is the improvements in reducing the variability in product from the equipment and more precision jobs can be carried out in the equipment.
4. Reduction in lubrication oil consumption.-The lubrication consumption reduction by eliminating the leaks and optimum consumption of lubricants by better monitoring.

From Planned maintenance pillar:

1. Reduction in scheduled down time- The achievements in reducing the planned maintennace time which will increases the availability for operation of the equipment.
2. Reduction in breakdown –The breakdowns elimination or reduction which improve the availability of the equipment for operation.
3. Reduction in scheduled miss due to operations –The improvements in carryout the planned maintennace activities as per the planned schedule, reduces the unexpected stoppage of the equipment.It increases the availability of the equipment.

From Quality maintenance pillar:

1. Reduction in inprocess defects/ reworks –The reductions achieved in the generation of defects at the process stage or the reduction in reworks of components generated from the equipment which increases the quality level performance.
2. Reduction in final defects-Reduction in the rejection of components at the final stage which increases the quality level performance of the equipment.

From Focussed Improvement pillar:

1. Increase in lean/kaizen projects on the equipment-The improvements in the small projects identification and implementation which will results in energy saving, easiness in operation or the saving of any input resourses.

3.11. Conclusion

This chapter discusses about the various referred papers associated with the studies done on TPM.

It includes the studies done on the improvements achieved by the organisations through total productive maintenance. The continual improvement with TPM, as the improvements in overall equipment effectiveness, overall line efficiency and the improvements in productivity, quality, delivery, safety and in environment performances, were evidenced in the referred studies.

The referred papers mentioned the different factors which have effect on TPM and also in TQM performances. The various success factors, as management commitment, human resource management as education and training, motivational steps as rewards and recognitions, the information management practices, the analysis and improvement activities were evidenced in the studies.

Also referred are the studies on the need for strategic direction, reliable data, strategic, tactical and operational information system requirements for the successful implementation of TPM.

The referred papers included the hurdles faced by the organizations while implementing TPM. The barriers in TPM implementation and its various failure reasons were also referred.

From these referred papers, the reserch gap is identified and the conceprtual frame work is formulated. The objectives of the research study are decided and the various dependent and independent variables are identified and the various indicators are decided based on the inputs from the referred papers.

The next chapter mentioned about the research design process based on the identified research objectives and the conceptual frame work.

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CHAPTER 4

RESEARCH DESIGN

This chapter on research design describe the sample design, data collection methods, and the analysis design, which explains the used statistical tools.

4.1. Hypothesis of the study

The literature review evidenced the impact of these various factors on the performance of TPM. All the referred papers mentioned about the positive impact of these practices on the overall performance of TPM. Based on that the following hypothesis were generated.

1. Management commitment, individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.
2. Equipment and process management practices , individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.
3. Training and development, individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.

4. Information architecture, individually or combined with other factors ,has positive effect of on the performance of the equipment in TPM practicing engineering companies.
5. Monitoring , analysis and improvement practices, individually or combined with other factors , has positive effect on the performance of the equipment in TPM practicing engineering companies.

4.2. Research design

Empirical survey-based research on the critical equipment from TPM practicing companies. The independent variables and indicators are fiixed based on the inputs from the referred research papers in this area.

The dependent variable as the performance of the equipment is identified based on the results from the pillars of autonomous maintenance, planned maintenance, quality maintenance and focused improvement pillars.

The schedule is designed based on the inputs from the questionnaire of previous researchers in this field, as well as the inputs from the questionnaire of Japan Institute of plant maintenance and input from the relevant books of TPM

4.3. Sample design

The equipment for the study were selected from the companies which are awarded for TPM as well where the TPM implementation is in progress. The inputs about the TPM practicing companies were collected from the data of TPM club of India , as well as the inputs from the TPM facilitators, also referred the company websites. The companies were selected based on convenient sampling. The companies which permitted to conduct the study were selected. Also a primary visit done on the companies and verified the potential of collection of data as per the designed schedule whether the sufficient details are available in that organisation. Based on that 19 companies were identified suitable for the data collection.

The identified companies for data collection are from the states of Kerala and Taminadu. The locations of the companies are mainly from Chennai and Coimbatore. The selected companies are all engineering companies which have a minimum number of more than 50 critical equipment. The population of the study is the crtical equipment where the TPM practices are started in the selected companies.

From the selected companies, the equipment were selected on a simple random sampling method, from the population of critical equipment. From the critical equipment a random sample of minimum 10 percentage of the equipment were selected for the data analysis. The numbers were generated by a pure random process so that any number has an equal probability of appearing in any position. Most random samples will be close to the population most of the time.

Only selected the equipment on which the TPM practices followed, and from the same companies wherever possible samples selected from different production units.

4.4. Analysis design.

The partial least square analysis is used and the statistical tool is Warp PLS 4.0 . Ned Kock (2013) in the Warp PLS 4.0 user manual, referred PLS-SEM as advantageous when used with small sample sizes .As per the reference from Hair et al.(2009) the user manual mentioned that primarily, PLS is a regression- based estimation method whose focus is on the prediction of a specific set of hypothesized relationships. The interpretation of the model fit and quality indices depends on the goal of the SEM analysis. If the goal is to only test hypotheses, each arrow represents a hypothesis.

As per Jorg et.al,(2009) PLS is most appropriate when sample sizes are small, when assumptions of multivariate normality and interval scaled data cannot be made,and when the researcher is primarily concerned with prediction of the dependent variable, and it has the distribution-free character.

WarpPLS 4.0 User Manual mentioned about the “stable” method as a quasi-parametric method that yields P values that approximate the most stable P values generated by the software’s existing resampling methods.,

The pattern loadings generated by Warp PLS were very similar to those generated by other PLS based SEM software.The pattern loadings and cross loadings provided by Warp PLS are from a pattern matrix which is obtained after the transformation of a structure matrix and the structure matrix contains the pearson correlations between indicators and latent variables.

The combined loadings and cross loadings table always shows loadings lower than 1, because that table combines structure loadings with pattern cross loadings. This obviates the need for a normalization step, which can distort loadings and cross loadings.

Model fit and quality indices.

Ned Kock (2013) in Warp PLS 4.0 use manual, model fit and quality indices are provided.It includes the average path coefficient (APC), average R-squared (ARS), average adjusted R-squared (AARS), average block variance inflation factor (AVIF), average full collinearity VIF (AFVIF), Tenenhaus GoF (GoF), Sympson's paradox ratio (SPR), R-squared contribution ratio (RSCR), statistical suppression ratio (SSR), and nonlinear bivariate causality direction ratio (NLBCDR).

Definition of various indices as reference from Ned Kock (2013) in Warp PLS 4.0 use manual

Latent variable (LV): It is a variable that is measured through multiple variables called indicators or manifest variables (MVs)

Indicator: Indicators are MVs that are actually used in the measurement model as direct measures of LVs.

Inner model.

In a structural equation modeling analysis, it is the part of the model that describes the relationships between the latent variables that make up the model. In this sense, the path coefficients are inner model parameter estimates.

Path coefficients:

It is noted as beta coefficients which is another term used to refer path coefficients in PLS-based SEM analyses, commonly used in multiple regression analyses.

R-squared coefficient. This measure reflects the percentage of explained variance for each of latent variables. The higher the R-squared coefficient, the better is the explanatory power of the predictors of the latent variable in the model, especially if the number of predictors is small.

Adjusted R-squared coefficients are equivalent to R-squared coefficients, with the key difference that they correct for spurious increases in R-squared coefficients due to predictors that add no explanatory value in each latent variable block. Consistently with general recommendations made by Cohen (1988), **models where R-squared coefficients or adjusted R-squared coefficients are below 0.02 should be considered for revision**

It is recommended that the **P values for the APC, ARS and AARS all be equal to or lower than 0.05**; that is, significant at the 0.05 level. A more relaxed rule would be that the **P values for the APC and ARS only be equal to or lower than 0.05**.

Reliability of a measurement instrument.

Reliability is a measure of the quality of a measurement instrument; the instrument itself is typically a set of question-statements. A measurement instrument has good reliability if the question-statements (or other measures) associated with each latent variable are understood in the same way by different respondents.

Cronbach's alpha coefficient. This is a measure of reliability associated with latent variable. It usually increases with the number of indicators used, and is often slightly lower than the composite reliability coefficient, another measure of reliability.

Composite reliability coefficient. This is a measure of reliability associated with a latent variable. Unlike the Cronbach's alpha coefficient, another measure of reliability, the compositive reliability coefficient takes indicator loadings into consideration in its calculation. It often is slightly higher than the Cronbach's alpha coefficient.

More conservatively, both the **compositive reliability and the Cronbach's alpha coefficients should be equal to or greater than 0.7** (Fornell & Larcker, 1981; Nunnaly, 1978; Nunnally & Bernstein, 1994). An even more relaxed version sets this threshold at 0.6 (Nunnally & Bernstein, 1994). If a latent variable does not satisfy any of these criteria, the reason will often be one or a few indicators that load weakly on the latent variable. These indicators should be considered for removal.

Convergent validity of a measurement instrument. Convergent validity is a measure of the quality of a measurement instrument; the instrument itself is typically a set of question-statements. A measurement instrument has good convergent validity if the question-statements (or other measures) associated with each latent variable are understood by the respondents in the same way as they were intended by the designers of the question-statements.

Discriminant validity of a measurement instrument. Discriminant validity is a measure of the quality of a measurement instrument; the instrument itself is typically a set of question-statements. A measurement instrument has good discriminant validity if the question-statements (or other measures) associated with each latent variable are not confused by the respondents, in terms of their meaning, with the question-statements associated with other latent variables.

Average variance extracted (AVE). A measure associated with a latent variable, which is used in the assessment of the discriminant validity of a measurement instrument. Less commonly, it can also be used for convergent validity assessment. For convergent validity assessment, the AVE threshold frequently recommended for acceptable validity is 0.5 (Fornell & Larcker, 1981), and applies only to reflective latent variables.

Variance inflation factor VIF: This is a measure of the degree of collinearity (or multicollinearity) among variables, including both indicators and latent variables. With latent variables, collinearity can take two main forms: vertical and lateral collinearity (Kock & Lynn, 2012). Vertical, or classic, collinearity is predictor-predictor latent variable collinearity in individual blocks. Lateral collinearity is a new term that refers to predictor-criterion latent variable collinearity; a type of collinearity that can lead to particularly misleading results. Full collinearity VIFs allow for the simultaneous assessment of both vertical and lateral collinearity in an SEM model.

Block VIFs of 3.3 or lower suggest the existence of no vertical multicollinearity in a latent variable block (Kock & Lynn, 2012). More conservatively, it is recommended that block VIFs be lower than 5; a more relaxed criterion is that they be lower than 10 (Hair et al., 1987; 2009; Kline, 1998). These criteria may be particularly relevant in the context of path analyses, where all latent variables are measured through single indicators.

It is generally undesirable to have different latent variables in the same model that measure the same thing; those should be combined into one single latent variable.

It is recommended (ideally) that both the AVIF and AFVIF be equal to or lower than 3.3, particularly in models where most of the variables are measured through two or more indicators. A more relaxed (acceptable) criterion is that both indices be equal to or lower than 5, particularly in models where most variables are single-indicator variables

Tenenhaus GoF (GoF), Similarly to the ARS, the GoF index, referred to as "Tenenhaus GoF" in honor of Michel Tenenhaus, is a measure of a model's explanatory power. As per the reference from Tenenhaus et al. (2005), Ned Kock (2013) defined the GoF as the square root of the product between what they refer to as the average communality index and the ARS. The communality index for a given latent variable is defined as the sum of the squared loadings for that latent variable, each loading associated with an indicator, divided by the number of indicators. As per the reference from Wetzels et al. (2009) , Ned Kock (2013) proposed the following thresholds for the GoF: small if equal to or greater than 0.1, medium if equal to or greater than 0.25, and large if equal to or greater than 0.36.

Sympson's paradox ratio (SPR),

As per the reference from Pearl (2009) and Wagner (1982), Ned Kock (2013),mentions SPR index as a measure of the extent to which a model is free from Simpson's paradox instances . An instance of Simpson's paradox occurs when a path coefficient and a correlation associated with a pair of linked variables have different signs. A Simpson's paradox instance is a possible indication of a causality problem, suggesting that a hypothesized path is either implausible or reversed. Ideally the SPR should equal 1, meaning that there are no instances of Simpson's paradox in a model; acceptable values of SPR are equal to or greater than 0.7, meaning that at least 70 percent of the paths in a model are free from Simpson's paradox.

RSCR. As per the reference from Pearl(2009) and Wagner (1982) , Ned Kock (2013) mentions RSCR index as a measure of the extent to which a model is free from negative R-squared contributions, which occur together with Simpson's paradox instances. When a predictor latent variable makes a negative contribution to the R-squared of a criterion latent variable (note: the predictor points at the criterion), this means that the predictor is actually reducing the percentage of variance explained in the criterion. Ideally the RSCR should equal 1, meaning that there are no negative R-squared contributions in a model; **acceptable values of RSCR are equal to or greater than 0.9**, meaning that at least 90 percent of the paths in a model are not associated with negative R-squared contributions.

SSR. As per the reference from MacKinnon et al., (2000) , Ned Kock (2013) mentions SSR index as a measure of the extent to which a model is free from statistical suppression instances. An instance of statistical suppression occurs when a path coefficient is greater, in absolute terms, than the corresponding correlation associated with a pair of linked variables. As per the reference from Spirtes et al., (1993) , Ned Kock (2013),mentions that, like a Simpson's paradox instance, a statistical suppression instance is a possible indication of a causality problem, suggesting that a hypothesized path is either implausible or reversed. Acceptable values of SSR are equal to or greater than 0.7, meaning that at least 70 percent of the paths in a model are free from statistical suppression

NLBCDR. Ned Kock (2013)) mentions NLBCDR index as a measure of the extent to which bivariate nonlinear coefficients of association provide support for the hypothesized directions of the causal links in a model. **Acceptable values of NLBCDR are equal to or greater than 0.7**, meaning that in at least 70 percent of path-related instances in a model the support for the reversed hypothesized direction of causality is weak or less. Here "less" may mean that the support for reversed hypothesized direction of causality is less than weak (e.g., neutral), or that the hypothesized direction of causality is supported.

4.5. Collection of data:

A structured schedule is used for data collection.. A five point rating scale is used to measure the effectiveness in implementation of TPM practices, as well as the level of the achievement of various results from equipment. The content validity of the designed schedule is done with the academic experts who have done research study about TPM and also with the TPM experts in industry. The convergent validity is done by using the Warp PLS software.

Data collection done by interviewing the concerned staff associated with the equipment, as equipment operators, maintenance people, concerned plant heads, and maintenance heads and further evaluated by observing the concerned equipment and associated records. Since the designed schedule need the input from people in different sections as mentioned above, the interviewing technique is found to be more adequate for the data collection method.

4.6. Measures of constructs

The questions framed are based on five points scale ranging from 1 to 5. Each dimension and performance parameter is taken.

Implementation dimensions

1. No implementation,2. Very little implementation, 3.Considerable level of implementation, 4.Good level of implementation, 5.Very good level of implementation

1.No implementation- Aware about the practices ,implementation not yet started fully.

2. Very little implementation- Implementation in progress , but not in complete level and not stable

3. Considerable level of implementation- Implemented in a considerable way. But still the various issues are reported frequently.

4.Good level of implementation-Implemented in a good level. There are no issues reported in recent periods.

5.Very good level of implementation-Implemented in a very good level. There are no issues reported in past long periods.

Five point rating scale

Five point rating scale (1 – No improvement; 2 – Very little improvement; 3 – Considerable improvement; 4 – Large improvement; 5 – Very large improvement).

1. No improvement-The present performance is not stable and no improvement observed

2. Very little improvement- The present performance level is stable, but no improvement is observed.
3. Considerable Improvement- Improvements observed, but not in consistent way.
4. Large Improvement- Improvement is observed in a consistent way
5. Very large improvement- Improvement is observed in a consistent way for long period

4.7. Conclusion.

This chapter detailed about the research hypothesis, research design, sample design, analysis methods used, the explanations of the various terms in the analysis tool, and about the data collection methods.

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CHAPTER 5

ANALYSIS AND PRESENTATION OF DATA

In this chapter the analysis of various performance indicators from TPM pillars, as from autonomous maintenance pillar, planned maintenance pillar, quality maintenance pillar and focused improvement pillar are done. The graphical presentation of the correlation between the various TPM implementation factors, as management commitment, equipment and process management, training and development, information architecture, and monitoring, analysis and improvement, with each dependent variables, as performance indicators from TPM pillars are done. Performance of each dependent and independent variable is presented with model fit analysis with graphical presentation.

5.1.ANALYSIS OF PERFORMANCE INDICATORS FROM AUTONOMOUS MAINTENANCE PILLAR

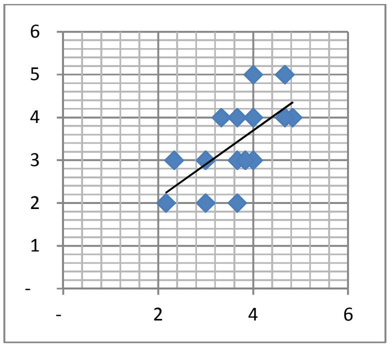
1.Performance Indicator: Reduction in scheduled down time:

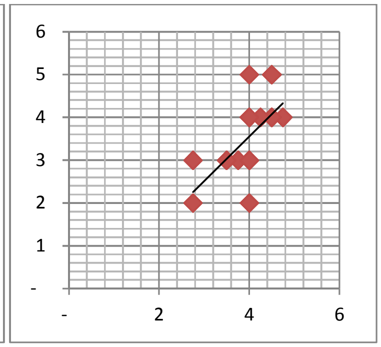
Table- 5.1 Correlation coefficient between TPM practices and Reduction in scheduled down time with P value:

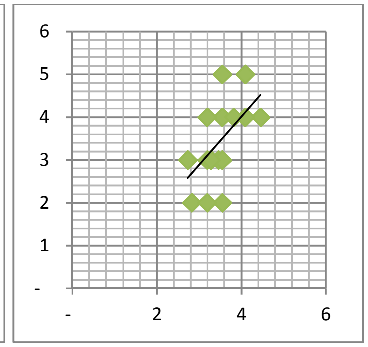
Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.707 P<0.001	0.658 P<0.001	0.607 P<0.001	0.614 P<0.001	0.750 P<0.001

Here all the factors shows significant positive correlation with the performance indicator of reduction in scheduled down time with P values <0.001

Figure-5.1 : Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance of Reduction in Scheduled down time



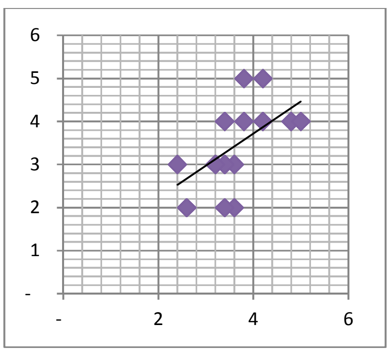


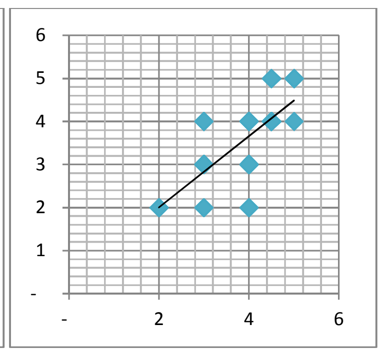


X –axis-Management Commitment

X –axis-Equipment and Process Management

X -Axis-Training and Development





X –axis-Information Architecture

X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

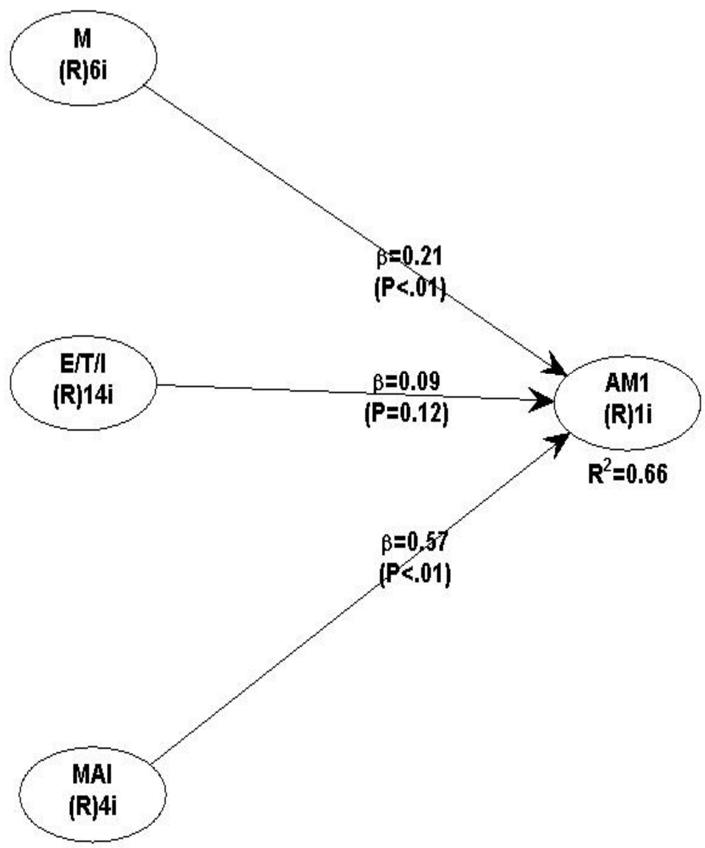
In the model fit analysis of this performance indicator , high level correlation observed between the factors of Equipment and Process management, Training and development and Information Architecture and showed high collenearity. So these three factors are combined together as a single factor for model fit.

Table-5.2 . Model fit analysis of various factors with the performance indicator of Reduction in scheduled down time.

Model fit of Reduction in scheduled down time with various factors.			
Ref:WarpPLS 4.0 User Manual	**Management Commitment**	**Equipment and Process Management** **Training and Development** **Information Architecture**	**Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	0.213 P=0.003	0.091 P=0.118	**0.571** **P<0.001**
Composite reliability coefficient (To be >0.7)	0.971	0.961	0.984
Cronbach's alpha Coefficient (To be >0.7)	0.964	0.955	0.979
Average variances extracted (To be >0.5)	0.847	0.642	0.940
Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)	M 11 0.989 M 12 0.886 M 13 0.896 M 14 0.937 M 15 0.906 M 16 0.903	EM3= 0.818 EM4= 0.704 TD1=0.888 TD2=0.899 TD5=0.744 TD6=0.839 TD8=0.710 TD9=0.775 TD10=0.630 TD11=0.850 IA1=0.609 IA3=0.911 IA4=0.929 IA5=0.825 (All values of P <0.001)	MAI1=0.969 MAI2=0.969 MAI3=0.969 MAI4=0.969 (All values of P <0.001)
Discriminant Validity	Correlations among l.vs. with sq. rts. of AVEs --- M E/T/I MAI AM1 M 0.920 0.788 0.795 0.707 E/T/I 0.788 0.801 0.676 0.636 MAI 0.795 0.676 0.969 0.750 AM1 0.707 0.636 0.750 1.000		

	Note: Square roots of average variances extracted (AVEs) shown on diagonal. P values for correlations ------------------------- M E/T/I MAI AM1 M 1.000 <0.001 <0.001 <0.001 E/T/I <0.001 1.000 <0.001 <0.001 MAI <0.001 <0.001 1.000 <0.001 AM1 <0.001 <0.001 <0.001 1.000		
Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).	4.073	2.740	3.376
Average path coefficient (APC)= 0.292, P <0.001, (>0.02 Small,.>0.15 Medium, >0.35 large) Average R Square (ARS)= 0.663, P <0.001(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998) Average Adjusted R Square (AARS) = 0.652, P<0.001 Average block VIF (AVIF) = 2.669 Average full collinearity VIF (AFVIF)= 3.178 Tenenhaus GoF (GoF)= 0.754 , small >= 0.1, medium >= 0.25, large >= 0.36 Sympson's paradox ratio (SPR)= 1.000 , acceptable if >= 0.7, ideally = 1 R-squared contribution ratio (RSCR)= 1.000, acceptable if >= 0.9, ideally = 1 Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7 Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7 (Reference : WarpPLS 4.0 User Manual)			

Figure-5.2 :Model Fit Graph



In the model fit analysis, the factor Monitoring, Analysis and Improvement (Beta Value 0.57 at P<0.001) have large effect (value >0.35) on the performance indicator of Reduction in scheduled down time with moderate R square value of 0.65(>0.33)

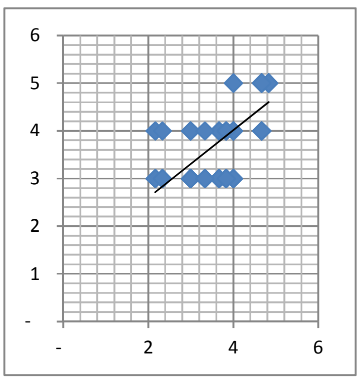
2.Performance Indicator: Increase in speed/output from the equipment:

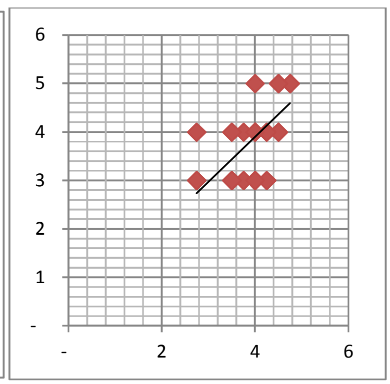
Table- 5.3. Correlation coefficient between TPM practices and Increase in speed / output from the equipment with P value.

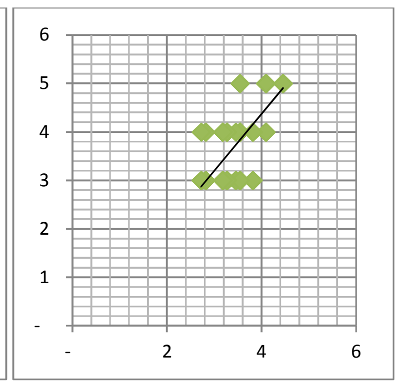
Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.677 P<0.001	0.616 P<0.001	0.688 P<0.001	0.752 P<0.001	0.487 P<0.001

Here all the factors shows significant positive correlation with the performance indicator of Increase in speed/Performance of the equipment with P values <0.001

Figure-5.3: Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of Increase in speed/output from the equipment:



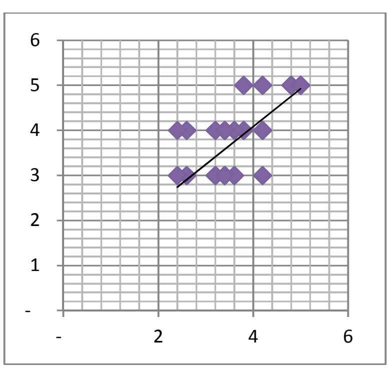


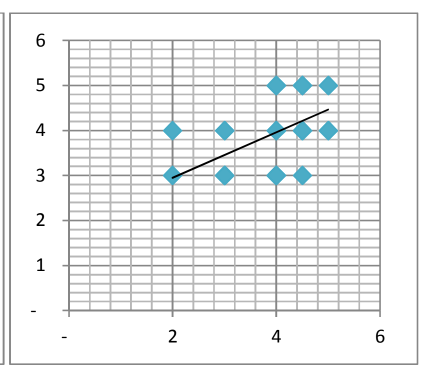


X –axis-Management Commitment

X –axis-Equipment and Process Management

X -Axis-Training and Development





X –axis-Information Architecture

X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator , high level correlation observed between the factors of Equipment and Process management, Training and development and Information Architecture and showed high collenearity. So these three factors are combined together as a single factor for model fit.

Table-5.4. Model fit analysis of various factors with the performance indicator of of increase in speed/output from the equipment

Model fit of Increase in speed/output from the equipment with various factors			
Ref:WarpPLS 4.0 User Manual	**Management Commitment**	**Equipment and Process Management** **Training and Development** **Information Architecture**	**Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	**0.627** **P<0.001**	0.193 P= 0.006	0.036 P=0.319
Composite reliability coefficient (To be >0.7)	0.971	0.957	0.984
Cronbach's alpha Coefficient (To be >0.7)	0.964	0.950	0.979
Average variances extracted (To be >0.5)	0.847	0.636	0.940
Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)	M1=0.989 M2=0.886 M3=0.896 M4=0.937 M5=0.906 M6=0.903 (All values of P <0.001)	EM 1= 0.782 EM3= 0.797 TD1=0.887 TD2=0.905 TD5=0.716 TD6=0.835 TD8=0.713 TD9=0.779 TD10=0.653 TD11=0.864 IA1=0.588 IA4=0.942 IA5=0.830 (All values of P <0.001)	MAI1=0.969 MAI2=0.969 MAI3=0.969 MAI4=0.969 (All values of P <0.001)

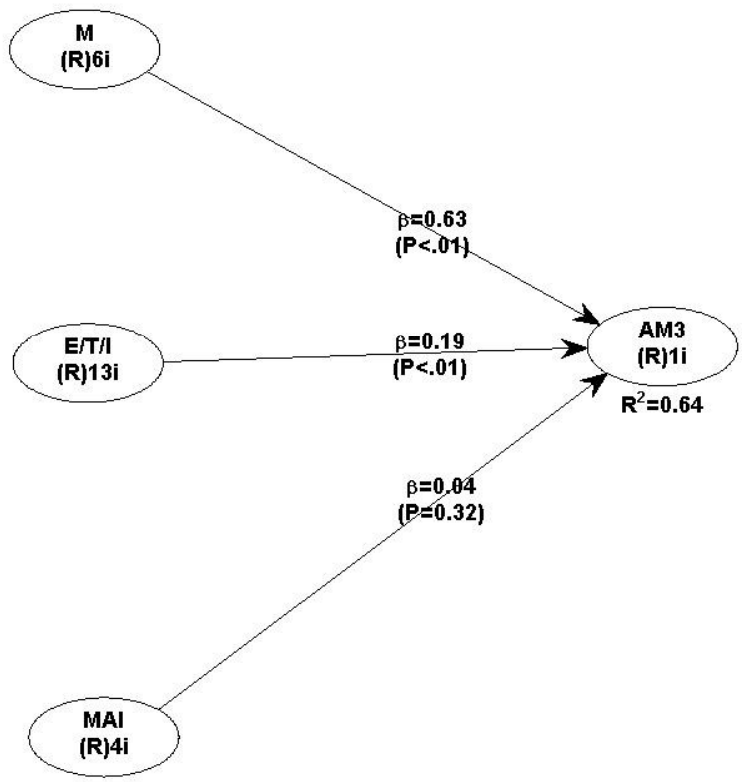
<table>
<tr><td>Discriminant Validity</td><td colspan="3">Correlations among l.vs. with sq. rts. of AVEs
----
M E/T/I MAI AM3
M 0.920 0.794 0.795 0.677
E/T/I 0.794 0.798 0.655 0.682
MAI 0.795 0.655 0.969 0.487
AM3 0.677 0.682 0.487 1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

M E/T/I MAI AM3
M 1.000 <0.001 <0.001 <0.001
E/T/I <0.001 1.000 <0.001 <0.001
MAI <0.001 <0.001 1.000 <0.001
AM3 <0.001 <0.001 <0.001 1.000</td></tr>
<tr><td>Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).</td><td>4.721</td><td>3.060</td><td>2.785</td></tr>
<tr><td colspan="4">Average path coefficient (APC)= 0.285, P <0.001, (>0.02 Small,.>0.15 Medium, >0.35 large)
Average R Square (ARS)= 0.643, P<0.001(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998)
Average Adjusted R Square (AARS) = 0.632, P<0.001
Average block VIF (AVIF) = 4.366
Average full collinearity VIF (AFVIF)= 3.168
Tenenhaus GoF (GoF)= 0.742 , small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)= 0.750 , acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)= 0.994, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7
(Reference : WarpPLS 4.0 User Manual)</td></tr>
</table>

Figure- 5.4-Model Fit Graph



In the model fit analysis the factors , management commitment has large effect (Beta value 0.63,value >0.35) on the performance indicator of Increase in speed/ output from the equipment, with moderate R square value of 0.63 (>0.33).

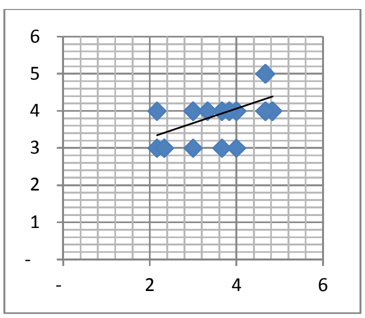
3.Performance Indicator: Increase in accuracy level of the equipment:

Table- 5.5. Correlation coefficient between TPM practices and Increase in accuracy/quality level of the equipment with P value.

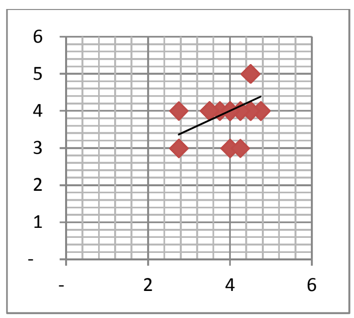
Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.609 P<0.001	0.563 P<0.001	0.523 P<0.001	0.532 P<0.001	0.497 P<0.001

Here all the factors shows significant positive correlation with the performance indicator of Increase in accuracy/quality level of the equipment with P values <0.001

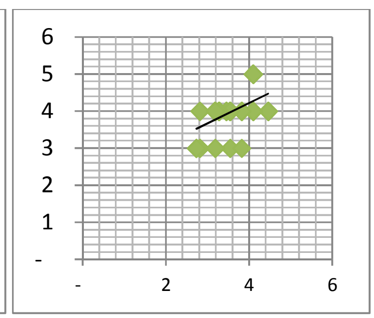
Figure-5.5 : Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of Increase in accuracy/quality level of the equipment



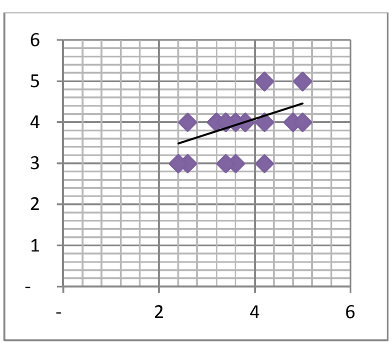
X –axis-Management Commitment



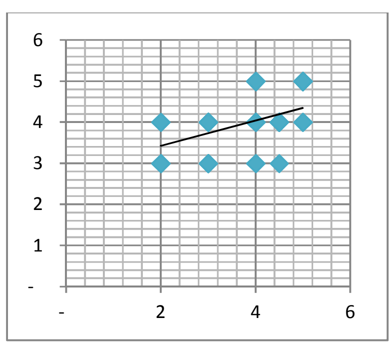
X –axis-Equipment and Process Management



X -Axis-Training and Development



X –axis-Information Architecture



X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator , high level correlation observed between the factors of Equipment/Process management, Training & development and Information Architecture and showed high collenearity. So these three factors are combined together as a single factor for model fit.

Table-5.6. Model fit analysis of various factors with the performance indicator of Increase in accuracy level of the equipment.

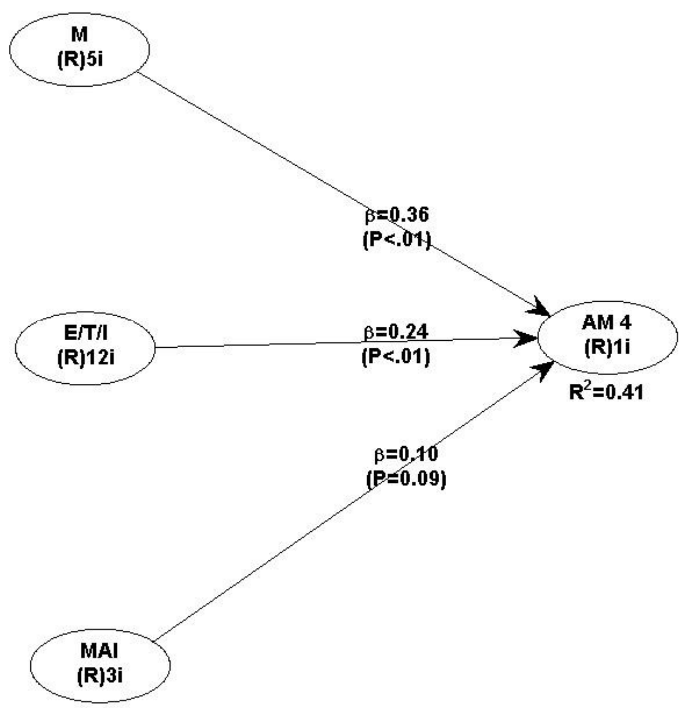
Model fit of Increase in accuracy/Quality level of the equipment with various factors			
Ref:WarpPLS 4.0 User Manual	**Management Commitment**	**Equipment and Process Management** **Training and Development** **Information Architecture**	**Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	**0.358** **P<0.001**	**0.241** **P<0.001**	0.101 P=0.094
Composite reliability coefficient (To be >0.7)	0.969	0.949	0.982
Cronbach's alpha Coefficient (To be >0.7)	0.959	0.940	0.972
Average variances extracted (To be >0.5)	0.860	0.612	0.947
Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)	M1=0.988 M2=0.912 M3=0.917 M4=0.920 M5=0.898 (All values of P <0.001)	EM 1= 0.799 EM3= 0.771 TD1=0.847 TD3=0.771 TD5=0.683 TD8=0.758 TD9=0.783 TD10=0.636 TD11=0.878 IA1=0.592 IA2=0.946 IA5=0.854 (All values of P <0.001)	MAI1=0.987 MAI2=0.987 MAI3=0.944 (All values of P <0.001)
Discriminant Validity	Correlations among l.vs. with sq. rts. of AVEs ---		

<table>
<tr>
<td></td>
<td colspan="3">M E/T/I MAI AM 4
M 0.928 0.775 0.792 0.613
E/T/I 0.775 0.783 0.659 0.532
MAI 0.792 0.659 0.973 0.522
AM 4 0.613 0.532 0.522 1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.
P values for correlations

M E/T/I MAI AM 4
M 1.000 <0.001 <0.001 <0.001
E/T/I <0.001 1.000 <0.001 <0.001
MAI <0.001 <0.001 1.000 <0.001
AM 4 <0.001 <0.001 <0.001 1.000</td>
</tr>
<tr>
<td>Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).</td>
<td>4.180</td>
<td>2.572</td>
<td>2.729</td>
</tr>
<tr>
<td colspan="4">Average path coefficient (APC)= 0.233, P<0.001, (>0.02 Small,.>0.15 Medium, >0.35 large)
Average R Square (ARS)= 0.412, P<0.001(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998)
Average Adjusted R Square (AARS) =0.393, P<0.001
Average block VIF (AVIF) = 2.671
Average full collinearity VIF (AFVIF)= 2.778
Tenenhaus GoF (GoF)= 0.593 , small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)= 1.000 , acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)= 1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7
(Reference : WarpPLS 4.0 User Manual)</td>
</tr>
</table>

Figure -5.6: Model Fit Graph



In the model fit analysis, the factor Management Commitment has large effect (Beta value 0.36, value >0.35) and the factors Equipment and Process management, Training and development and Information Architecture as combined together has medium effect (Beta value 0.24, value >0.15) on the performance indicator of Increase in accuracy/quality level of the equipment, with moderate R square value of 0.40 (>0.33).

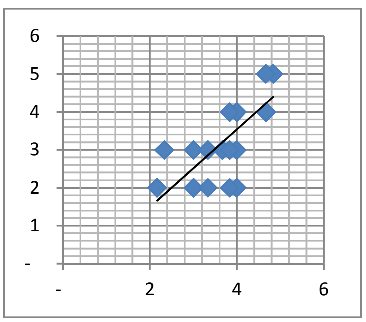
4.Performance Indicator: Reduction in lubrication oil consumption:

Table- 5.7. Correlation coefficient between TPM practices and Reduction in lubrication oil consumption of the equipment with P value.

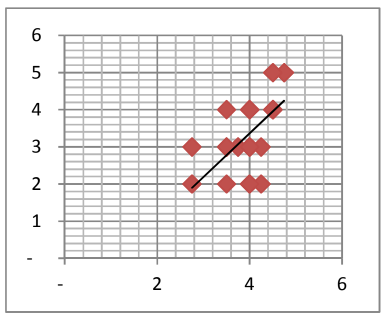
Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.790 P<0.001	0.630 P<0.001	0.688 P<0.001	0.725 P<0.001	0.610 P<0.001

Here all the factors shows significant positive correlation with the performance indicator of Reduction in lubrication oil consumption of the equipment with P values <0.001

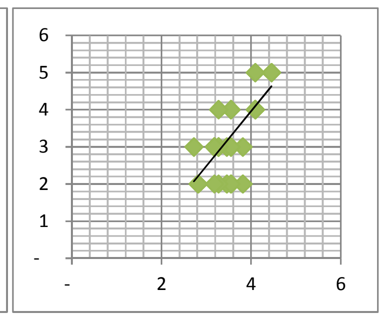
Figure-5.7 : Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of Reduction in lubrication oil consumption of the equipment



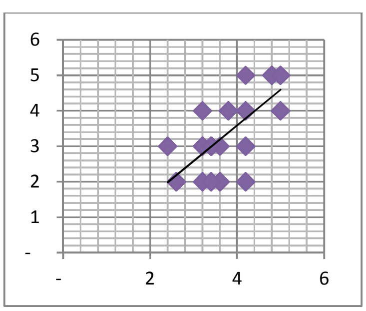
X –axis-Management Commitment



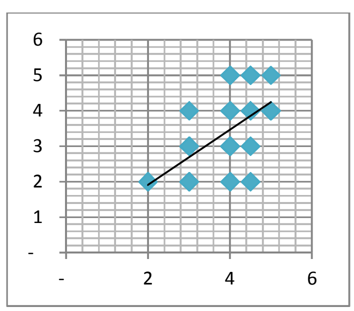
X –axis-Equipment and Process Management



X -Axis-Training and Development



X –axis-Information Architecture



X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator , high level correlation observed between the factors of Equipment/Process management, Training & development and Information Architecture and showed high collenearity. So these three factors are combined together as a single factor for model fit.

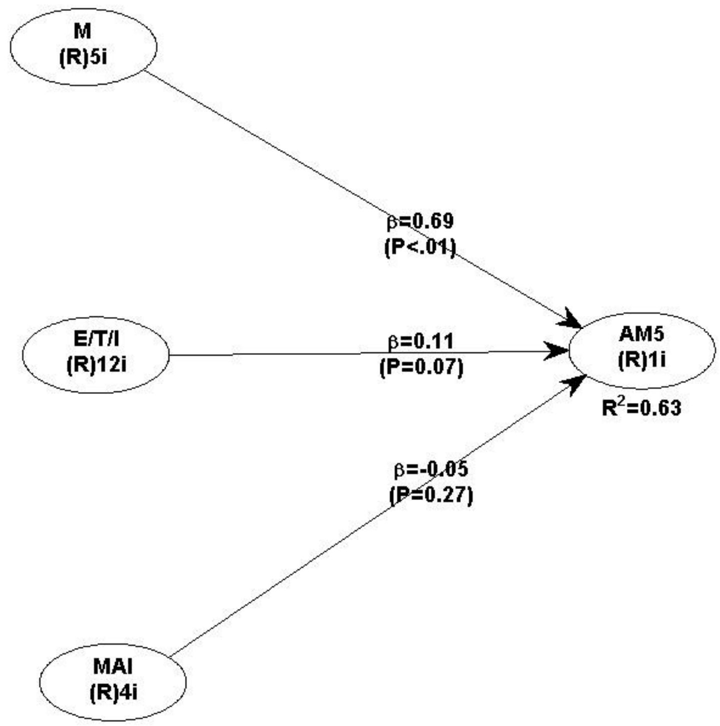
Table-5.8. Model fit analysis of various factors with the performance indicator of Reduction in lubrication oil consumption of the equipment.

Table-5.8: Model fit analysis of various factors with the performance indicator of Reduction in lubrication oil consumption of the equipment.			
Ref:WarpPLS 4.0 User Manual	**Management Commitment**	**Equipment and Process Management** **Information Architecture** **Training and Development**	**Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	**0.688** **P<0.001**	0.114 P= 0.069	-0.047 P=0.267
Composite reliability coefficient (To be >0.7)	0.969	0.948	0.984
Cronbach's alpha Coefficient (To be >0.7)	0.959	0.938	0.979
Average variances extracted (To be >0.5)	0.860	0.605	0.940
Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)	M1=0.988 M2=0.912 M3=0.917 M4=0.920 M5=0.898 (All values of P <0.001)	EM 3= 0.838 EM4= 0.766 TD1=0.897 TD2=0.904 TD4=0.542 TD5=0.759 TM6=0.820 TD8=0.704	MAI1=0.969 MAI2=0.969 MAI3=0.969 MAI4=0.969 (All values of P <0.001)

		TD9=0.771 TD11=0.820 IA1=0.624 IA5=0.813 (All values of P <0.001)	
Discriminant Validity	Correlations among l.vs. with sq. rts. of AVEs --- M E/T/I MAI AM5 M 0.928 0.732 0.794 0.775 E/T/I 0.732 0.778 0.679 0.618 MAI 0.794 0.679 0.969 0.610 AM5 0.775 0.618 0.610 1.000 Note: Square roots of average variances extracted (AVEs) shown on diagonal. P values for correlations ------------------------- M E/T/I MAI AM5 M 1.000 <0.001 <0.001 <0.001 E/T/I <0.001 1.000 <0.00 1 <0.001 MAI <0.001 <0.001 1.000 <0.001 AM5 <0.001 <0.001 <0.001 1.000		
Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).	4.663	2.319	2.869
Average path coefficient (APC)= 0.283, P<0.001, (>0.02 Small,.>0.15 Medium, >0.35 large) Average R Square (ARS)= 0.628, P<0.001(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998) Average Adjusted R Square (AARS) =0.617 , P<0.001 Average block VIF (AVIF) = 5.839 Average full collinearity VIF (AFVIF)= 3.098 Tenenhaus GoF (GoF)= 0.731 , small >= 0.1, medium >= 0.25, large >= 0.36 Sympson's paradox ratio (SPR)= 0.667, acceptable if >= 0.7, ideally = 1 R-squared contribution ratio (RSCR)= 0.976, acceptable if >= 0.9, ideally = 1 Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7 Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7 (Reference : WarpPLS 4.0 User Manual)			

Figure:5.8

Model Fit Graph



In the model fit analysis the factor, Management Commitment has large effect (Beta value 0.69, value >0.35) on the performance indicator of Decrease in lubrication oil consumption of the equipment, with moderate R square value of 0.62 (>0.33)

5.2.ANALYSIS OF PERFORMANCE INDICATORS FROM PLANNED MAINTENANCE PILLAR

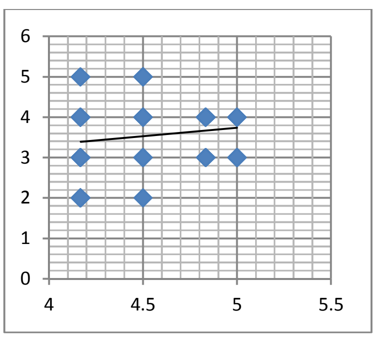
1.Performance Indicator: Reduction in scheduled down time:

Table- 5.9. Correlation coefficient between TPM practices and Reduction in scheduled down time from the equipment with P value.

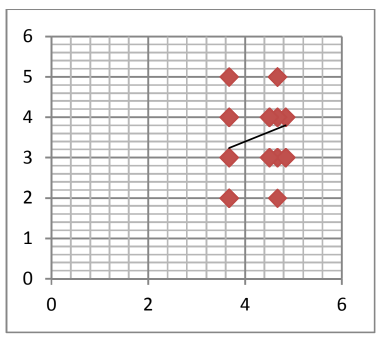
Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.266 P=0.008	0.285 P=0.004	0.249 P=0.012	0.062 P=0.539	0.022 P=0.826

Here all the factors shows in significant positive correlation with the performance indicator of Reduction in scheduled down time

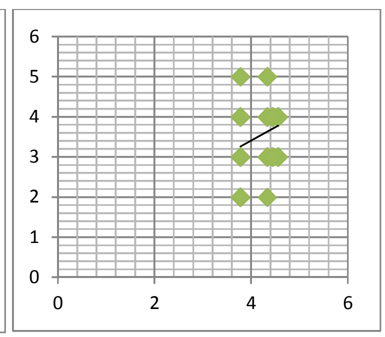
Figure-5.9 Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of Reduction in scheduled down time of the equipment.



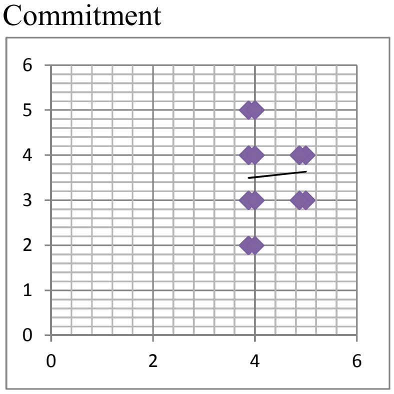
X –axis-Management Commitment



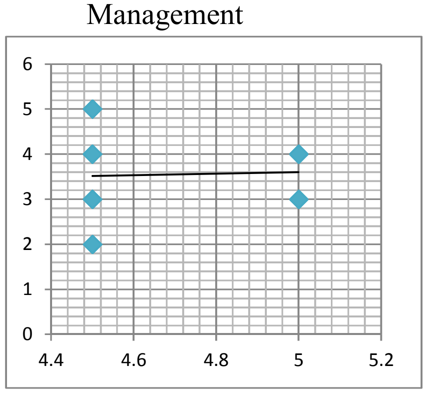
X –axis-Equipment and Process Management



X -Axis-Training and Development



X –axis-Information Architecture



X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator, high level correlation observed between the factors of, Management Commitment , Equipment and Process management and Training and development and between the factors of Information Architecture and Monitoring, Analysis and Improvement and showed high collenearity. So these three factors and two factoers are combined together ,and still the shows average block VIF with infinite collenearity.

Table-5.10. Model fit analysis of various factors with the performance indicator of Reduction in scheduled down time of the equipment.

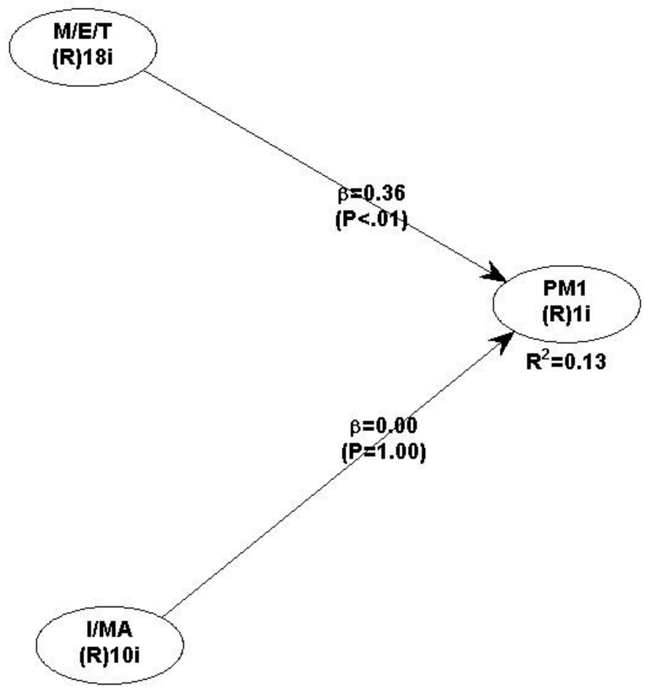
Model fit analysis of various factors with the performance indicator of Reduction in scheduled down time of the equipment.		
Ref:WarpPLS 4.0 User Manual	**Management Commitment** **Equipment and Process Management** **Training and Development**	**Information Architecture** **Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	**0.356** **P< 0.001**	0.00 P=1.00
Composite reliability coefficient (To be >0.7)	0.978	0.978
Cronbach's alpha Coefficient (To be >0.7)	0.975	0.973
Average variances extracted (To be >0.5)	0.720	0.820
Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)	M1=0.971 M2=0.971 M3=0.573 M5=0.971 M6=0.716 EM1= 0.687 EM2= 0.971 EM3=0.971 EM4=0.749 EM5=0.716 EM6=0.953	IA1=0.978 IA2=0.978 IA3=0.978 IA4=0.965 IA5=0.978 IA6=0.649 IA7=0.978 IA8=0.978 MAI1=0.744 MAI2=0.744 (All values of P <0.001)

<table>
<tr><td></td><td>TD1=0.971
TD2=0.971
TD4=0.573
TD6=0.971
TD7=0.971
TD8=0.573
TD9=0.716
(All values of P <0.001)</td><td></td></tr>
<tr><td>Discriminant Validity</td><td colspan="2">Correlations among l.vs. with sq. rts. of AVEs
----
<table>
<tr><td></td><td>M/E/T</td><td>I/MA</td><td>PM1</td></tr>
<tr><td>M/E/T</td><td>0.848</td><td>0.844</td><td>0.256</td></tr>
<tr><td>I/MA</td><td>0.844</td><td>0.906</td><td>0.111</td></tr>
<tr><td>PM1</td><td>0.256</td><td>0.111</td><td>1.000</td></tr>
</table>
Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

<table>
<tr><td></td><td>M/E/T</td><td>I/MA</td><td>PM1</td></tr>
<tr><td>M/E/T</td><td>1.000</td><td><0.001</td><td>0.010</td></tr>
<tr><td>I/MA</td><td><0.001</td><td>1.000</td><td>0.272</td></tr>
<tr><td>PM1</td><td>0.010</td><td>0.272</td><td>1.000</td></tr>
</table>
</td></tr>
<tr><td>Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).</td><td>3.842</td><td>3.635</td></tr>
<tr><td colspan="3">Average path coefficient (APC)= 0.356, P<0.001, (>0.02 Small,.>0.15 Medium, >0.35 large)
Average R Square (ARS)= 0.127, P=0.025 (0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998)
Average Adjusted R Square (AARS) = 0.118, P=0.031
Average block VIF (AVIF) = Inf.
Average full collinearity VIF (AFVIF)= 2.864
Tenenhaus GoF (GoF)= 0.328 , small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)= 1.000 , acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)= 1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7
(Reference : WarpPLS 4.0 User Manual)</td></tr>
</table>

Figure :5.10- Model Fit Graph



Here ,the factors Management Commitment, Equipment and Process Management and Training and Development are combined together as single factor and the factors Information Architecture, Monitoring, Analysis and Improvement are combined together as another single factors.

In the model fit analysis the combined factor , Management Commitment, Equipment and Process Management and Training and Development has large effect (Beta Value 0.36, value >0.35) on the performance indicator of Reduction in the scheduled down time with R square value of 0.12 (<0.19). Also the Average block VIF (AVIF) shows the infinite value which affects the reliability of the results.

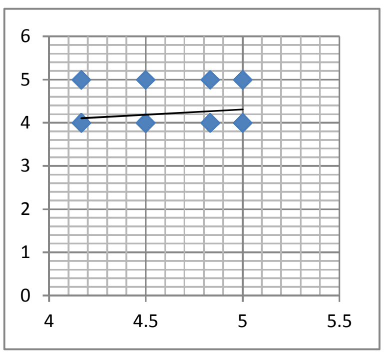
2.Performance Indicator: Reduction in the schedule miss due to operations:

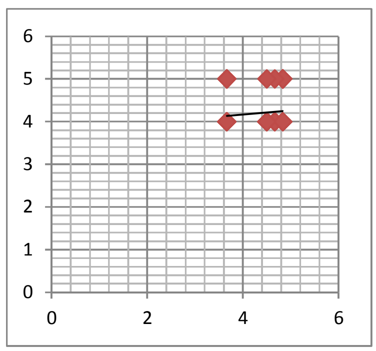
Table- 5.11. Correlation coefficient between TPM practices and schedule miss due to operations of the equipment with P value.

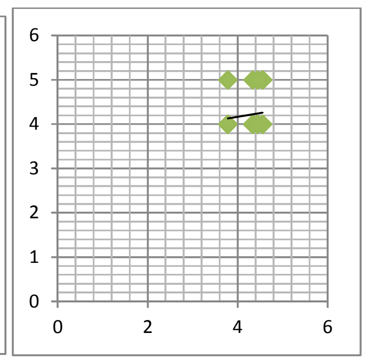
Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.120 P=0.236	0.114 P=0.257	0.135 P=0.181	0.221 P=0.027	0.210 P=0.036

Here all the factors shows in significant positive correlation with the performance indicator of reduction in the schedule miss due to operations.

Figure 5.11- Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of schedule miss due to operations of the equipment



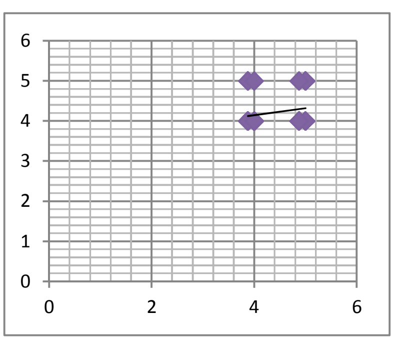


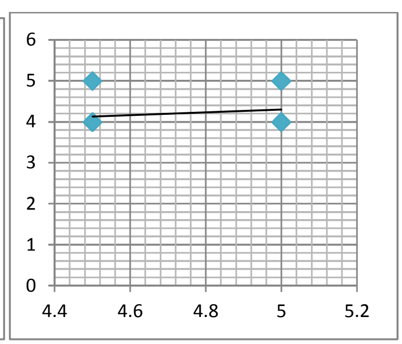


X –axis-Management Commitment

X –axis-Equipment and Process Management

X -Axis-Training and Development





X –axis-Information Architecture

X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

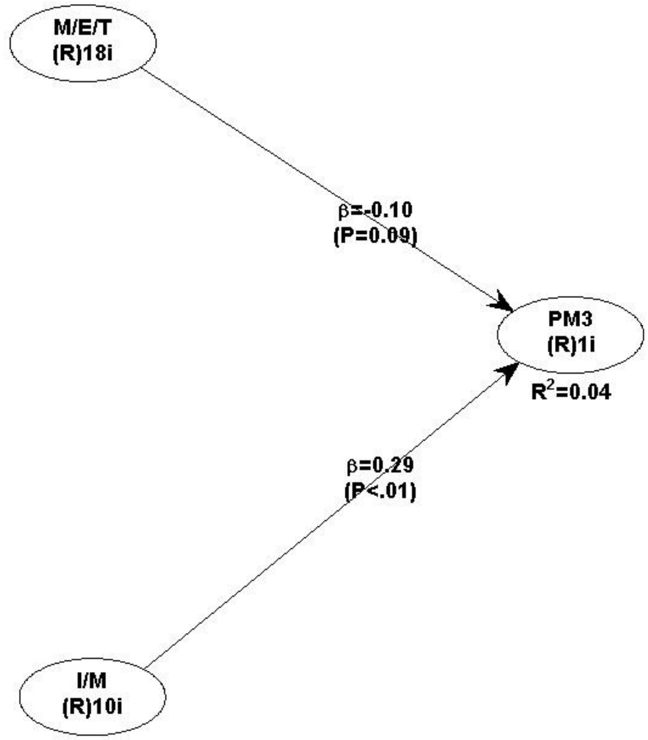
In the analysis of this performance indicator , high level correlation observed between the factors of, Management Commitment , Equipment and Process management and Training and development and between the factors of Information Architecture and Monitoring, Analysis and Improvement and showed high collenearity. So these three factors and two factors are combined together for model to fit.

Table: 5.12. Model fit analysis of various factors with the performance indicator of Reduction in the schedule miss due to operations of the equipment.

Model fit analysis of various factors with the performance indicator of Reduction in the schedule miss due to operations of the equipment.		
Ref:WarpPLS 4.0 User Manual	**Management Commitment** **Equipment and Process Management** **Training and Development**	**Information Architecture** **Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	-0.104 P= 0.088	**0.290** **P<0.001**
Composite reliability coefficient (To be >0.7)	0.978	0.978
Cronbach's alpha Coefficient (To be >0.7)	0.975	0.973
Average variances extracted (To be >0.5)	0.720	0.820
Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)	M1=0.971 M2=0.971 M3=0.573 M5=0.971 M6=0.716 EM1= 0.687 EM2= 0.971 EM3=0.971 EM4=0.749 EM5=0.716 EM6=0.953 TD1=0.971	IA1=0.978 IA2=0.978 IA3=0.978 IA4=0.965 IA5=0.978 IA6=0.649 IA7=0.978 IA8=0.978 MAI1=0.744 MAI2=0.744 (All values of P <0.001)

	TD2=0.971 TD4=0.573 TD6=0.971 TD7=0.971 TD8=0.573 TD9=0.716 (All values of P <0.001)	
Discriminant Validity	Correlations among l.vs. with sq. rts. of AVEs -- M/E/T I/M PM3 M/E/T 0.848 0.844 0.141 I/M 0.844 0.906 0.202 PM3 0.141 0.202 1.000 Note: Square roots of average variances extracted (AVEs) shown on diagonal. P values for correlations ------------------------- M/E/T I/M PM3 M/E/T 1.000 <0.001 0.162 I/M <0.001 1.000 0.044 PM3 0.162 0.044 1.000	
Full collinearity VIF **(**Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).	3.497	3.574
Average path coefficient (APC)= 0.197, P=0.003, (>0.02 Small,.>0.15 Medium, >0.35 large) Average R Square (ARS)= 0.044, P=0.141(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998) Average Adjusted R Square (AARS) = 0.024, P=0.188 Average block VIF (AVIF) = 3.486 Average full collinearity VIF (AFVIF)= 2.706 Tenenhaus GoF (GoF)= 0.193 , small >= 0.1, medium >= 0.25, large >= 0.36 Sympson's paradox ratio (SPR)= 0.500 , acceptable if >= 0.7, ideally = 1 R-squared contribution ratio (RSCR)= 0.800, acceptable if >= 0.9, ideally = 1 Statistical suppression ratio (SSR)= 0.500 , acceptable if >= 0.7 Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7 (Reference : WarpPLS 4.0 User Manual)		

Figure 5.12- Model Fit Graph



In the model fit analysis the combined factor ,Information Architecture and Monitoring, Analysis and Improvement has medium effect (Beta Value 0.290,value >0.15) on the performance indicator of Reduction in the schedule miss due to operations with R square value of 0.04 (<0.19).

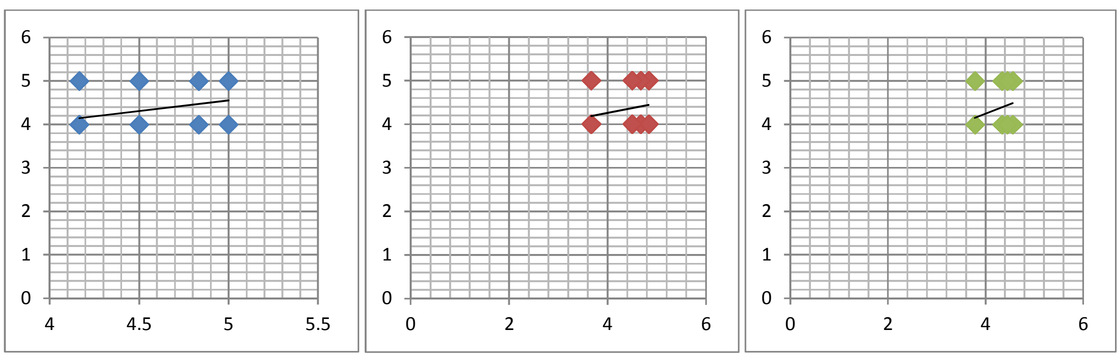
3.Performance Indicator: Decrease in breakdown:

Table- 5.13. Correlation coefficient between TPM practices and Reduction in breakdown of the equipment with P value.

Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.280 P=0.005	0.227 P=0.023	0.297 P=0.003	**0.377** **P<0.001**	**0.379** **P<0.001**

Here the factors Information Architecture and Monitoring , Analysis and Improvement shows significant positive correlation with P values <0.001 and other factors shows insignificant positive correlation with the performance indicator of reduction in breakdown.

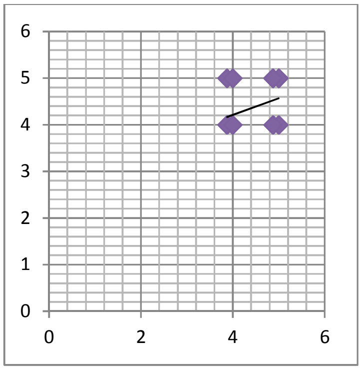
Figure :5.13- Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of reduction in breakdown.

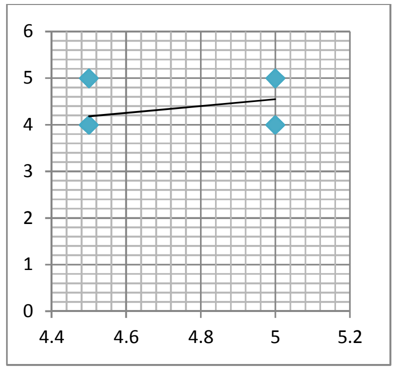


X –axis-Management Commitment

X –axis-Equipment and Process Management

X -Axis-Training and Development





X –axis-Information Architecture

X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator , high level correlation observed between the factors of,Management Commitment , Equipment and Process management and Training and development and between the factors of Information Architecture and Monitoring, Analysis and Improvement and showed high collenearity. So these three factors and two factors are combined together for model to fit.

Table-5.14 . Model fit analysis of various factors with the performance indicator of Reduction in Breakdown of the equipment.

Model fit analysis of various factors with the performance indicator of Reduction in Breakdown of the equipment		
Ref:WarpPLS 4.0 User Manual	**Management Commitment** **Equipment and Process Management** **Training and Development**	**Information Architecture** **Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	-0.133 P=0.041	**0.487** **P<0.001**
Composite reliability coefficient (To be >0.7)	0.978	0.978
Cronbach's alpha Coefficient (To be >0.7)	0.975	0.973
Average variances extracted	0.720	0.820

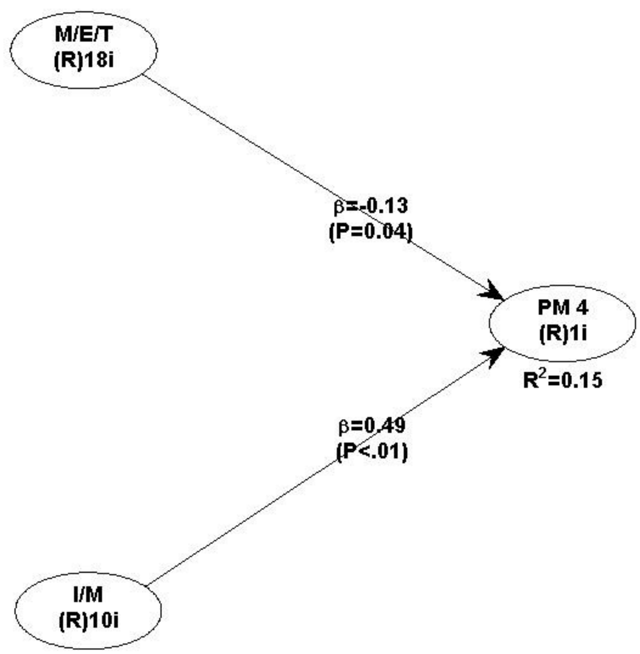
<table>
<tr><td>(To be >0.5)</td><td></td><td></td></tr>
<tr><td>Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)</td><td>M1=0.971
M2=0.971
M3=0.573
M5=0.971
M6=0.716
EM 1= 0.687
EM2= 0.971
EM3= 0.971
EM4=0.749
EM5=0.716
EM6=0.953
TD1=0.971
TD2=0.971
TD4=0.573
TD6=0.971
TD7=0.971
TD8=0.573
TD9=0.716
(All values of P <0.001)</td><td>IA1=0.978
IA2=0.978
IA3=0.978
IA4=0.965
IA5=0.978
IA6=0.649
IA7=0.978
IA8=0.978
MAI1=0.744
MAI2=0.744
(All values of P <0.001)</td></tr>
<tr><td>Discriminant Validity</td><td colspan="2">Correlations among l.vs. with sq. rts. of AVEs
----
<table><tr><td></td><td>M/E/T</td><td>I/M</td><td>PM 4</td></tr><tr><td>M/E/T</td><td>0.848</td><td>0.844</td><td>0.278</td></tr><tr><td>I/M</td><td>0.844</td><td>0.906</td><td>0.374</td></tr><tr><td>PM 4</td><td>0.278</td><td>0.374</td><td>1.000</td></tr></table>
Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

<table><tr><td></td><td>M/E/T</td><td>I/M</td><td>PM 4</td></tr><tr><td>M/E/T</td><td>1.000</td><td><0.001</td><td>0.005</td></tr><tr><td>I/M</td><td><0.001</td><td>1.000</td><td><0.001</td></tr><tr><td>PM 4</td><td>0.005</td><td><0.001</td><td>1.000</td></tr></table></td></tr>
<tr><td>Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).</td><td>3.507</td><td>3.763</td></tr>
<tr><td colspan="3">Average path coefficient (APC)= 0.310, P<0.001, (>0.02 Small,.>0.15 Medium, >0.35 large)
Average R Square (ARS)= 0.145, P=0.015(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998)
Average Adjusted R Square (AARS) = 0.127, P=0.024
Average block VIF (AVIF) = 3.486
Average full collinearity VIF (AFVIF)= 2.813
Tenenhaus GoF (GoF)= 0.350 , small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)= 0.500 , acceptable if >= 0.7, ideally = 1</td></tr>
</table>

R-squared contribution ratio (RSCR)= 0.831, acceptable if >= 0.9, ideally = 1 Statistical suppression ratio (SSR)= 0.500 , acceptable if >= 0.7 Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7 (Reference : WarpPLS 4.0 User Manual)

Figure -5.14- Model Fit Graph



In the model fit analysis the combined factor ,Information Architecture and Monitoring, Analysis and Improvement have large effect (Beta Value 0.487,value >0.35) on the performance indicator of Reduction in break down with R square value of 0.13 (<0.19).

5.3.ANALYSIS OF PERFORMANCE INDICATORS FROM QUALITY MAINTENANCE PILLAR:

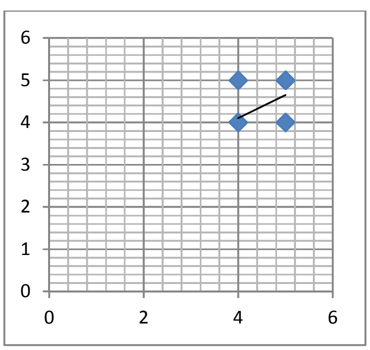
1.Performance Indicator: Decrease in Inprocess rejections/ Reworks:

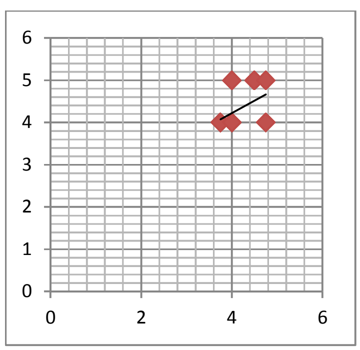
Table- 5.15. Correlation coefficient between TPM practices and Decrease in Inprocess rejections/ Reworks from the equipment with P value.

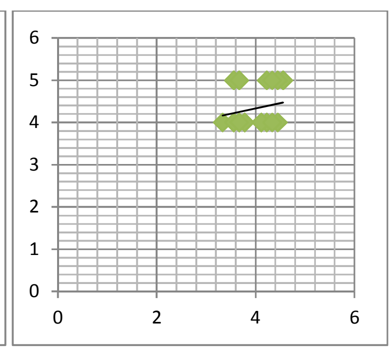
Management Commitment	Equipment and Process Management	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.578 P<0.001	0.571 P<0.001	0.175 P=0.081	0.600 P<0.001	0.578 P<0.001

Here the factors Management commitment, Equipment and Process Management ,Information Architecture and Monitoring , Analysis and Improvement etc shows significant positive correlation with P values <0.001 and other factor Training and development shows insignificant positive correlation with the performance indicator of reduction in inprocess rejections/Reworks.

Figure -5.15- Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of reduction in, inprocess rejections/Reworks.



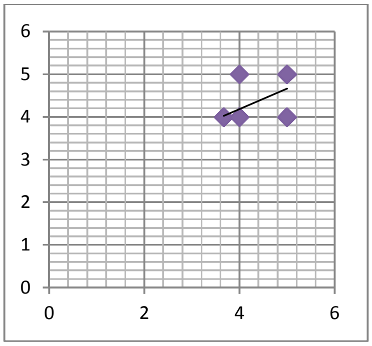


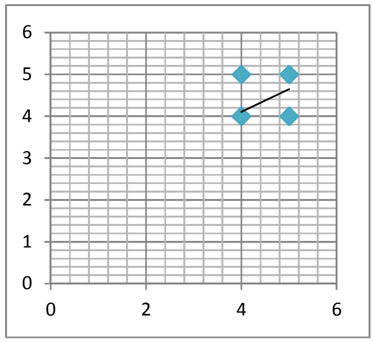


X –axis-Management Commitment

X –axis-Equipment and Process Management

X -Axis-Training and Development





X –axis-Information Architecture

X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator , high level correlation observed between the factors of Management Commitment , Equipment and Process management , Information Architecture and Monitoring, Analysis and Improvement and showed high collenearity. So these factors are combined together for model to fit.

Table-5.16 Model fit analysis of various factors with the performance indicator of In process rejections/ Reworks from the equipment.

Model fit analysis of various factors with the performance indicator of In process rejections/ Reworks from the equipment		
Ref:WarpPLS 4.0 User Manual	**Management Commitment** **Equipment and Process Management** **Information Architecture** **Monitoring, Analysis and Improvement**	**Training and Development**
β Value Small >0.02, Medium>0.15, Large>0.35	**0.574** **P<0.001**	0.039 P=0.306
Composite reliability coefficient (To be >0.7)	0.999	0.923
Cronbach's alpha Coefficient (To be >0.7)	0.999	0.900
Average variances extracted	0.988	0.635

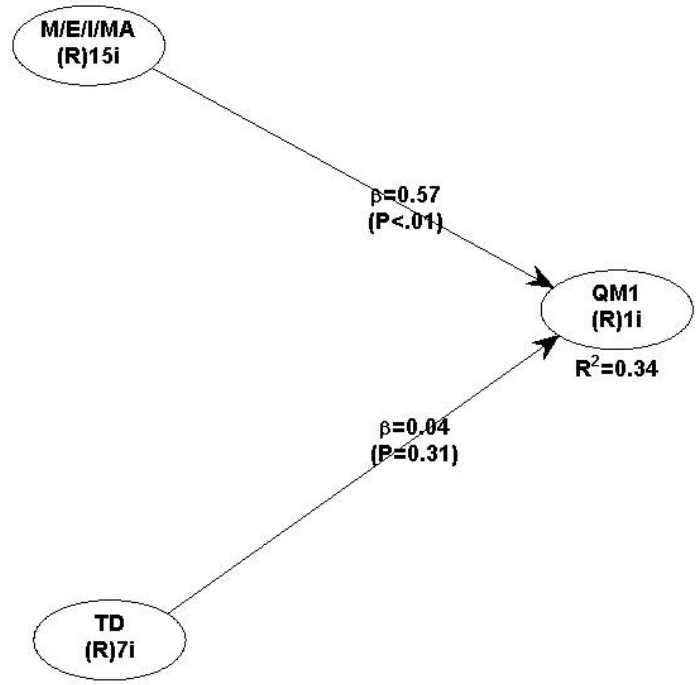
<table>
<tr><td>(To be >0.5)</td><td></td><td></td></tr>
<tr><td>Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)</td><td>M1=1.000
M2=1.000
M3=1.000
M4=1.000
M5=1.000
EM1= 1.000
EM2= 1.000
EM4=1.000
IA1=1.000
IA2=1.000
IA3=0.909
MAI1=1.000
MAI2=1.000
MAI3=1.000
MAI4=1.000
(All values of P <0.001)</td><td>TD1=0.924
TD2=0.924
TD3=0.625
TD6=0.734
TD7=0.806
TD8=0.658
TD9=0.850
(All values of P <0.001)</td></tr>
<tr><td>Discriminant Validity</td><td colspan="2">Correlations among l.vs. with sq. rts. of AVEs
----
<table><tr><th></th><th>M/E/I/M</th><th>TD</th><th>QM1</th></tr><tr><td>M/E/I/M</td><td>0.994</td><td>0.234</td><td>0.583</td></tr><tr><td>TD</td><td>0.234</td><td>0.797</td><td>0.173</td></tr><tr><td>QM1</td><td>0.583</td><td>0.173</td><td>1.000</td></tr></table>
Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

<table><tr><th></th><th>M/E/I/M</th><th>TD</th><th>QM1</th></tr><tr><td>M/E/I/M</td><td>1.000</td><td>0.019</td><td><0.001</td></tr><tr><td>TD</td><td>0.019</td><td>1.000</td><td>0.085</td></tr><tr><td>QM1</td><td><0.001</td><td>0.085</td><td>1.000</td></tr></table></td></tr>
<tr><td>Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).</td><td>1.557</td><td>1.060</td></tr>
<tr><td colspan="3">Average path coefficient (APC)= 0.306, P<0.001, (>0.02 Small,.>0.15 Medium, >0.35 large)
Average R Square (ARS)= 0.341, P<0.001(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998)
Average Adjusted R Square (AARS) = 0.327, P<0.001
Average block VIF (AVIF) = 1.058
Average full collinearity VIF (AFVIF)= 1.378
Tenenhaus GoF (GoF)= 0.546 , small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)= 1.000 , acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)= 1.000, acceptable if >= 0.9, ideally = 1</td></tr>
</table>

Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7
(Reference : WarpPLS 4.0 User Manual)

Figure-5. 16. Model Fit Graph



In the model fit analysis the combined factor , Management Commitment, Equipment and Process Management, Information Architecture, and Monitoring, Analysis and Improvement have large effect (Beta Value 0.574, value >0.35) on the performance indicator of Reduction in inprocess defects/ rework with moderate R square value of 0.33(0.33-moderate).

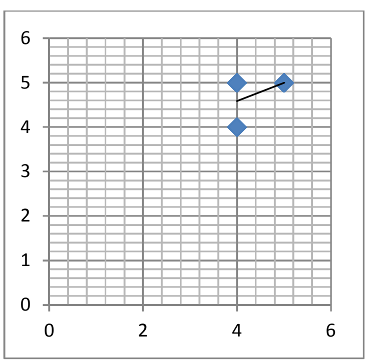
2.Performance Indicator: Decrease in final rejections:

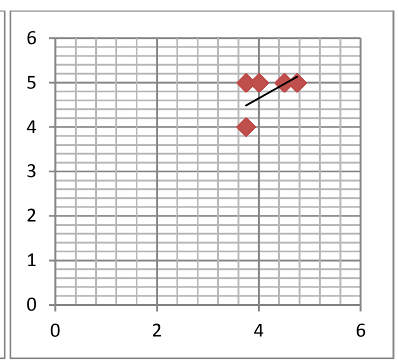
Table- 5.17. Correlation coefficient between TPM practices and Decrease in final rejections from the equipment with P value.

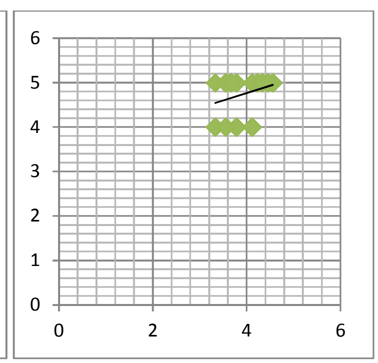
Management Commitment	Equipment&Process Management	Training & Development	Information Architecture	Monitoring, Analysis & Improvement
0.471 P<0.001	0.491 P<0.001	0.271 P=0.006	0.559 P<0.001	0.471 P<0.001

Here the factors Management commitment, Equipment and Process Management ,Information Architecture and Monitoring , Analysis and Improvement shows significant positive correlation with P values <0.001 and other factor Training and development shows insignificant positive correlation with the performance indicator of reduction in final rejections.

Figure -5.17: Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of reduction in final rejections.



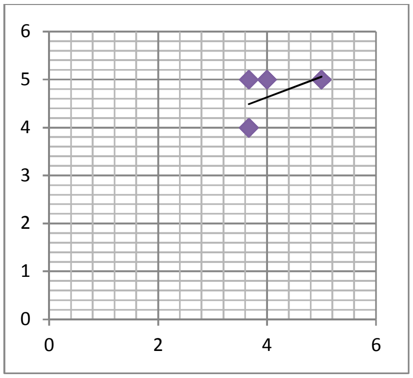


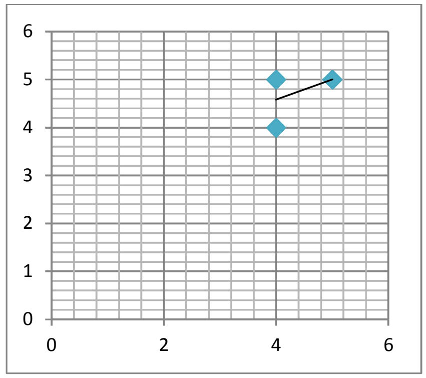


X –axis-Management Commitment

X –axis-Equipment and Process Management

X -Axis-Training and Development





X –axis-Information Architecture

X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator , high level correlation observed between the factors of, Management Commitment , Equipment and Process management , Information Architecture and Monitoring, Analysis and Improvement and showed high collenearity. So these factors are combined together for model to fit.

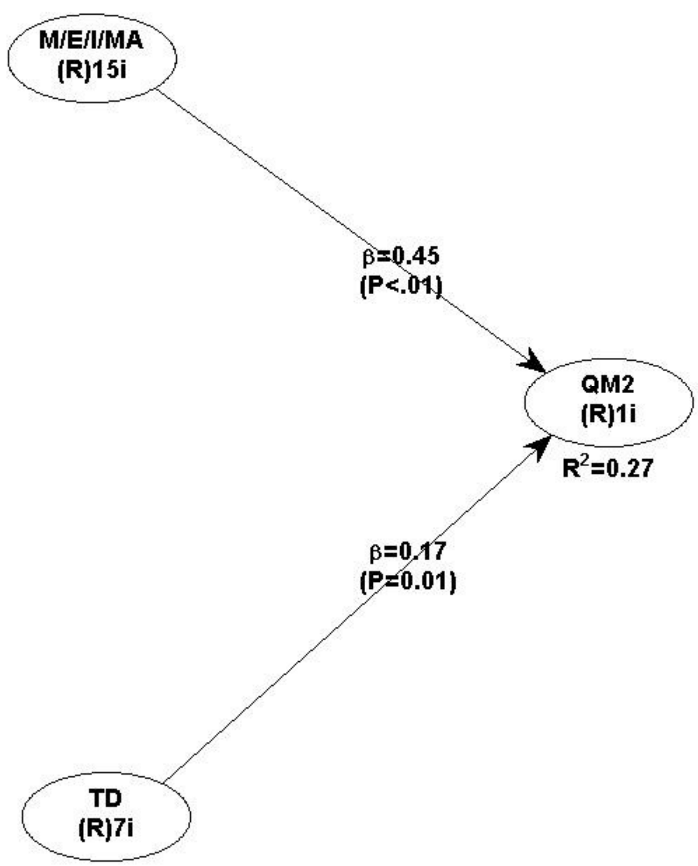
Table -5.18. Model fit analysis of various factors with the performance indicator of Decrease in final rejections from the equipment.

Model fit analysis of various factors with the performance indicator of Decrease in final rejections from the equipment.		
Ref:WarpPLS 4.0 User Manual	**Management Commitment** **Equipment and Process Management** **Information Architecture** **Monitoring, Analysis and Improvement**	**Training and Development**
β Value Small >0.02, Medium>0.15, Large>0.35	**0.449** **P<0.001**	0.168 P=0.015
Composite reliability coefficient (To be >0.7)	0.999	0.923
Cronbach's alpha Coefficient (To be >0.7)	0.999	0.900

Average variances extracted (To be >0.5)	0.988	0.635
Convergent validity (The value of P to be <0.5 and Loadings to be > 0.5)	M1=1.000 M2=1.000 M3=1.000 M4=1.000 M5=1.000 EM1= 1.000 EM2= 1.000 EM4=1.000 IA1=1.000 IA2=1.000 IA3=0.909 MAI1=1.000 MAI2=1.000 MAI3=1.000 MAI4=1.000 (All values of P <0.001)	TD1=0.924 TD2=0.924 TD3=0.625 TD6=0.734 TD7=0.806 TD8=0.658 TD9=0.850 (All values of P <0.001)
Discriminant Validity	Correlations among l.vs. with sq. rts. of AVEs -- M/E/I/M TD QM2 M/E/I/M 0.994 0.234 0.488 TD 0.234 0.797 0.273 QM2 0.488 0.273 1.000 Note: Square roots of average variances extracted (AVEs) shown on diagonal. P values for correlations ------------------------- M/E/I/M TD QM2 M/E/I/M 1.000 0.019 <0.001 TD 0.019 1.000 0.006 QM2 <0.001 0.006 1.000	
Full collinearity VIF **(**Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).	1.332	1.096
Average path coefficient (APC)= 0.309, P<0.001, (>0.02 Small,.>0.15 Medium, >0.35 large) Average R Square (ARS)= 0.265, P<0.001(0.67 -Substantial,0.33- Moderate, 0.19-Weak, By Chin 1998) Average Adjusted R Square (AARS) = 0.250, P<0.001 Average block VIF (AVIF) = 1.058 Average full collinearity VIF (AFVIF)= 1.263 Tenenhaus GoF (GoF)= 0.481 , small >= 0.1, medium >= 0.25, large >= 0.36 Sympson's paradox ratio (SPR)= 1.000 , acceptable if >= 0.7, ideally = 1 R-squared contribution ratio (RSCR)= 1.000, acceptable if >= 0.9, ideally = 1		

Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7
(Reference : WarpPLS 4.0 User Manual)

Figure 5.18-Model Fit Graph



In the model fit analysis the combined factor , Management Commitment, Equipment and Process Management, Information Architecture, and Monitoring, Analysis and Improvement has large effect (Beta Value 0.45,value >0.35) on the performance indicator of Reduction in inprocess defects/ rework with weak R square value of 0.25 (>0.19)

5.4 .ANALYSIS OF PERFORMANCE INDICATOR FROM FOCUSSED IMPROVEMENT PILLAR:

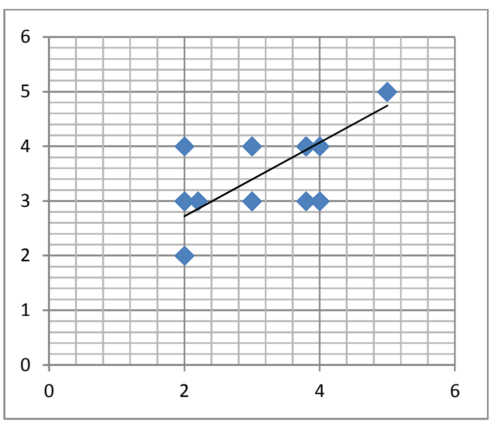
1.Performance Indicator: Increase in Lean/Kaizen projects:

Table- 5.19. Correlation coefficient between TPM practices and Increase in Lean/Kaizen projects from the equipment with P value.

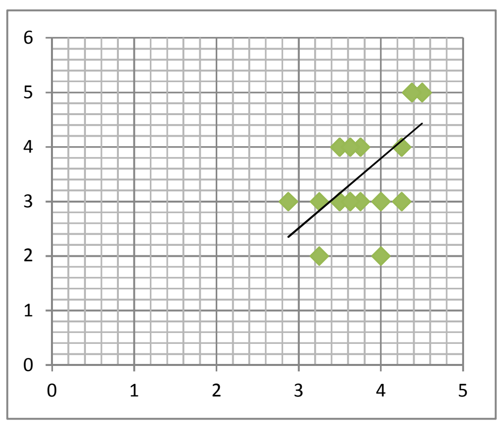
Management Commitment	Training and Development	Information Architecture	Monitoring, Analysis and Improvement
0.822 P<0.001	0.582 P<0.001	0.607 P<0.001	0.628 P<0.001

Here all the factors shows significant positive correlation with the performance indicator of Increase in Lean/Kaizen projects with P values <0.001.

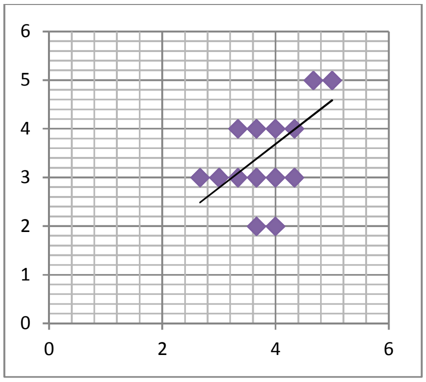
Figure-5.19: Graphical presentation of correlation between TPM factors and performance –In all the graph, X axis shows the implementation of various TPM factors and Y axis shows the performance indicator of Increase in Lean/Kaizen projects

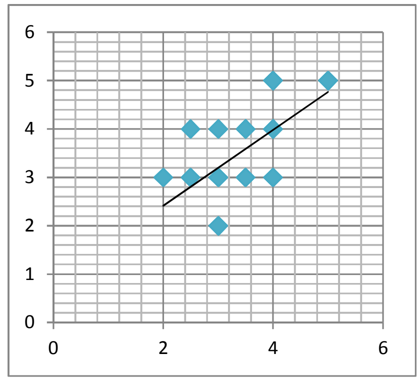


X –axis-Management Commitment



X -Axis-Training and Development





X –axis-Information Architecture

X –axis-Monitoring, Analysis and Improvement

Model Fit analysis:

In the analysis of this performance indicator , high level correlation observed between the factors of, Information Architecture and Monitoring, Analysis & Improvement and showed high collenearity. So these factors are combined together for model to fit.

Table - 5.20: Model fit analysis of various factors with the performance indicator of Increase in Lean/Kaizen projects.

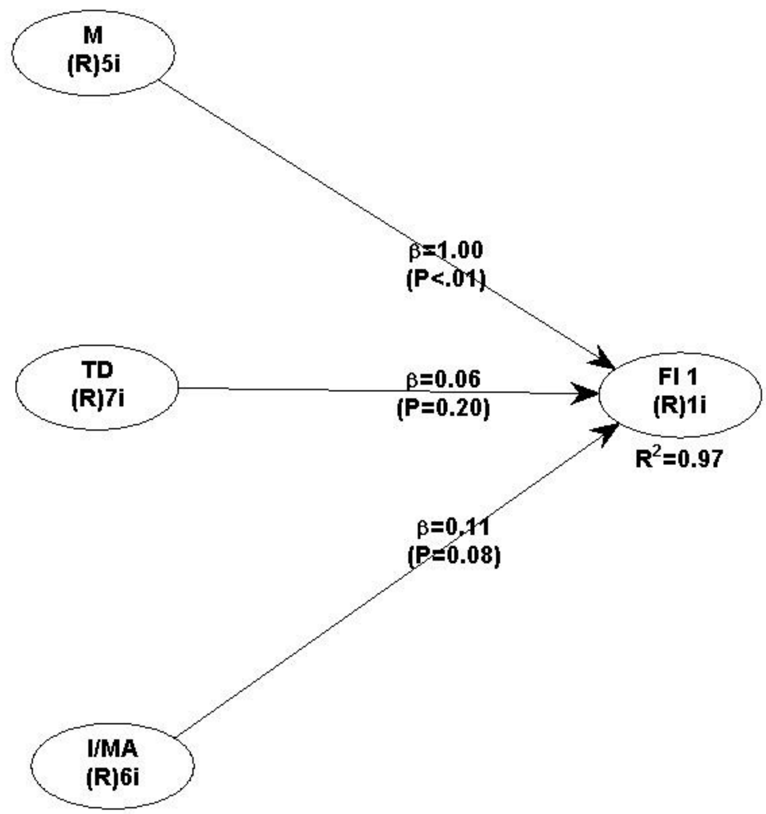
Model fit analysis of various factors with the performance indicator of Increase in Lean/Kaizen projects			
Ref:WarpPLS 4.0 User Manual	**Management Commitment**	**Training and Development**	**Information Architecture** **Monitoring, Analysis and Improvement**
β Value Small >0.02, Medium>0.15, Large>0.35	**1.000** **P<0.001**	0.063 P= 0.204	0.109 P= 0.079
Composite reliability coefficient (To be >0.7)	0.995	0.919	0.955
Cronbach's alpha Coefficient (To be >0.7)	0.993	0.894	0.943
Average variances extracted (To be >0.5)	0.974	0.625	0.781
Convergent	M1=0.988	TD1=0.925	IA2=0.909

<table>
<tr><td>validity
(The value of P to be <0.5 and Loadings to be > 0.5)</td><td>M2=0.997
M3=0.997
M4=0.997
M5=0.957
(All values of P <0.001)</td><td>TD2=0.958
TD3=0.652
TD5=0.606
TD6=0.800
TD7=0.699
TD8=0.828
(All values of P <0.001)</td><td>IA3=0.960
MAI1=0.841
MAI2=0.841
MAI3=0.872
MAI4=0.872
(All values of P <0.001)</td></tr>
<tr><td>Discriminant Validity</td><td colspan="3">Correlations among l.vs. with sq. rts. of AVEs
----
<table>
<tr><td></td><td>M</td><td>TD</td><td>I/MA</td><td>FI 1</td></tr>
<tr><td>M</td><td>0.987</td><td>0.738</td><td>0.830</td><td>0.822</td></tr>
<tr><td>TD</td><td>0.738</td><td>0.791</td><td>0.774</td><td>0.544</td></tr>
<tr><td>I/MA</td><td>0.830</td><td>0.774</td><td>0.884</td><td>0.636</td></tr>
<tr><td>FI 1</td><td>0.822</td><td>0.544</td><td>0.636</td><td>1.000</td></tr>
</table>
Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

<table>
<tr><td></td><td>M</td><td>TD</td><td>I/MA</td><td>FI 1</td></tr>
<tr><td>M</td><td>1.000</td><td><0.001</td><td><0.001</td><td><0.001</td></tr>
<tr><td>TD</td><td><0.001</td><td>1.000</td><td><0.001</td><td><0.001</td></tr>
<tr><td>I/MA</td><td><0.001</td><td><0.001</td><td>1.000</td><td><0.001</td></tr>
<tr><td>FI 1</td><td><0.001</td><td><0.001</td><td><0.001</td><td>1.000</td></tr>
</table></td></tr>
<tr><td>Full collinearity VIF (Relaxed criterion is that they be lower than 10 -Hair et al., 1987; 2009; Kline, 1998).</td><td>6.511</td><td>2.724</td><td>3.970</td></tr>
<tr><td colspan="4">Average path coefficient (APC)= 0.391, P<0.001, (>0.02 Small,.>0.15 Medium, >0.35 large)
Average R Square (ARS)= 0.973, P<0.001(0.67 -Substantial,0.33- Moderate, 0.19- Weak, By Chin 1998)
Average Adjusted R Square (AARS) = 0.972, P<0.001
Average block VIF (AVIF) = 3.588
Average full collinearity VIF (AFVIF)= 4.097
Tenenhaus GoF (GoF)= 0.907 , small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)= 1.000 , acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)= 1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)= 1.000 , acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)= 1.000, acceptable if >= 0.7
(Reference : WarpPLS 4.0 User Manual)</td></tr>
</table>

Figure :5.20- Model Fit Graph



In the model fit analysis the factor Management Commitment has large effect (Beta value 1.00, value >0.35) on the performance indicator of Increase in Lean/Kaizen projects with substantial R square value of 0.97 (>0.67)

5.5. Conclusion of this chapter.

The chapter analysed the various performance indicators from TPM pillars, as from autonomous maintenance pillar, planned maintenance pillar, quality maintenance pillar and focused improvement pillar with the various implementtaion factors .

The analytical results are given in the chapter with each indicatorwise.

These analysis leads to the further conclusions for the set objectives and hypothesis.

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CHAPTER 6

FINDINGS & RECOMMENDATIONS

This chapter details about the consolidated findings based on the analysis of various performance indicators from TPM pillars . The relation ship of each independent variable as implementation factor, with various performance indicators are consolidated and the results are explained. The conclusion of findings and the recommendations were given. The theoretical, industrial and managerial implications of the study also were given. Also given the limitations of the study and the scope for further research.

6.1. Consolidated findings:

Hypothesis -1

Management commitment, individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.

Findings:

The Partial Least Square (PLS) analysis showed the following results for the factor management commitment with various performance indicators.

Table 6.1.

Management commitment							
		Correlation	P value	Beta value (>0.02 Small, >0.15Medium, >0.35 large)	P value	Average adjusted R square value (0.67 Substantial, 0.33- Moderate, 0.19-Weak)	P value
Autonomous Maintenance							
1	Reduction of scheduled down time	0.707	<0.001	0.213	<0.01	0.652	<0.001
2	Increase in speed/ output from the equipment	0.677	<0.001	0.627	<0.001	0.632	<0.001
3	Increase in accuracy level of the equipment	0.609	<0.001	0.358	<0.001	0.393	<0.001
4	Reduction in lubrication oil consumption	0.790	<0.001	0.688	<0.001	0.617	<0.001
Planned Maintenance							
1	Reduction in scheduled down	0.266	<0.01	0.356 Combined with	<0.001	0.118	0.031

	time			the factors of equipment and process management and training and development			
2	Reduction in schedule miss due to operations	0.120	0.236	-0.104 Combined with the factors of equipment and process management and training and development	0.088	0.024	0.188
3	Reduction in breakdown	0.280	<0.01	-0.133 Combined with the factors of equipment and process management and training and development	0.041	0.127	0.024
Quality maintenance							
1	Reduction in process defects/reworks	0.578	<0.001	0.574 Combined with the factors of equipment and process management, information architecture and monitoring, analysis and	<0.001	0.33	<0.001

				improvement.			
2	Reduction in final defects	0.471	<0.001	0.449 Combined with the factors of equipment and process management, information architecture and monitoring, analysis and improvement.	<0.001	0.250	<0.001
Focussed improvement							
1	Increase in the lean/kaizen projects	0.822	<0.001	0.972	<0.001	0.972	<0.001

Reliability and validity

Cronbach's alpha coefficient- The measure of reliability associated the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Composite reliability coefficient- The measure of reliability associated with the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Convergent validity of measurement instrument assessment, the AVE threshold frequently is greater than 0.5 in all the performance indicators from the analysed TPM pillars.

Hence the reliability and validity have been confirmed.

Relation ship between the factor management commitment with various TPM performance indicators:

a) The factor management commitment has significant positive correlation with p value <0.001 level

From Autonomous maintenance pillar

1. Reduction in scheduled down time
2. Increase in speed/ output from the equipment

3. Increase in accuracy level of the equipment
4. Reduction in oil consumption

From Quality maintenance pillar;

1. Reduction in process defects/reworks combined with other factors
2. Reduction in final defects combined with other factors

From focussed improvement pillar the increase in the lean/kaizen projects

b) The factor management commitment has significant positive correlation with p value <0.01 level

From planned maintenance pillar

1. Reduction in scheduled down time
2. Reduction in breakdown

c) The factor management commitment has insignificant positive correlation with

Reduction in schedule miss due to operations from planned maintenance pillar

As per the findings of TPM practices and the resulted performance, significant positive correlation of nine performance indicators and insignificant positive correlation of one performance indicators were identified with the factor of management commitment.

The effect of the factor management commitment on various TPM performance indicators:

a) The factor management commitment has large effect with substantial R square value with

Increase in lean/kaizen projects from focussed improvement pillar

b) The factor management commitment has large effect with moderate R square value with

From autonomous maintenance pillar

1. Increase in speed/ output from the equipment
2. Increase in accuracy level of the equipment

3. Reduction in lubrication oil consumption

c) The factor management commitment combined with other factors has large effect with moderate R square value with

Reduction in inprocess defects/ reworks from quality maintenance pillar.

d) The factor management commitment combined with other factors has large effect with weak R square value with

Reduction in final defects from quality maintenance pillar

e)The factor management commitment has medium effect with moderate R square value with

Reduction in scheduled down time from autonomous maintenance pillar

<u>Hypothesis -2</u>

Equipment and process management practices has individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.

Table :6.2

Equipment & Process Management							
		Correla tion	P value	Beta value (>0.02 Small, >0.15Medium, >0.35 large)	P value	Average adjusted R square value (0.67 Substantial, 0.33- Moderate, 0.19-Weak)	P value
Autonomous Maintenance							
1	Reduction of scheduled down time	0.658	<0.001	0.091	0.118	0.652	<0.001
2	Increase in speed / output from the equipment	0.616	<0.001	0.193 Combined with the	<0.01	0.632	<0.001

				factors of training and development and information architecture			
3	Increase in accuracy level of the equipment	0.563	<0.001	0.241 Combined with the factors of training and development and information architecture	<0.001	0.393	<0.001
4	Reduction in lubrication oil consumption	0.630	<0.001	0.114 Combined with the factors of training and development and information architecture	0.069	0.617	<0.001
Planned Maintenance							
1	Reduction in scheduled down time	0.285	<0.01	0.356 Combined with the factors of management commitment and training and	<0.001	0.118	0.031

				development			
2	Reduction in schedule miss due to operations	0.114	0.257	-0.104 Combined with the factors of management commitment and training and development	0.088	0.024	0.188
3	Reduction in breakdown	0.227	0.023	-0.133 Combined with the factors of management commitment and training and development	0.041	0.127	0.024
Quality maintenance							
1	Reduction in process defects	0.571	<0.001	0.574 Combined with the factors of management commitment, information architecture and monitoring analysis and improvement	<0.001	0.327	<0.001
2	Reduction in final defects	0.491	<0.001	0.449 Combined	<0.001	0.25	<0.001

				with the factors of management commitment, information architecture and monitoring analysis and improvement			

Reliability and validity

Cronbach's alpha coefficient- The measure of reliability associated the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.
Composite reliability coefficient- The measure of reliability associated with the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.
Convergent validity of measurement instrument assessment, the AVE threshold frequently is greater than 0.5 in all the performance indicators from the analysed TPM pillars.
Hence the reliability and validity have been confirmed.

Relation ship between the factor equipment & process management practices with various TPM performance indicators:

a) **The factor equipment and process management has significant positive correlation with p value <0.001**

From autonomous maintenance pillar

1. Reduction in scheduled down time

2. Increase in speed/ output from the equipment

3. Increase in accuracy level of the equipment

4. Reduction in lubrication oil consumption

From Quality maintenance pillar:

1. Reduction in process defects/reworks

2. Reduction in final defects

b) The factor equipment and process management has significant positive correlation with p value <0.01

Reduction in scheduled down time from planned maintenance pillar

c) The factor equipment and process management has insignificant positive correlation with

From planned maintenance pillar

1. Reduction in schedule miss due to operations
2. Reduction in breakdown

As per the findings of TPM practices and the resulted performance, significant positive correlation of seven performance indicators and insignificant positive correlation of two performance indicators were identified with the factor of equipment and process management practices.

The effect of the factor equipment and process management practices on various TPM performance indicators:

a) **The factor equipment and process management combined with other factors has large effect with moderate R square value with**
   Reduction in process defects/reworks from quality maintenance Pillar
b) **The factor equipment and process management combined with other factors has large effect with weak R square value with**
   Reduction in final defect from quality maintenance Pillar
c) **The factor equipment and process management combined with other factors has medium effect with moderate R square value with**

   From autonomous maintenance pillar

   1. Increase in speed/ output from the equipment

2. Increase in accuracy level of the equipment

d) The factor equipment and process management combined with other factors has small effect with moderate R square value with

From autonomous maintenance pillar

1. Reduction in scheduled down time.
2. Reduction in lubrication oil consumption

<u>Hypothesis -3</u>

Training and development individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.

Table :6.3

Training and Development							
		Correlation	P value	Beta value (>0.02 Small, >0.15 Medium, >0.35 large)	P value	Average adjusted R square value (0.67 Substantial, 0.33- Moderate, 0.19-Weak)	P value
Autonomous Maintenance							
1	Reduction of scheduled down time	0.607	<0.001	0.091 with equipment and process management and information architecture	0.118	0.652	<0.001
2	Increase in speed/ output from the equipment	0.688	<0.001	0.193 with equipment and process management and information architecture	<0.01	0.632	<0.001

3	Increase in accuracy level of the equipment	0.523	<0.001	0.241 with equipment and Process management and information architecture	<0.001	0.393	<0.001
. 4	Reduction in lubrication oil consumption	0.688	<0.001	0.114 with equipment and process management and information architecture	0.069	0.617	<0.001
Planned Maintenance							
1	Reduction in scheduled down time	0.249	0.012	0.356 with management commitment and equipment and process management	<0.001	0.118	0.031
2	Reduction in schedule miss due to operations	0.135	0.181	-0.104 with management commitment and equipment and process management	0.088	0.024	0.188
3	Reduction in breakdown	0.297	<0.01	-0.133 with management commitment and equipment and process management	0.041	0.127	0.024
Quality maintenance							
1	Reduction in	0.175	0.081	0.039	0.306	0.327	<0.001

	process defects						
2	Reduction in final defects	0.27	<0.01	0.168	0.015	0.250	<0.001
Focussed improvement							
1	Increase number of lean/kaizen projects	0.582	<0.001	0.063	0.204	0.972	<0.001

Reliability and validity

Cronbach's alpha coefficient- The measure of reliability associated the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Composite reliability coefficient- The measure of reliability associated with the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Convergent validity of measurement instrument assessment, the AVE threshold frequently is greater than 0.5 in all the performance indicators from the analysed TPM pillars.

Hence the reliability and validity have been confirmed.

Relation ship between the factor training and development practices with various TPM performance indicators:

a) **The factor training and development has significant positive correlation with p value <0.001**

From autonomous maintenance pillar

1. Reduction in scheduled down time

2. Increase in speed/ output from the equipment

3. Increase in accuracy level of the equipment

4. Reduction in oil consumption

From focussed improvement Pillar

Increase in the lean/kaizen projects

b) The factor training and development has significant positive correlation with p value <0.01 levels

1. Reduction in breakdown from planned maintenance pillar
2. Reduction in final defects from quality maintenance pillar

c) The factor training and development has insignificant positive correlation with

From planned maintenance pillar

1. Reduction in schedule miss due to operations
2. Reduction in scheduled down time

From quality maintenance pillar

Reduction in inprocess defects

As per the findings of TPM practices and the resulted performance, significant positive correlation of seven performance indicators and insignificant positive correlation of three performance indicators were identified with the factor of training and development.

The effect of the factor training and development practices on various TPM performance indicators:

a) **The factor training and development practices combined with the other factors has medium effect with moderate R square value with**

   From autonomous maintenance pillar

   1. Increase in speed/ output from the equipment
   2. Increase in accuracy level of the equipment

b) **The factor training and development has medium effect with weak R square value with**

   Reduction in final defects from quality maintenance pillar

c) The factor training & development has small effect with substantial R square value with

Increase in lean/kaizen projects from focussed improvement pillar

d) The factor training and development has small effect with moderate R square value with

Reduction in inprocess defects from quality maintenance pillar

e) The factor training and development combined with the other factors has small effect with moderate R square value with

From autonomous maintenance pillar

1. Reduction in scheduled down time
2. Reduction in lubrication oil consumption

<u>Hypothesis -4</u>

Information architecture individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.

Table:6.4

Information Architecture							
		Correlation	P value	Beta value (>0.02 Small, >0.15 Medium, >0.35 large)	P value	Average adjusted R square value (0.67 -Substantial, 0.33-Moderate, 0.19-Weak)	P value
Autonomous Maintenance							
1	Reduction of scheduled down time	0.614	<0.001	0.091 with equipment and process	0.118	0.652	<0.001

				management and training and development			
2	Increase in speed/ output from the equipment	0.752	<0.001	0.193 with equipment and Process management and information architecture	<0.01	0.632	<0.001
3	Increase in accuracy level of the equipment	0.532	<0.001	0.241 with equipment and process management and training and development	<0.001	0.393	<0.001
4	Reduction in lubrication oil consumption	0.725	<0.001	0.114 equipment and process management and training and development	0.069	0.617	<0.001
Planned Maintenance							
1	Reduction in scheduled down time	0.062	0.539	0.00	P=1.00	0.118	0.031
2	Reduction in schedule miss due to operations	0.221	0.027	0.290 with monitoring, analysis and improvement	<0.001	0.024	0.188
3	Reduction in breakdown	0.377	<0.001	0.487 with monitoring, analysis and improvement	<0.001	0.127	0.024

Quality maintenance							
1	Reduction in process defects	0.600	<0.001	0.574 with management commitment, equipment and process management and monitoring, analysis and improvement	<0.001	0.327	<0.001
2	Reduction in final defects	0.557	<0.001	0.449 with management commitment, equipment and process management and monitoring, analysis and improvement	<0.001	0.250	<0.001
Focussed improvement							
1	Increase number of lean/kaizen projects	0.607	<0.001	0.109 with monitoring, analysis and improvement	0.079	0.972	<0.001

Reliability and validity

Cronbach's alpha coefficient- The measure of reliability associated the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Composite reliability coefficient- The measure of reliability associated with the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Convergent validity of measurement instrument assessment, the AVE threshold frequently is greater than 0.5 in all the performance indicators from the analysed TPM pillars.

Hence the reliability and validity have been confirmed.

Relation ship between the factor information architecture practices with various TPM performance indicators:

a) **The factor information architecture has significant positive correlation with p value <0.001.**

From autonomous maintenance pillar

1. Reduction in scheduled down time
2. Increase in speed/ output from the equipment
3. Increase in accuracy level of the equipment
4. Reduction in lubrication oil consumption

From planned maintenance pillar

Reduction in breakdown

From quality maintenance pillar:

1. Reduction in process defects/reworks
2. Reduction in final defects

From focussed improvement Pillar

Increase in the lean/kaizen projects

b) The factor information architecture has insignificant positive correlation with

From planned maintenance pillar

1. Reduction in scheduled down time
2. Reduction in schedule miss due to operations

As per the findings of TPM practices and the resulted performance, significant positive correlation of eight performance indicators and insignificant positive correlation of two performance indicators were identified with the factor of information architecture .

The effect of the factor information architecture practices on various TPM performance indicators:

a) The factor information architecture combined other factors has large effect with moderate R square value with

Reduction in inprocess defects/ reworks from quality maintenance Pillar

b) The factor information architecture combined other factors has medium effect with moderate R square value with

From autonomous maintenance pillar

1. Increase in speed/ output from the equipment
2. Increase in accuracy level of the equipment

c) The factor information architecture combined with other factors has large effect with weak R square value with

Reduction in final defects from quality maintenance pillar

d) The factor information architecture combined with the factor has small effect with substantial R square value with

Increase in the lean/kaizen projects from focussed improvement Pillar

The factor information architecture combined with other factors has small effect with moderate R square value with

From autonomous maintenance pillar

1. Reduction in scheduled down time

2. Reduction in lubrication oil consumption

Hypothesis -5

Monitoring , analysis and improvement individually or combined with other factors, has positive effect on the performance of the equipment in TPM practicing engineering companies.

Table :6.5

Monitoring, Analysis & Improvement							
		Correlation	P value	Beta value (>0.02 Small, >0.15 Medium, >0.35 large)	P value	Average adjusted R square value (0.67 Substantial, 0.33- Moderate, 0.19-Weak)	P value
Autonomous Maintenance							
1	Reduction of scheduled down time	0.750	<0.001	0.571	<0.001	0.652	<0.001
2	Increase in speed / output from the equipment	0.487	<0.001	0.036	P=0.319	0.632	<0.001
3	Increase in accuracy level of the equipment	0.497	<0.001	0.101	P=0.094	0.393	<0.001
4	Reduction in lubrication oil consumption	0.610	<0.001	-0.047	P=0.267	0.617	<0.001
Planned Maintenance							
1	Reduction in scheduled down time	0.022	0.826	0.00	P=1.00	0.118	0.031
2	Reduction in schedule miss due to operations	0.210	0.036	0.290 with information architecture	<0.001	0.024	0.188
3	Reduction in	0.379	<0.001	0.487 with	<0.001	0.127	0.024

	breakdown			information architecture			
Quality maintenance							
1	Reduction in process defects	0.578	<0.001	0.574 with management commitment, equipment and process management and information architecture	<0.001	0.327	<0.001
2	Reduction in final defects	0.471	<0.001	0.449 with management commitment, equipment and process management and information architecture	<0.001	0.250	<0.001
Focussed improvement							
1	Increase number of lean/kaizen projects	0.628	<0.001	0.109 with information architecture	0.079	0.972	<0.001

Reliability and validity

Cronbach's alpha coefficient- The measure of reliability associated the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Composite reliability coefficient- The measure of reliability associated with the latent variable is greater than 0.7 in all the performance indicators from the analysed TPM pillars.

Convergent validity of measurement instrument assessment, the AVE threshold frequently is greater than 0.5 in all the performance indicators from the analysed TPM pillars.

Hence the reliability and validity have been confirmed.

Relation ship between the factor Monitoring, Analysis and Improvement practices with various TPM performance indicators:

a) **The factor monitoring, analysis and improvement has significant positive correlation with p value <0.001**

From autonomous maintenance pillar

1. Reduction in scheduled down time
2. Increase in speed/ output from the equipment
3. Increase in accuracy level of the equipment
4. Reduction in oil consumption

From planned maintenance pillar

Reduction in breakdown

From quality maintenance pillar:

1. Reduction in process defects/reworks
2. Reduction in final defects

From focussed improvement Pillar

Increase in the lean/kaizen projects

b) **The factor monitoring, analysis and improvement has insignificant positive correlation with**

Planned maintenance pillar

1. Reduction in scheduled down time
2. Reduction in schedule miss due to operations

As per the findings of TPM practices and the resulted performance, significant positive correlation of eight performance indicators and insignificant positive correlation of two performance indicators were identified with the factor of monitoring, analysis and improvement practices.

The effect of the factor monitoring, analysis and improvement practices on various TPM performance indicators:

a) **The factor Monitoring, Analysis and Improvement has large effect with moderate R square value with**

   Reduction of scheduled down time from autonomous maintenance Pillar

b) **The factor monitoring, analysis and improvement combined with other factors has large effect with moderate R square value with**

   Reduction in process defects/reworks from quality maintenance Pillar

c) **The factor monitoring, analysis and improvement combined with other factors has large effect with weak R square value with**

   Reduction in final defects from quality maintenance pillar

d) **The factor monitoring, analysis and improvement combined with other factors has small effect with substantial R square value with**

   Increase in the lean/kaizen projects from focussed improvement Pillar

d) **The factor monitoring, analysis and improvement has small effect with moderate R square value with**

   Increase in speed/ output from the equipment from autonomous maintenance pillar

6.2. Conclusion of findings.

The findings are based on the composite reliability analysis, cronbach's alpha coefficient ,average variances extracted, covergent validity analysis,discriminat validity analysis and full collinearity VIF.

1. The hypothesis was to assess the positive effect of management commitment individually or combined with other factors, on the performance of equipment in various TPM practicing engineering companies.

In the analysed TPM pillars the independent variable management commitment, which has the indicators of fixing the targets for improvement , assigning responsibilities of the equipment, providing of resources as including training and the periodical review of the planned activities chaired by top management, the continuation of the activities even with the change in persons, and particulaly for the autonomous maintenance and planned maintenance pillars the indicators of clear assigning of the duties of autonomous maintenance and planned maintenance activities. As mentioned above positive correlation is identified for this variable with the performance indicators from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillars.

The findings are

Management commitment has large effect with substantial R square value with increase in lean/kaizen projects from focussed improvement pillar

Management commitment has large effect with moderate R square value with

1. Increase in speed/ output from the equipment 2. Increase in accuracy level of the equipment and 3. Reduction in lubrication oil consumption, from autonomous maintenance pillar

Management commitment combined with other factors has large effect with moderate R square value with reduction in inprocess defects/ reworks from quality maintenance pillar.

Management commitment combined with other factors has large effect with weak R square value with reduction in final defects from quality maintenance pillar

Management commitment has medium effect with moderate R square value with reduction in scheduled down time from autonomous maintenance pillar

The findings revealed the importance of this variable management commitment and its indicators on the performance of the equipment in the success of TPM implementaion.

2. The hypothesis was to assess the positive effect of equipment and process management practices individually or combined with other factors, on the performance of equipment in various TPM practicing engineering companies.

For the autonomous maintenance pillar the indicators used for this independent variable are, operator level actions to remove dirt ,scattered materials, oil leakages, bolt tightening etc on the equipment, cleaning materials , tools , spares etc are to be kept near to equipment, storage procedures for tools, jigs ,etc with routine cleaning are available for the equipment, and the lubrication is to be standardised, monitored and automated.

For the planned maintenance pillar, the indicators used are as maintenance time cycle is established for effective weakness improvement of the equipment, major parts of the equipment prone to wear and tear are put to predictive maintenance, equipment diagnostic technologies as vibration analysis ,and TBM & CBM are used, equipment analysis by instruments and sensors and maintenance cycle are determined, equipment improved for ease of autonomous maintenance, and failure analysis done on the equipment to enhance improvement.

For the quality maintenance pillar the indicators used are, monitoring of inward material for identifying the defects, equipment is monitored regularly for its performance level on quality, monitoring of production done at frequent periods by sensors for identifying the defects, and the analytical tools as pareto analysis, why-why analysis, etc are effectively used in defect analysis.

As mentioned above positive correlation is identified for this variable with the performance indicators of autonomous maintenance ,planned maintenance, and qualty maintenance pillar.

The findings are

Equipment and process management practices combined with other factors has large effect with moderate R square value with reduction in process defects/reworks from quality maintenance Pillar

Equipment and process management combined with other factors has large effect with weak R square value with reduction in final defect from quality maintenance Pillar

Equipment and process management combined with other factors has medium effect with moderate R square value with increase in speed/ output from the equipment and increase in accuracy level of the equipment from autonomous maintenance pillar

Equipment and process management combined with other factors has small effect with moderate R square value with reduction in scheduled down time and reduction in lubrication oil consumption from autonomous maintenance pillar

3. The hypothesis was to assess the positive effect of training and development practices individually or combined with other factors on the performance of equipment in various TPM practicing engineering companies.

For all the analysed pillars the indicators used for this independent variable are, necessary skill requirements identified for the equipment, on the job training programmes are available for the equipment operation for upgradation of the skill of staff members, internal trainers are available for the equipment, retired staff is engaged with training activity to share their experience on the equipment, training conducted by lubricant vendors to solve the problems of the equipment, and video technology supported training done on the equipment and multi skill training on the equipment for operation and maintenance, and increase in employee suggestions/,quality circle participation for the improvement of the equipment

For the autonomous maintenance pillar particularly the indicators are added as, each employee have their own schedule on the equipment operation and maintenance, training by cooperate companies to lead the level of assessment of the equipment, own research and by outside consultants like OEM's for better cleaning and lubrication of the equipment.

For the planned maintenance pillar particularly, the indicators are added as, training done on hydraulics, pneumatics, electrical, and instruments, and for increase in the employee suggestions, quality circle participation for the improvement of the equipment,

For the quality maintenance pillar the particularly, the indicator as necessary training and research to reduce the defects caused by equipment is added.

As mentioned above positive correlation is identified with this variable for the performance indicators of autonomous maintenance ,planned maintenance, quality maintenance and focussed improvement pillar.

The findings are, the variable training and development practices combined with the other factors has medium effect with moderate R square value with increase in speed/ output from the equipment and increase in accuracy level of the equipment from autonomous maintenance pillar

Training and development has medium effect with weak R square value with reduction in final defects from quality maintenance pillar

Training and development has small effect with substantial R square value with increase in lean/kaizen projects from focussed improvement pillar

Training and development has small effect with moderate R square value with reduction in inprocess defects from quality maintenance pillar

Training and development combined with the other factors has small effect with moderate R square value with reduction in scheduled down time and reduction in lubrication oil consumption from autonomous maintenance pillar

4. The hypothesis was to assess the positive effect of information architecture practices individually or combined with other factors on the performance of equipment in various TPM practicing engineering companies.

For all the pillars, the indicators as speedy information processing system and efficient distribution about the performance status of the equipment, and for the pillars of autonomous maintenance and planned maintenance, operators mini manual available with description of production system, machine abnormalities about the equipment, one point lessons available with plant description on the equipment, review of O &M manuals about the equipment done with updated field conditions etc. Particularly for the autonomous maintenance pillar the tags kept on the equipment in problem areas and the contents are transferred to log books and particularly for the pillar of planned maintenance, communication of problems of the equipment from other users with vendors, CMMS used in for the analysis of equipment deterioration, breakdown, spares management, and maintenance requirements of the equipment is published well in advance were added .

For the quality improvement pillar, system is established for information on defective products from the equipment for further tracking, and mistake proofing systems in progress on the equipment were added.

For the focussed improvement pillar the indicators used in the study are speedy information processing and efficient distribution about the performance status of the equipment, the availability of the information on improvements on similar equipments , and the review of loss from the equipment is to be performed regularly for zero loss activity.

As mentioned above for this variable, positive correlation is identified with the performance indicators of autonomous maintenance ,planned maintenance, qualty maintenance and focussed improvement pillar.

The findings are the variable information architecture combined other factors has large effect with moderate R square value with reduction in inprocess defects/ reworks from quality maintenance pillar

Information architecture combined other factors has medium effect with moderate R square value with increase in Increase in speed/ output from the equipment and increase in accuracy level of the equipment from autonomous maintenance pillar

Information architecture combined with other factors has large effect with weak R square value with reduction in final defects from quality maintenance pillar

Information architecture combined with the factor has small effect with substantial R square value with increase in the lean/kaizen projects from focussed improvement Pillar

Information architecture combined with other factors has small effect with moderate R square value with reduction in scheduled down time and reduction in lubrication oil consumption from autonomous maintenance pillar

5. The hypothesis was to assess the positive effect of monitoring , analysis and improvement practices, individually or combined with other factors , on the performance of the equipment in various TPM practicing engineering companies.

For all the pillars the indicators identified are as, the results are reviewed against the targets at frequent period, collection of feed back from the stake holders, the real problems are to be analysed and the reasons are to be identified, and corrective actions done on all the problems

As mentioned above positive correlation is identified for this variable with the performance indicators of autonomous maintenance ,planned maintenance, qualty maintenance and focussed improvement pillar.

The findings are the monitoring, analysis and improvement practices has large effect with moderate R square value with reduction of scheduled down time from autonomous maintenance Pillar

Monitoring, analysis and improvement combined with other factors has large effect with moderate R square value with reduction in process defects/reworks from quality maintenance Pillar

Monitoring, analysis and improvement combined with other factors has large effect with weak R square value with reduction in final defects from quality maintenance Pillar

Monitoring, analysis and improvement combined with other factors has small effect with substantial R square value with increase in the lean/kaizen projects from focussed improvement pillar

Monitoring, analysis and improvement has small effect with moderate R square value with increase in speed/ output from the equipment from autonomous maintenance pillar.

6.3. Recommendations.

Management commitment:

While evaluating the hypothesis, the variable management commitment shown significant positive correlation with nine performance indicators from different TPM pillars.

The variable management commitment has insignificant positive correlation with one performance indicator

The variable management commitment shown the positive effect on various performance indicators of TPM individually or combine with other factors. This variable has positive effect on the performance indicators from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillar, even though for some of them the beta value is small and R square value is weak. So the practices associated with management commitment is positively influencing the results from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillars.

So based on these findings it can be recommended that, the management commitment for improvement as fixing of particular periodical targets for attaining the identified performances from the equipment has to be done.The targets for the improvements of the equipment are to be fixed based on the present performance level. The past data about the performance is to be analysed and based on that data, the next level of the target is to be fixed and a time based action plan is to be done.

The responsibility is to be assigned on equipment wise for attaining the targets, and in case of any change in persons the alternate person is to be assigned for the responsibilities, so that the planned activities are to be continued with the change in persons also.

The top management have to provide the necessary resources for attaining the targets, as arranging provision for training .

The top management have to conduct the periodic review for the progress of activities and to chair the meeting for giving necessary support and corrective measures. In the review the progress of the activities regarding the TPM implementation are to be discussed and the corrective actions are to be done for the various hurdles in the implementation.

The duties of operators and maintenance persons are to be assigned so that the activities are to be carried out smoothly.

Equipment and Process Management:

When evaluating the hypothesis 2 ,the variable equipment and process management shown significant positive correlation with seven performance indicators from different TPM pillars.

The variable equipment and process management has insignificant positive correlation with two performance indicators.

The variable equipment and process management shown the positive effect on various performance indicators of TPM individually or combine with other factors. This variable has positive effect on the performance indicators from autonomous maintenance,planned maintenance, and quality maintenance, even though for some of them the beta value is small and R square value is weak. So the practices associated with equipment and process management is positively influencing the results from autonomous maintenance,planned maintenance, and quality maintenance pillars.

So based on these findings the practices recommended that, in autonomous maintenance activities the routine maintenance activities as the removal of dust , removal of scattered materials as chips, are to be done by the operator. The oil leakages are to be addressed by the operator and the necessary cleaning to be done and the identification of the sources of the leaks are to be done for arresting the leaks. The arresting of the leaks and the corrective actions of the sources are to be done based on the volume of activities to be done.

The conditions of the bolts are to be monitored and tightened wherever required since the looseness is one of the biggest cause of breakdown.The lubrication oils and the necessary tools are to be kept near to the machine so that the concerned persons can easily identify the lubricants and the necessary tools can also be easiliy identified which will eliminate the searching time for the same. The type or name of the lubricant to be used at various points are to be indicated at the spots, and the required levels are to be marked so that the lubrication activities are to be carried out in a smooth manner. The lubrication containers are to be properly labelled. Wherever possible the automated lubrication systems can be used.

The necessary tools required at different spots for the bolts are to be marked and the tools are to be arranged with a proper identification so that the right tool can be used at the first attempt.The tools can be safely chained wherever possible or small tool boxes should be provided.

The planned maintenance activities are to be focussed on the analysis of the breakdown of the equipment and to increase the performance level of the equipment caused by the lower output or speed. The identification of the weaks parts of the equipment is to be done with breakdown analysis. The weak parts are to be modified for the improved performance and output. For the failures on the equipment, the corrective measures to be done based on the root cause analysis as defining the problem, look out the causes including the engineering, operations, maintenance, design, weather, procedure and many others. The actions to be done on the causes for overcoming the reoccurences of the same.

The planned maintenance activities are to be done in line with the manufactures guidelines. The condition based maintenance activities based on the vibration analysis, heat analysis of bearings using sensors are to be done. The time based maintenance, based on the weaker parts or weak equipment identification can also be done. The maintenance schedule can be modified based on the planned maintenance and condition based maintenance activities.

The planned maintenance activities can include the modification of the equipment for the easiness of the autonomous maintenance activities, as for the easy accessability for the cleaning, lubrication and bolt tightening activities.

In quality maintenance, the defects and the reworks are to be analysed for the identification of the root causes, as it is due to the equipment, operators defects or material defects. The necessary actions are to be done for the improvement of the equipment parts which causes the defects or reworks. Wherever possible the sensors can be used in the equipment for easy identification of the defective products.

Training and development .

When evaluating the hypothesis 3, the variable training and development shown significant positive correlation with seven performance indicators and insignificant positive correlation with three performance indicators.

The variable training and development shown the positive effect on various performance indicators of TPM individually or combine with other factors. This variable has positive effect on the performance indicators from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillar, even though for some of them the beta value is small and R square value is weak. So the practices associated with training and development is positively influencing the results from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillars.

The skill requirements for the operators and the maintenance persons are to be done, based on the requirements for the particular equipment. The skills are to be based on the education, experience for identification of the right man for the right job.

Necessary trainings are to be planned based on the identification of the training needs and the trainings are to be conducted as per the plan .On the job trainings are to be conducted for the development of the multiskill workers.

For conducting the training, the equipment manufactures are to be engaged for the delivering all the aspects of the equipment. The retired persons are to be engaged for sharing their experience to the present employees. The internal trainers are to be developed from the organsiation.The video technology training can support the employees for visual understaning of the equipment parts, the working of different parts and the potentail abnormalities. Also the training from the similar companies are to be engaged for the sharing of the best pratices.

The training from the lubricant vendors will support for the better lubrication practices and for the selection of the right lubricants.

Information Architecure :

Information architecture shown the significant positive correlation with eight performance indicators and insignificant positive correlation with two performance indicators.

The variable information architecture shown the positive effect on various performance indicators of TPM individually or combine with other factors. This variable has positive effect on the performance indicators from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillar, even though for some of them the beta value is small and R square value is weak. So the practices associated with Information Architecture is positively influencing the results from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillars.

The information system is to be improved for the speedy processing of the information on the performance of the equipment.

The operators mini manuals are to be reviewed and updated with the field conditions for understading the live status.The mini manual must mention about the operations of the equipment,how the machine works inside with pictures, the standard operating procedures of the machine , how to identify the abnormal operations and the actions to be done,the defects observed by the teams in the past, the detailed readings,grease types,and about cleaning materials and techniques.

The tags are to kept at the abnormal areas of the equipment for the identification and necessary actions by the concerned persons.

For the planned maintenance, the computerised maintenance management system can support for the updation of the performance of the equipment. The data regarding the breakdown parts of the equipment, the frequency of breakdowns and the life of the different spares are to be recorded. Also the generation of the defects and the associated equipment details are to be recorded.

The necessary information from the vendors of the equipment for the planned activities are to be done. The problems of the equipment are to be shared with the vendors. The planned maintenance activities are to be published in advance, so that the activities can be complied with out any delay. The necessary production planning can be done based on the advance receipt of the maintenance planning.

The system is to be established for tracing the defective products from the particular equipment with the time and location of the defects from the equipment for the particular corrective measures. The mistake proofing systems can eliminate or reduce the defects with the information about the right practices for the right products.

For the focussed improvement, the information system about the improvements on similar equipment are to be recorded and used. The data regarding the loss from the equipment are to be recorded which can include the speed loss, energy loss and the data regarding the uneasy activities on the equipment. This information will guide for the improvements on the equipment by the kaizen projects.

Monitoring, Analysis and Improvement

Monitoring, analysis and improvement shown the significant positive correlation with eight performance indicators and insignificant positive correlation with two performance indicators.

The variable monitoring, analysis and improvement shown the positive effect on various performance indicators of TPM individually or combine with other factors. This variable has positive effect on the performance indicators from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillar, even though for some of them the beta value is small and R square value is weak. So the practices associated with Monitoring, analysis and improvement is positively influencing the results from autonomous maintenance,planned maintenance, quality maintenance and focussed improvement pillars.

The fixed targets are to be reviewed for the achieved results at frequent periods. The necessary feed back from the operators and from the maintenance are to be analysed for the proper actions. The various analysis tools including the statistical analysis are to be done for the proper corrective actions. The root cause analysis of the various issues are to be done for the real corrective actions.

So the companies practicing TPM have to strengthen these practices to get results from the equipment through different TPM pillars

6.4. The implications of the study.

Managerial implications :

A number of studies are done on TPM by the previous researchers , about the hurdles faced by the organisations in implementing the practices. This study done on the implementaion of various TPM practices and its effect on performance of the equipment. This can give a fruitful guidance to the management for effectively implemeting the TPM practices for attaining the result from the equipment. The study revealed various factors of TPM implementation and it will give a focussed approch to the management for effective implementation.

Theoritical implications

In this study, the schedule for data collection is designed based on the inputs from the various previous studies on this area ,from the inputs from JIPM questionnaire and from the book 'TPM reloaded' by Joel Levitt. The study verified the level of implementation of the various TPM practices suggested and its results in performance on the equipment. The evaluation of these practices and the results, gives more relevance to the mentioned practices.

The book titled as 'Quality and Reliability Engineering-Recent Trends and Future Directions' based on the 'International conference on quality and reliability' organised by Indian Statistical Institute,Bangalore, includes a chapter based on this research study titled as 'A study on TPM implementation : Factors and Performance'

Implication to the industry;

In the present scenario, the various challenges to the industry are in the realsm of productivity, quality and total quality management. The technological advancements have resulted in the introduction of sophisticated equipment which supports for increased productivity, quality and delivery of products.The upkeep of equipment has its own importance since the condition and performance of the equipment have large role in providing the quality and output of the products. This study on the TPM practices and the effect on equipment have implication on the industry for more understaning about the TPM implementation concepts,and the potentail benefits from equipment to the competitiveness of the industry.

6.5.Limitations of this study.

The study is limited to the relationship and effects of various factors, on TPM performance based on various performance indicators from Autonomous maintenance, Planned maintenance, Quality maintenance and Focussed improvement Pillars. The data collection is done based on the status of TPM practices implemented and the equipment performance attained.

The study done on the critical equipment for which the organisation give high level attention for maintaining so that any issues on the same will affect their production operations directly. There are a number of other equipment in the studied organisation , which are not considered in this study as it would make the study too large .

The study done on the samples of production equipment from the engineering companies only and TPM is practicing in other sectors of industries as process industries and even service sectors also.

The time period of implementation of these practices or the cost -return factors are not considered in this study.

The TPM pillars includes the development management which is associated with the design and development of products or equipments or processes is not covered in this study.

The TPM pillars includes the health, safety and environment pillar also. It is generally measured on company wide and since this study is based on equipment performance these factors are not evaluated.

6.6. Scope for further research.

There is scope for study about the success factors of TPM in different sectors of economy.

There is scope for study on any effect of the duration of implemenation of practices on the performance and also the influence of any organisational cultural factors on the success of TPM.

The study on the cost benefenit analysis by TPM implementation can also be done.

There is scope for study on the pillars TPM as development management, as well as health, safety and environment.

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1. **SEM analysis results of Reduction in Scheduled down time of the equipment from Autonomous Maintenance pillar**

AM1 ALL

```
**********************************
* General SEM analysis results *
**********************************

General project information
---------------------------

Version of WarpPLS used: 4.0

Model fit and quality indices
-----------------------------

Average path coefficient (APC)=0.292, P<0.001
Average R-squared (ARS)=0.663, P<0.001
Average adjusted R-squared (AARS)=0.652, P<0.001
Average block VIF (AVIF)=2.669, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=3.178, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.754, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements
----------------------
Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 4
Number of indicators used in model: 25
Number of iterations to obtain estimates: 5
************************************
* Path coefficients and P values *
************************************
Path coefficients
-----------------
```

	M	E/T/I	MAI	AM1
M				
E/T/I				
MAI				
AM1	0.213	0.091	0.571	

```
P values
--------
```

	M	E/T/I	MAI	AM1
M				
E/T/I				
MAI				
AM1	0.003	0.118	<0.001	

```
****************************************
* Combined loadings and cross-loadings *
****************************************
```

	M	E/T/I	MAI	AM1	Type (a	SE	P value
L 11	0.989	0.015	0.081	-0.101	Reflect	0.076	<0.001
L 12	0.886	-0.322	0.377	0.155	Reflect	0.076	<0.001
L 13	0.896	-0.267	-0.041	0.294	Reflect	0.076	<0.001
L 14	0.937	0.007	0.011	-0.445	Reflect	0.076	<0.001
L 15	0.906	0.152	-0.463	0.462	Reflect	0.076	<0.001
L 16	0.903	0.404	0.035	-0.335	Reflect	0.076	<0.001
PP 13	-0.935	0.818	0.124	0.071	Reflect	0.076	<0.001
PP 14	-0.945	0.704	0.509	0.654	Reflect	0.076	<0.001
TD 11	-0.367	0.888	-0.283	0.067	Reflect	0.076	<0.001
TD 12	-0.186	0.899	-0.254	-0.034	Reflect	0.076	<0.001

AM1 ALL

TD 15	-0.045	0.744	-0.156	0.604	Reflect	0.076	<0.001
TD 16	0.287	0.839	-0.320	0.463	Reflect	0.076	<0.001
TD 18	0.506	0.710	0.514	-0.449	Reflect	0.076	<0.001
TD 19	0.328	0.775	0.073	-0.012	Reflect	0.076	<0.001
TD110	0.369	0.630	-0.469	-0.151	Reflect	0.076	<0.001
TD111	0.071	0.850	0.495	-0.725	Reflect	0.076	<0.001
IM 11	-0.672	0.609	0.072	0.432	Reflect	0.076	<0.001
IM 13	0.594	0.911	-0.103	-0.100	Reflect	0.076	<0.001
IM 14	0.658	0.929	-0.254	-0.201	Reflect	0.076	<0.001
IM 15	0.083	0.825	0.175	-0.401	Reflect	0.076	<0.001
MAI 11	-0.030	-0.068	0.969	0.041	Reflect	0.076	<0.001
MAI 12	-0.030	-0.068	0.969	0.041	Reflect	0.076	<0.001
MAI 13	0.030	0.068	0.969	-0.041	Reflect	0.076	<0.001
MAI 14	0.030	0.068	0.969	-0.041	Reflect	0.076	<0.001
AM 1	-0.000	-0.000	0.000	1.000	Reflect	0.076	<0.001

****

* Normalized combined loadings and cross-loadings *

****

	M	E/T/I	MAI	AM1
L 11	0.610	0.015	0.082	-0.103
L 12	0.592	-0.370	0.432	0.177
L 13	0.600	-0.264	-0.041	0.291
L 14	0.646	0.006	0.008	-0.337
L 15	0.575	0.141	-0.429	0.428
L 16	0.580	0.418	0.036	-0.346
PP 13	-0.545	0.771	0.072	0.041
PP 14	-0.661	0.547	0.356	0.457
TD 11	-0.261	0.763	-0.201	0.048
TD 12	-0.145	0.739	-0.198	-0.026
TD 15	-0.057	0.571	-0.197	0.761
TD 16	0.347	0.565	-0.387	0.560
TD 18	0.574	0.521	0.583	-0.509
TD 19	0.572	0.572	0.127	-0.021
TD110	0.379	0.727	-0.482	-0.155
TD111	0.056	0.640	0.387	-0.566
IM 11	-0.583	0.634	0.063	0.374
IM 13	0.706	0.573	-0.122	-0.119
IM 14	0.645	0.616	-0.249	-0.197
IM 15	0.082	0.651	0.174	-0.399
MAI 11	-0.029	-0.067	0.624	0.041
MAI 12	-0.029	-0.067	0.624	0.041
MAI 13	0.032	0.074	0.604	-0.045
MAI 14	0.032	0.074	0.604	-0.045
AM 1	-0.000	-0.000	0.000	1.000

****

* Latent variable coefficients *

****

R-squared coefficients

M	E/T/I	MAI	AM1
			0.663

Adjusted R-squared coefficients

M	E/T/I	MAI	AM1
			0.652

Composite reliability coefficients

M	E/T/I	MAI	AM1
0.971	0.961	0.984	1.000

AM1 ALL

Cronbach's alpha coefficients

M	E/T/I	MAI	AM1
0.964	0.955	0.979	1.000

Average variances extracted

M	E/T/I	MAI	AM1
0.847	0.642	0.940	1.000

Full collinearity VIFs

M	E/T/I	MAI	AM1
4.073	2.740	3.376	2.525

Q-squared coefficients

M	E/T/I	MAI	AM1
			0.664

****
* Ccorrelations among latent variables and errors *
****

Correlations among l.vs. with sq. rts. of AVEs

	M	E/T/I	MAI	AM1
M	0.920	0.788	0.795	0.707
E/T/I	0.788	0.801	0.676	0.636
MAI	0.795	0.676	0.969	0.750
AM1	0.707	0.636	0.750	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M	E/T/I	MAI	AM1
M	1.000	<0.001	<0.001	<0.001
E/T/I	<0.001	1.000	<0.001	<0.001
MAI	<0.001	<0.001	1.000	<0.001
AM1	<0.001	<0.001	<0.001	1.000

2. SEM analysis results of Increase in Speed/Performance of the equipment from Autonomous Maintenance pillar

AM 2 ALL

```
**********************************
* General SEM analysis results *
**********************************
General project information
---------------------------
Version of WarpPLS used: 4.0

Model fit and quality indices
-----------------------------
Average path coefficient (APC)=0.285, P<0.001
Average R-squared (ARS)=0.643, P<0.001
Average adjusted R-squared (AARS)=0.632, P<0.001
Average block VIF (AVIF)=4.366, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=3.168, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.742, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.

General model elements
-----------------------
Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 4
Number of indicators used in model: 24
Number of iterations to obtain estimates: 5

**********************************
* Path coefficients and P values *
**********************************
Path coefficients
-----------------
```

	M	E/T/I	MAI	AM3
M				
E/T/I				
MAI				
AM3	0.627	0.193	0.036	

P values

	M	E/T/I	MAI	AM3
M				
E/T/I				
MAI				
AM3	<0.001	0.006	0.319	

```
****************************************
* Combined loadings and cross-loadings *
****************************************
```

	M	E/T/I	MAI	AM3	Type (a	SE	P value
L 11	0.989	-0.004	0.007	-0.008	Reflect	0.076	<0.001
L 12	0.886	-0.188	0.338	-0.336	Reflect	0.076	<0.001
L 13	0.896	-0.236	0.099	-0.016	Reflect	0.076	<0.001
L 14	0.937	-0.077	-0.225	0.089	Reflect	0.076	<0.001
L 15	0.906	0.177	-0.163	0.079	Reflect	0.076	<0.001
L 16	0.903	0.324	-0.039	0.183	Reflect	0.076	<0.001
PP 1	0.913	0.782	-0.339	-0.105	Reflect	0.076	<0.001
PP 1	-1.104	0.797	0.298	0.170	Reflect	0.076	<0.001
TD 11	-0.411	0.887	-0.143	-0.136	Reflect	0.076	<0.001
TD 1	-0.111	0.905	-0.247	-0.285	Reflect	0.076	<0.001

AM 3ALL

TD	1	0.058	0.716	0.231	-0.120	Reflect	0.076	<0.001
TD	1	0.387	0.835	-0.045	-0.119	Reflect	0.076	<0.001
TD	1	0.160	0.713	0.388	0.407	Reflect	0.076	<0.001
TD	1	0.305	0.779	0.121	-0.152	Reflect	0.076	<0.001
TD110		0.204	0.653	-0.408	-0.204	Reflect	0.076	<0.001
TD111		-0.265	0.864	0.236	0.146	Reflect	0.076	<0.001
IM	1	-0.487	0.588	0.290	-0.216	Reflect	0.076	<0.001
IM	1	0.484	0.942	-0.274	0.135	Reflect	0.076	<0.001
IM	1	-0.191	0.830	0.036	0.417	Reflect	0.076	<0.001
MAI		0.074	-0.040	0.969	-0.096	Reflect	0.076	<0.001
MAI		0.074	-0.040	0.969	-0.096	Reflect	0.076	<0.001
MAI	1	-0.074	0.040	0.969	0.096	Reflect	0.076	<0.001
MAI	1	-0.074	0.040	0.969	0.096	Reflect	0.076	<0.001
AM3		-0.000	0.000	0.000	1.000	Reflect	0.076	<0.001

****

* Normalized combined loadings and cross-loadings *

****

		M	E/T/I	MAI	AM3
L	11	0.608	-0.004	0.007	-0.008
L	12	0.628	-0.170	0.305	-0.304
L	13	0.624	-0.226	0.095	-0.016
L	14	0.620	-0.066	-0.195	0.078
L	15	0.586	0.200	-0.184	0.090
L	16	0.563	0.483	-0.059	0.272
PP	1	0.881	0.567	-0.327	-0.101
PP	1	-0.615	0.733	0.166	0.095
TD	11	-0.278	0.733	-0.097	-0.092
TD	1	-0.079	0.715	-0.175	-0.202
TD	1	0.089	0.579	0.351	-0.183
TD	1	0.510	0.589	-0.059	-0.157
TD	1	0.274	0.507	0.663	0.695
TD	1	0.460	0.577	0.183	-0.230
TD110		0.197	0.716	-0.396	-0.198
TD111		-0.292	0.618	0.260	0.161
IM	1	-0.430	0.657	0.256	-0.191
IM	1	0.564	0.594	-0.319	0.157
IM	1	-0.235	0.612	0.044	0.514
MAI		0.074	-0.040	0.674	-0.097
MAI		0.074	-0.040	0.674	-0.097
MAI	1	-0.077	0.042	0.646	0.101
MAI	1	-0.077	0.042	0.646	0.101
AM3		-0.000	0.000	0.000	1.000

****

* Latent variable coefficients *

****

R-squared coefficients

M	E/T/I	MAI	AM3
			0.643

Adjusted R-squared coefficients

M	E/T/I	MAI	AM3
			0.632

Composite reliability coefficients

M	E/T/I	MAI	AM3
0.971	0.957	0.984	1.000

Cronbach's alpha coefficients

M	E/T/I	MAI	AM3
0.964	0.950	0.979	1.000

Average variances extracted

M	E/T/I	MAI	AM3
0.847	0.636	0.940	1.000

Full collinearity VIFs

M	E/T/I	MAI	AM3
4.721	3.060	2.785	2.104

Q-squared coefficients

M	E/T/I	MAI	AM3
			0.595

****
* Ccorrelations among latent variables and errors *
****

Correlations among l.vs. with sq. rts. of AVEs

	M	E/T/I	MAI	AM3
M	0.920	0.794	0.795	0.677
E/T/I	0.794	0.798	0.655	0.682
MAI	0.795	0.655	0.969	0.487
AM3	0.677	0.682	0.487	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M	E/T/I	MAI	AM3
M	1.000	<0.001	<0.001	<0.001
E/T/I	<0.001	1.000	<0.001	<0.001
MAI	<0.001	<0.001	1.000	<0.001
AM3	<0.001	<0.001	<0.001	1.000

3. SEM analysis results of Increase in accuracy level of the equipment from Autonomous Maintenance pillar

AM 3 ALL

```
*********************************
* General SEM analysis results *
*********************************
General project information
---------------------------
Version of WarpPLS used: 4.0

Model fit and quality indices
-----------------------------
Average path coefficient (APC)=0.233, P<0.001
Average R-squared (ARS)=0.412, P<0.001
Average adjusted R-squared (AARS)=0.393, P<0.001
Average block VIF (AVIF)=2.671, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=2.778, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.593, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements
----------------------
Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 4
Number of indicators used in model: 21
Number of iterations to obtain estimates: 5

**********************************
* Path coefficients and P values *
**********************************
Path coefficients
-----------------

        M       E/T/I   MAI     AM 4
M
E/T/I
MAI
AM 4    0.358   0.241   0.101

P values
--------

        M       E/T/I   MAI     AM 4
M
E/T/I
MAI
AM 4    <0.001  0.001   0.094


****************************************
* Combined loadings and cross-loadings *
****************************************

        M       E/T/I   MAI     AM 4    Type (a SE      P value
   L  1 0.988   0.088   0.004   0.036   Reflect 0.076   <0.001
   L  1 0.912   -0.334  0.382   0.222   Reflect 0.076   <0.001
   L  1 0.917   -0.189  0.066   -0.142  Reflect 0.076   <0.001
   L  1 0.920   0.151   -0.246  -0.177  Reflect 0.076   <0.001
   L  1 0.898   0.281   -0.208  0.061   Reflect 0.076   <0.001
   PP   0.745   0.799   -0.304  -0.058  Reflect 0.076   <0.001
   PP   -1.075  0.771   0.294   0.092   Reflect 0.076   <0.001
   TD 1 -0.545  0.847   -0.087  0.131   Reflect 0.076   <0.001
                                   Page 1
```

TD	0.309	0.771	-0.193	0.307	Reflect	0.076	<0.001
TD	-0.051	0.683	0.264	0.222	Reflect	0.076	<0.001
TD	0.434	0.758	0.295	-0.330	Reflect	0.076	<0.001
TD	0.269	0.783	0.094	0.007	Reflect	0.076	<0.001
TD11	0.325	0.636	-0.483	-0.326	Reflect	0.076	<0.001
TD11	-0.166	0.878	0.227	-0.286	Reflect	0.076	<0.001
IM	-0.890	0.592	0.272	0.681	Reflect	0.076	<0.001
IM	0.500	0.946	-0.289	-0.107	Reflect	0.076	<0.001
IM	-0.064	0.854	-0.022	-0.144	Reflect	0.076	<0.001
MAI	-0.044	-0.081	0.987	0.114	Reflect	0.076	<0.001
MAI	-0.044	-0.081	0.987	0.114	Reflect	0.076	<0.001
MAI	0.093	0.169	0.944	-0.238	Reflect	0.076	<0.001
AM4	-0.000	0.000	0.000	1.000	Reflect	0.076	<0.001

****
* Normalized combined loadings and cross-loadings *
****

	M	E/T/I	MAI	AM 4
L 1	0.609	0.098	0.004	0.040
L 1	0.606	-0.370	0.422	0.246
L 1	0.646	-0.169	0.059	-0.127
L 1	0.631	0.129	-0.209	-0.151
L 1	0.601	0.317	-0.234	0.068
PP	0.808	0.588	-0.330	-0.063
PP	-0.606	0.801	0.166	0.052
TD 1	-0.393	0.764	-0.062	0.095
TD	0.452	0.584	-0.283	0.450
TD	-0.092	0.558	0.476	0.401
TD	0.595	0.578	0.404	-0.453
TD	0.470	0.589	0.164	0.013
TD11	0.294	0.792	-0.438	-0.295
TD11	-0.153	0.684	0.208	-0.262
IM	-0.648	0.633	0.198	0.495
IM	0.501	0.639	-0.289	-0.107
IM	-0.063	0.696	-0.022	-0.143
MAI	-0.043	-0.078	0.656	0.111
MAI	-0.043	-0.078	0.656	0.111
MAI	0.100	0.182	0.649	-0.257
AM4	-0.000	0.000	0.000	1.000

****
* Latent variable coefficients *
****

R-squared coefficients

M	E/T/I	MAI	AM 4
			0.412

Adjusted R-squared coefficients

M	E/T/I	MAI	AM 4
			0.393

Composite reliability coefficients

M	E/T/I	MAI	AM 4
0.969	0.949	0.982	1.000

AM 3 ALL

Cronbach's alpha coefficients

M	E/T/I	MAI	AM 4
0.959	0.940	0.972	1.000

Average variances extracted

M	E/T/I	MAI	AM 4
0.860	0.612	0.947	1.000

Full collinearity VIFs

M	E/T/I	MAI	AM 4
4.180	2.572	2.729	1.629

Q-squared coefficients

M	E/T/I	MAI	AM 4
			0.430

****

* Ccorrelations among latent variables and errors *

****

Correlations among l.vs. with sq. rts. of AVEs

	M	E/T/I	MAI	AM 4
M	0.928	0.775	0.792	0.613
E/T/I	0.775	0.783	0.659	0.532
MAI	0.792	0.659	0.973	0.522
AM 4	0.613	0.532	0.522	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M	E/T/I	MAI	AM 4
M	1.000	<0.001	<0.001	<0.001
E/T/I	<0.001	1.000	<0.001	<0.001
MAI	<0.001	<0.001	1.000	<0.001
AM 4	<0.001	<0.001	<0.001	1.000

4. SEM analysis results of Reduction in lubrication oil consumption of the equipment from Autonomous Maintenance pillar

~~AM ALL~~ AM4

```
*********************************
* General SEM analysis results *
*********************************

General project information
---------------------------
Version of WarpPLS used: 4.0

Model fit and quality indices
-----------------------------
Average path coefficient (APC)=0.283, P<0.001
Average R-squared (ARS)=0.628, P<0.001
Average adjusted R-squared (AARS)=0.617, P<0.001
Average block VIF (AVIF)=5.839, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=3.098, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.731, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=0.667, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=0.958, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements
----------------------
Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 4
Number of indicators used in model: 22
Number of iterations to obtain estimates: 5

***********************************
* Path coefficients and P values *
***********************************

Path coefficients
-----------------
```

	M	E/T/I	MAI	AM5
M				
E/T/I				
MAI				
AM5	0.688	0.114	-0.047	

```
P values
--------
```

	M	E/T/I	MAI	AM5
M				
E/T/I				
MAI				
AM5	<0.001	0.069	0.267	

```
*****************************************
* Combined loadings and cross-loadings *
*****************************************
```

	M	E/T/I	MAI	AM5	Type (a	SE	P value
L 1	0.988	0.080	-0.012	-0.003	Reflect	0.076	<0.001
L 1	0.912	-0.196	0.338	-0.533	Reflect	0.076	<0.001
L 1	0.917	-0.163	0.068	0.082	Reflect	0.076	<0.001
L 1	0.920	0.013	-0.164	0.257	Reflect	0.076	<0.001
L 1	0.898	0.265	-0.231	0.197	Reflect	0.076	<0.001
PP	-0.695	0.838	0.063	-0.055	Reflect	0.076	<0.001
PP	-0.259	0.766	0.589	-0.336	Reflect	0.076	<0.001

AM &P ALL

TD 1	0.083	0.897	-0.391	-0.301	Reflect	0.076	<0.001
TD	0.401	0.904	-0.434	-0.491	Reflect	0.076	<0.001
TD	0.126	0.542	-0.373	0.858	Reflect	0.076	<0.001
TD	0.506	0.759	0.000	-0.334	Reflect	0.076	<0.001
TD	0.407	0.820	-0.092	-0.027	Reflect	0.076	<0.001
TD	-0.334	0.704	0.338	0.900	Reflect	0.076	<0.001
TD	0.376	0.771	0.006	0.061	Reflect	0.076	<0.001
TD11	-0.316	0.820	0.214	0.237	Reflect	0.076	<0.001
IM	0.279	0.624	0.145	-0.881	Reflect	0.076	<0.001
IM	-0.508	0.813	0.009	0.619	Reflect	0.076	<0.001
MAI	0.149	-0.029	0.969	-0.166	Reflect	0.076	<0.001
MAI	0.149	-0.029	0.969	-0.166	Reflect	0.076	<0.001
MAI	-0.149	0.029	0.969	0.166	Reflect	0.076	<0.001
MAI	-0.149	0.029	0.969	0.166	Reflect	0.076	<0.001
AM5	-0.000	-0.000	-0.000	1.000	Reflect	0.076	<0.001

****
* Normalized combined loadings and cross-loadings *
****

	M	E/T/I	MAI	AM5
L 1	0.596	0.085	-0.013	-0.003
L 1	0.621	-0.143	0.247	-0.389
L 1	0.605	-0.173	0.072	0.087
L 1	0.608	0.014	-0.185	0.290
L 1	0.569	0.311	-0.272	0.232
PP	-0.456	0.805	0.042	-0.036
PP	-0.245	0.635	0.559	-0.319
TD 1	0.060	0.780	-0.282	-0.217
TD	0.279	0.756	-0.302	-0.342
TD	0.132	0.519	-0.391	0.899
TD	0.599	0.600	0.001	-0.396
TD	0.552	0.578	-0.125	-0.037
TD	-0.325	0.483	0.329	0.876
TD	0.650	0.565	0.011	0.105
TD11	-0.355	0.621	0.241	0.266
IM	0.217	0.730	0.113	-0.684
IM	-0.448	0.621	0.008	0.546
MAI	0.149	-0.029	0.645	-0.166
MAI	0.149	-0.029	0.645	-0.166
MAI	-0.151	0.030	0.629	0.168
MAI	-0.151	0.030	0.629	0.168
AM5	-0.000	-0.000	-0.000	1.000

****
* Latent variable coefficients *
****

R-squared coefficients

M	E/T/I	MAI	AM5
			0.628

Adjusted R-squared coefficients

M	E/T/I	MAI	AM5
			0.617

AM & ALL

Composite reliability coefficients

M	E/T/I	MAI	AM5
0.969	0.948	0.984	1.000

Cronbach's alpha coefficients

M	E/T/I	MAI	AM5
0.959	0.938	0.979	1.000

Average variances extracted

M	E/T/I	MAI	AM5
0.860	0.605	0.940	1.000

Full collinearity VIFs

M	E/T/I	MAI	AM5
4.663	2.319	2.869	2.542

Q-squared coefficients

M	E/T/I	MAI	AM5
			0.678

****
* Ccorrelations among latent variables and errors *
****

Correlations among l.vs. with sq. rts. of AVEs

	M	E/T/I	MAI	AM5
M	0.928	0.732	0.794	0.775
E/T/I	0.732	0.778	0.679	0.618
MAI	0.794	0.679	0.969	0.610
AM5	0.775	0.618	0.610	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M	E/T/I	MAI	AM5
M	1.000	<0.001	<0.001	<0.001
E/T/I	<0.001	1.000	<0.001	<0.001
MAI	<0.001	<0.001	1.000	<0.001
AM5	<0.001	<0.001	<0.001	1.000

C

5. SEM analysis results of Reduction in Scheduled down time of the equipment from Planned maintenance pillar

```
                                              PM1 ALL
********************************
* General SEM analysis results *
********************************
General project information
---------------------------

Version of WarpPLS used: 4.0

Model fit and quality indices
-----------------------------
Average path coefficient (APC)=0.356, P<0.001
Average R-squared (ARS)=0.127, P=0.025
Average adjusted R-squared (AARS)=0.118, P=0.031
Average block VIF (AVIF)=Inf, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=2.864, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.328, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements
----------------------
Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 3
Number of indicators used in model: 29
Number of iterations to obtain estimates: 6

*********************************
* Path coefficients and P values *
*********************************
Path coefficients
-----------------
        M/E/T   I/MA    PM1
M/E/T
I/MA
PM1     0.356

P values
--------
        M/E/T   I/MA    PM1
M/E/T
I/MA
PM1     <0.001

****************************************
* Combined loadings and cross-loadings *
****************************************

        M/E/T   I/MA    PM1     Type (a SE      P value
L  11   0.971   -0.276  0.121   Reflect 0.076   <0.001
L  12   0.971   -0.276  0.121   Reflect 0.076   <0.001
L  13   0.573   0.619   -0.476  Reflect 0.076   <0.001
L  15   0.971   -0.276  0.121   Reflect 0.076   <0.001
L  16   0.716   1.303   0.010   Reflect 0.076   <0.001
PP  11  0.687   -1.050  -0.277  Reflect 0.076   <0.001
PP  12  0.971   -0.276  0.121   Reflect 0.076   <0.001
PP  13  0.971   -0.276  0.121   Reflect 0.076   <0.001
PP  14  0.749   -1.174  0.143   Reflect 0.076   <0.001
PP  15  0.716   1.303   0.010   Reflect 0.076   <0.001
PP  16  0.953   0.160   -0.183  Reflect 0.076   <0.001
TD 11   0.971   -0.276  0.121   Reflect 0.076   <0.001
                                          Page 1
```

PM1 ALL

TD	12	0.971	-0.276	0.121	Reflect	0.076	<0.001
TD	14	0.573	0.619	-0.476	Reflect	0.076	<0.001
TD	16	0.971	-0.276	0.121	Reflect	0.076	<0.001
TD	17	0.971	-0.276	0.121	Reflect	0.076	<0.001
TD	18	0.573	0.619	-0.476	Reflect	0.076	<0.001
TD	19	0.716	1.303	0.010	Reflect	0.076	<0.001
IM	11	-0.386	0.978	0.010	Reflect	0.076	<0.001
IM	12	-0.386	0.978	0.010	Reflect	0.076	<0.001
IM	13	-0.386	0.978	0.010	Reflect	0.076	<0.001
IM	14	0.431	0.965	0.072	Reflect	0.076	<0.001
IM	15	-0.386	0.978	0.010	Reflect	0.076	<0.001
IM	16	0.153	0.649	-0.476	Reflect	0.076	<0.001
IM	17	-0.386	0.978	0.010	Reflect	0.076	<0.001
IM	18	-0.386	0.978	0.010	Reflect	0.076	<0.001
MAI	11	1.178	0.744	0.121	Reflect	0.076	<0.001
MAI	12	1.178	0.744	0.121	Reflect	0.076	<0.001
PM	1	-0.000	0.000	1.000	Reflect	0.076	<0.001

****

* Normalized combined loadings and cross-loadings *

****

		M/E/T	I/MA	PM1
L	11	0.770	-0.227	0.099
L	12	0.770	-0.227	0.099
L	13	0.662	0.778	-0.598
L	15	0.770	-0.227	0.099
L	16	0.590	0.959	0.007
PP	11	0.891	-0.535	-0.141
PP	12	0.770	-0.227	0.099
PP	13	0.770	-0.227	0.099
PP	14	0.852	-0.565	0.069
PP	15	0.590	0.959	0.007
PP	16	0.740	0.179	-0.205
TD	11	0.770	-0.227	0.099
TD	12	0.770	-0.227	0.099
TD	14	0.662	0.778	-0.598
TD	16	0.770	-0.227	0.099
TD	17	0.770	-0.227	0.099
TD	18	0.662	0.778	-0.598
TD	19	0.590	0.959	0.007
IM	11	-0.284	0.806	0.007
IM	12	-0.284	0.806	0.007
IM	13	-0.284	0.806	0.007
IM	14	0.590	0.708	0.099
IM	15	-0.284	0.806	0.007
IM	16	0.192	0.749	-0.598
IM	17	-0.284	0.806	0.007
IM	18	-0.284	0.806	0.007
MAI	11	0.969	0.590	0.099
MAI	12	0.969	0.590	0.099
PM	1	-0.000	0.000	1.000

****

* Latent variable coefficients *

****

R-squared coefficients

M/E/T	I/MA	PM1
		0.127

PM1 ALL

Adjusted R-squared coefficients

M/E/T	I/MA	PM1
		0.118

Composite reliability coefficients

M/E/T	I/MA	PM1
0.978	0.978	1.000

Cronbach's alpha coefficients

M/E/T	I/MA	PM1
0.975	0.973	1.000

Average variances extracted

M/E/T	I/MA	PM1
0.720	0.820	1.000

Full collinearity VIFs

M/E/T	I/MA	PM1
3.842	3.635	1.116

Q-squared coefficients

M/E/T	I/MA	PM1
		0.144

****
* correlations among latent variables and errors *
****

Correlations among l.vs. with sq. rts. of AVEs

	M/E/T	I/MA	PM1
M/E/T	0.848	0.844	0.256
I/MA	0.844	0.906	0.111
PM1	0.256	0.111	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M/E/T	I/MA	PM1
M/E/T	1.000	<0.001	0.010
I/MA	<0.001	1.000	0.272
PM1	0.010	0.272	1.000

6. SEM analysis results of Reduction in Schedule miss due to operations of the equipment from Planned maintenance pillar

PM 3 ALL

****

* General SEM analysis results *

****

General project information

Version of WarpPLS used: 4.0

Model fit and quality indices

Average path coefficient (APC)=0.197, P=0.003
Average R-squared (ARS)=0.044, P=0.141
Average adjusted R-squared (AARS)=0.024, P=0.188
Average block VIF (AVIF)=3.486, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=2.706, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.193, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=0.500, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=0.800, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=0.500, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements

Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 3
Number of indicators used in model: 29
Number of iterations to obtain estimates: 6

****

* Path coefficients and P values *

****

Path coefficients

	M/E/T	I/M	PM3
M/E/T			
I/M			
PM3	-0.104	0.290	

P values

	M/E/T	I/M	PM3
M/E/T			
I/M			
PM3	0.088	<0.001	

****

* Combined loadings and cross-loadings *

****

	M/E/T	I/M	PM3	Type (a	SE	P value
L 11	0.971	-0.249	-0.195	Reflect	0.076	<0.001
L 12	0.971	-0.249	-0.195	Reflect	0.076	<0.001
L 13	0.573	0.511	0.770	Reflect	0.076	<0.001
L 15	0.971	-0.249	-0.195	Reflect	0.076	<0.001
L 16	0.716	1.305	-0.016	Reflect	0.076	<0.001
PP 11	0.687	-1.113	0.448	Reflect	0.076	<0.001
PP 12	0.971	-0.249	-0.195	Reflect	0.076	<0.001
PP 13	0.971	-0.249	-0.195	Reflect	0.076	<0.001
PP 14	0.749	-1.141	-0.232	Reflect	0.076	<0.001
PP 15	0.716	1.305	-0.016	Reflect	0.076	<0.001
PP 16	0.953	0.118	0.296	Reflect	0.076	<0.001
TD 11	0.971	-0.249	-0.195	Reflect	0.076	<0.001
TD 12	0.971	-0.249	-0.195	Reflect	0.076	<0.001
TD 14	0.573	0.511	0.770	Reflect	0.076	<0.001

Page 1

						PM 2 ALL	
TD	16	0.971	-0.249	-0.195	Reflect	0.076	<0.001
TD	17	0.971	-0.249	-0.195	Reflect	0.076	<0.001
TD	18	0.573	0.511	0.770	Reflect	0.076	<0.001
TD	19	0.716	1.305	-0.016	Reflect	0.076	<0.001
IM	11	-0.383	0.978	-0.016	Reflect	0.076	<0.001
IM	12	-0.383	0.978	-0.016	Reflect	0.076	<0.001
IM	13	-0.383	0.978	-0.016	Reflect	0.076	<0.001
IM	14	0.452	0.965	-0.117	Reflect	0.076	<0.001
IM	15	-0.383	0.978	-0.016	Reflect	0.076	<0.001
IM	16	0.012	0.649	0.770	Reflect	0.076	<0.001
IM	17	-0.383	0.978	-0.016	Reflect	0.076	<0.001
IM	18	-0.383	0.978	-0.016	Reflect	0.076	<0.001
MAI	11	1.214	0.744	-0.195	Reflect	0.076	<0.001
MAI	12	1.214	0.744	-0.195	Reflect	0.076	<0.001
PM 3		-0.000	0.000	1.000	Reflect	0.076	<0.001

****
* Normalized combined loadings and cross-loadings *
****

		M/E/T	I/M	PM3
L	11	0.793	-0.198	-0.156
L	12	0.793	-0.198	-0.156
L	13	0.608	0.553	0.833
L	15	0.793	-0.198	-0.156
L	16	0.582	0.959	-0.012
PP	11	0.911	-0.567	0.229
PP	12	0.793	-0.198	-0.156
PP	13	0.793	-0.198	-0.156
PP	14	0.925	-0.542	-0.110
PP	15	0.582	0.959	-0.012
PP	16	0.735	0.137	0.342
TD	11	0.793	-0.198	-0.156
TD	12	0.793	-0.198	-0.156
TD	14	0.608	0.553	0.833
TD	16	0.793	-0.198	-0.156
TD	17	0.793	-0.198	-0.156
TD	18	0.608	0.553	0.833
TD	19	0.582	0.959	-0.012
IM	11	-0.282	0.796	-0.012
IM	12	-0.282	0.796	-0.012
IM	13	-0.282	0.796	-0.012
IM	14	0.594	0.712	-0.153
IM	15	-0.282	0.796	-0.012
IM	16	0.013	0.687	0.833
IM	17	-0.282	0.796	-0.012
IM	18	-0.282	0.796	-0.012
MAI	11	0.968	0.608	-0.156
MAI	12	0.968	0.608	-0.156
PM 3		-0.000	0.000	1.000

****
* Latent variable coefficients *
****

R-squared coefficients

M/E/T	I/M	PM3
		0.044

PM 3 ALL

Adjusted R-squared coefficients

M/E/T	I/M	PM3
		0.024

Composite reliability coefficients

M/E/T	I/M	PM3
0.978	0.978	1.000

Cronbach's alpha coefficients

M/E/T	I/M	PM3
0.975	0.973	1.000

Average variances extracted

M/E/T	I/M	PM3
0.720	0.820	1.000

Full collinearity VIFs

M/E/T	I/M	PM3
3.497	3.574	1.046

Q-squared coefficients

M/E/T	I/M	PM3
		0.123

* Ccorrelations among latent variables and errors *

Correlations among l.vs. with sq. rts. of AVEs

	M/E/T	I/M	PM3
M/E/T	0.848	0.844	0.141
I/M	0.844	0.906	0.202
PM3	0.141	0.202	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M/E/T	I/M	PM3
M/E/T	1.000	<0.001	0.162
I/M	<0.001	1.000	0.044
PM3	0.162	0.044	1.000

7.SEM analysis results of Reduction in breakdown of the equipment from Planned maintenance pillar

PM 4 ALL

****
* General SEM analysis results *
****

General project information

Version of WarpPLS used: 4.0

Model fit and quality indices

Average path coefficient (APC)=0.310, P<0.001
Average R-squared (ARS)=0.145, P=0.015
Average adjusted R-squared (AARS)=0.127, P=0.024
Average block VIF (AVIF)=3.486, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=2.813, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.350, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=0.500, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=0.831, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=0.500, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements

Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 3
Number of indicators used in model: 29
Number of iterations to obtain estimates: 6

****
* Path coefficients and P values *
****

Path coefficients

	M/E/T	I/M	PM 4
M/E/T			
I/M			
PM 4	-0.133	0.487	

P values

	M/E/T	I/M	PM 4
M/E/T			
I/M			
PM 4	0.041	<0.001	

****
* Combined loadings and cross-loadings *
****

	M/E/T	I/M	PM 4	Type (a	SE	P value
L 11	0.971	-0.376	0.083	Reflect	0.076	<0.001
L 12	0.971	-0.376	0.083	Reflect	0.076	<0.001
L 13	0.573	1.012	-0.326	Reflect	0.076	<0.001
L 15	0.971	-0.376	0.083	Reflect	0.076	<0.001
L 16	0.716	1.294	0.007	Reflect	0.076	<0.001
P 11	0.687	-0.821	-0.190	Reflect	0.076	<0.001
P 12	0.971	-0.376	0.083	Reflect	0.076	<0.001
P 13	0.971	-0.376	0.083	Reflect	0.076	<0.001
P 14	0.749	-1.292	0.098	Reflect	0.076	<0.001
P 15	0.716	1.294	0.007	Reflect	0.076	<0.001
P 16	0.953	0.311	-0.125	Reflect	0.076	<0.001
TD 11	0.971	-0.376	0.083	Reflect	0.076	<0.001
TD 12	0.971	-0.376	0.083	Reflect	0.076	<0.001
TD 14	0.573	1.012	-0.326	Reflect	0.076	<0.001

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Pm3
PM ~~4~~ ALL

TD	16	0.971	-0.376	0.083	Reflect	0.076	<0.001
TD	17	0.971	-0.376	0.083	Reflect	0.076	<0.001
TD	18	0.573	1.012	-0.326	Reflect	0.076	<0.001
TD	19	0.716	1.294	0.007	Reflect	0.076	<0.001
IM	11	-0.379	0.978	0.007	Reflect	0.076	<0.001
IM	12	-0.379	0.978	0.007	Reflect	0.076	<0.001
IM	13	-0.379	0.978	0.007	Reflect	0.076	<0.001
IM	14	0.487	0.965	0.050	Reflect	0.076	<0.001
IM	15	-0.379	0.978	0.007	Reflect	0.076	<0.001
IM	16	-0.218	0.649	-0.326	Reflect	0.076	<0.001
IM	17	-0.379	0.978	0.007	Reflect	0.076	<0.001
IM	18	-0.379	0.978	0.007	Reflect	0.076	<0.001
MAI	11	1.272	0.744	0.083	Reflect	0.076	<0.001
MAI	12	1.272	0.744	0.083	Reflect	0.076	<0.001
PM 4		-0.000	0.000	1.000	Reflect	0.076	<0.001

```
*****************************************************
* Normalized combined loadings and cross-loadings *
*****************************************************
```

		M/E/T	I/M	PM 4
L	11	0.778	-0.283	0.062
L	12	0.778	-0.283	0.062
L	13	0.648	0.932	-0.300
L	15	0.778	-0.283	0.062
L	16	0.563	0.960	0.005
PP	11	0.930	-0.498	-0.115
PP	12	0.778	-0.283	0.062
PP	13	0.778	-0.283	0.062
PP	14	0.925	-0.578	0.044
PP	15	0.563	0.960	0.005
PP	16	0.733	0.393	-0.159
TD	11	0.778	-0.283	0.062
TD	12	0.778	-0.283	0.062
TD	14	0.648	0.932	-0.300
TD	16	0.778	-0.283	0.062
TD	17	0.778	-0.283	0.062
TD	18	0.648	0.932	-0.300
TD	19	0.563	0.960	0.005
IM	11	-0.281	0.770	0.005
IM	12	-0.281	0.770	0.005
IM	13	-0.281	0.770	0.005
IM	14	0.678	0.692	0.069
IM	15	-0.281	0.770	0.005
IM	16	-0.201	0.733	-0.300
IM	17	-0.281	0.770	0.005
IM	18	-0.281	0.770	0.005
MAI	11	0.957	0.596	0.062
MAI	12	0.957	0.596	0.062
PM 4		-0.000	0.000	1.000

```
********************************
* Latent variable coefficients *
********************************
```

R-squared coefficients

M/E/T	I/M	PM 4
		0.145

Adjusted R-squared coefficients

M/E/T	I/M	PM 4
		0.127

Page 2

PM 4 ALL

Composite reliability coefficients

M/E/T	I/M	PM 4
0.978	0.978	1.000

Cronbach's alpha coefficients

M/E/T	I/M	PM 4
0.975	0.973	1.000

Average variances extracted

M/E/T	I/M	PM 4
0.720	0.820	1.000

Full collinearity VIFs

M/E/T	I/M	PM 4
3.507	3.763	1.170

Q-squared coefficients

M/E/T	I/M	PM 4
		0.155

****
* Ccorrelations among latent variables and errors *
****

Correlations among l.vs. with sq. rts. of AVEs

	M/E/T	I/M	PM 4
M/E/T	0.848	0.844	0.278
I/M	0.844	0.906	0.374
PM 4	0.278	0.374	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M/E/T	I/M	PM 4
M/E/T	1.000	<0.001	0.005
I/M	<0.001	1.000	<0.001
PM 4	0.005	<0.001	1.000

8. SEM analysis results of Reduction in inprocess rejections/reworks from the equipment from Quality Maintenance pillar

```
                                      QM1 ALL
*********************************
* General SEM analysis results *
*********************************
General project information
---------------------------
Version of WarpPLS used: 4.0

Model fit and quality indices
-----------------------------
Average path coefficient (APC)=0.306, P<0.001
Average R-squared (ARS)=0.341, P<0.001
Average adjusted R-squared (AARS)=0.327, P<0.001
Average block VIF (AVIF)=1.058, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=1.378, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.546, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements
----------------------
Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 3
Number of indicators used in model: 23
Number of iterations to obtain estimates: 5

**********************************
* Path coefficients and P values *
**********************************
Path coefficients
-----------------
        M/E/I/M TD      QM1
M/E/I/M
TD
QM1     0.574   0.039

P values
--------
        M/E/I/M TD      QM1
M/E/I/M
TD
QM1     <0.001  0.306

****************************************
* Combined loadings and cross-loadings *
****************************************
        M/E/I/M TD      QM1     Type (a SE      P value
L   21  1.000   -0.007  -0.011  Reflect 0.076  <0.001
L   22  1.000   -0.007  -0.011  Reflect 0.076  <0.001
L   23  1.000   -0.007  -0.011  Reflect 0.076  <0.001
L   24  1.000   -0.007  -0.011  Reflect 0.076  <0.001
L   25  1.000   -0.007  -0.011  Reflect 0.076  <0.001
PP  21  1.000   -0.007  -0.011  Reflect 0.076  <0.001
PP  22  1.000   -0.007  -0.011  Reflect 0.076  <0.001
PP  24  1.000   -0.007  -0.011  Reflect 0.076  <0.001
IM  21  1.000   -0.007  -0.011  Reflect 0.076  <0.001
IM  22  1.000   -0.007  -0.011  Reflect 0.076  <0.001
IM  23  0.909   0.103   0.167   Reflect 0.076  <0.001
MAI  21 1.000   -0.007  -0.011  Reflect 0.076  <0.001
MAI  22 1.000   -0.007  -0.011  Reflect 0.076  <0.001
MAI  23 1.000   -0.007  -0.011  Reflect 0.076  <0.001
                                    Page 1
```

					QM1 ALL	
MAI 24	1.000	-0.007	-0.011	Reflect	0.076	<0.001
TD 11	-0.177	0.924	0.069	Reflect	0.076	<0.001
TD 12	-0.177	0.924	0.069	Reflect	0.076	<0.001
TD 13	0.324	0.625	-0.371	Reflect	0.076	<0.001
TD 16	0.291	0.734	0.017	Reflect	0.076	<0.001
TD 17	0.051	0.806	-0.142	Reflect	0.076	<0.001
TD 18	0.004	0.658	0.288	Reflect	0.076	<0.001
TD 19	-0.154	0.850	0.020	Reflect	0.076	<0.001
QM 1	0.000	0.000	1.000	Reflect	0.076	<0.001

****
* Normalized combined loadings and cross-loadings *
****

	M/E/I/M	TD	QM1
L 21	0.850	-0.007	-0.011
L 22	0.850	-0.007	-0.011
L 23	0.850	-0.007	-0.011
L 24	0.850	-0.007	-0.011
L 25	0.850	-0.007	-0.011
PP 21	0.850	-0.007	-0.011
PP 22	0.850	-0.007	-0.011
PP 24	0.850	-0.007	-0.011
IM 21	0.850	-0.007	-0.011
IM 22	0.850	-0.007	-0.011
IM 23	0.800	0.127	0.205
MAI 21	0.850	-0.007	-0.011
MAI 22	0.850	-0.007	-0.011
MAI 23	0.850	-0.007	-0.011
MAI 24	0.850	-0.007	-0.011
TD 11	-0.182	0.988	0.071
TD 12	-0.182	0.988	0.071
TD 13	0.412	0.930	-0.472
TD 16	0.403	0.812	0.024
TD 17	0.061	0.978	-0.171
TD 18	0.006	0.836	0.431
TD 19	-0.172	0.989	0.022
QM 1	0.000	0.000	1.000

****
* Latent variable coefficients *
****

R-squared coefficients

M/E/I/M	TD	QM1
		0.341

Adjusted R-squared coefficients

M/E/I/M	TD	QM1
		0.327

Composite reliability coefficients

M/E/I/M	TD	QM1
0.999	0.923	1.000

Page 2

QM1 ALL

Cronbach's alpha coefficients

M/E/I/M	TD	QM1
0.999	0.900	1.000

Average variances extracted

M/E/I/M	TD	QM1
0.988	0.635	1.000

Full collinearity VIFs

M/E/I/M	TD	QM1
1.557	1.060	1.517

Q-squared coefficients

M/E/I/M	TD	QM1
		0.349

****
* Ccorrelations among latent variables and errors *
****

Correlations among l.vs. with sq. rts. of AVEs

	M/E/I/M	TD	QM1
M/E/I/M	0.994	0.234	0.583
TD	0.234	0.797	0.173
QM1	0.583	0.173	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M/E/I/M	TD	QM1
M/E/I/M	1.000	0.019	<0.001
TD	0.019	1.000	0.085
QM1	<0.001	0.085	1.000

9. SEM analysis results of Reduction in final defects from the equipment from Quality Maintenance pillar

QM 2ALL

```
*********************************
* General SEM analysis results *
*********************************
```

General project information

Version of WarpPLS used: 4.0

Model fit and quality indices

Average path coefficient (APC)=0.309, P<0.001
Average R-squared (ARS)=0.265, P<0.001
Average adjusted R-squared (AARS)=0.250, P<0.001
Average block VIF (AVIF)=1.058, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=1.263, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.481, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements

Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 3
Number of indicators used in model: 23
Number of iterations to obtain estimates: 5

```
**********************************
* Path coefficients and P values *
**********************************
```

Path coefficients

	M/E/I/M	TD	QM2
M/E/I/M			
TD			
QM2	0.449	0.168	

P values

	M/E/I/M	TD	QM2
M/E/I/M			
TD			
QM2	<0.001	0.015	

```
*****************************************
* Combined loadings and cross-loadings *
*****************************************
```

	M/E/I/M	TD	QM2	Type (a	SE	P value
L 21	1.000	-0.003	-0.026	Reflect	0.076	<0.001
L 22	1.000	-0.003	-0.026	Reflect	0.076	<0.001
L 23	1.000	-0.003	-0.026	Reflect	0.076	<0.001
L 24	1.000	-0.003	-0.026	Reflect	0.076	<0.001
L 25	1.000	-0.003	-0.026	Reflect	0.076	<0.001
PP 21	1.000	-0.003	-0.026	Reflect	0.076	<0.001
PP 22	1.000	-0.003	-0.026	Reflect	0.076	<0.001
PP 24	1.000	-0.003	-0.026	Reflect	0.076	<0.001
IM 21	1.000	-0.003	-0.026	Reflect	0.076	<0.001
IM 22	1.000	-0.003	-0.026	Reflect	0.076	<0.001
IM 23	0.909	0.040	0.405	Reflect	0.076	<0.001
MAI 21	1.000	-0.003	-0.026	Reflect	0.076	<0.001
MAI 22	1.000	-0.003	-0.026	Reflect	0.076	<0.001
MAI 23	1.000	-0.003	-0.026	Reflect	0.076	<0.001

Page 1

					QM 2ALL	
MAI 24	1.000	-0.003	-0.026	Reflect	0.076	<0.001
TD 11	-0.151	0.924	0.030	Reflect	0.076	<0.001
TD 12	-0.151	0.924	0.030	Reflect	0.076	<0.001
TD 13	0.158	0.625	-0.111	Reflect	0.076	<0.001
TD 16	0.088	0.734	0.467	Reflect	0.076	<0.001
TD 17	0.168	0.806	-0.436	Reflect	0.076	<0.001
TD 18	0.138	0.658	0.075	Reflect	0.076	<0.001
TD 19	-0.129	0.850	-0.031	Reflect	0.076	<0.001
QM 2	0.000	0.000	1.000	Reflect	0.076	<0.001

****
* Normalized combined loadings and cross-loadings *
****

	M/E/I/M	TD	QM2
L 21	0.886	-0.003	-0.026
L 22	0.886	-0.003	-0.026
L 23	0.886	-0.003	-0.026
L 24	0.886	-0.003	-0.026
L 25	0.886	-0.003	-0.026
PP 21	0.886	-0.003	-0.026
PP 22	0.886	-0.003	-0.026
PP 24	0.886	-0.003	-0.026
IM 21	0.886	-0.003	-0.026
IM 22	0.886	-0.003	-0.026
IM 23	0.764	0.049	0.500
MAI 21	0.886	-0.003	-0.026
MAI 22	0.886	-0.003	-0.026
MAI 23	0.886	-0.003	-0.026
MAI 24	0.886	-0.003	-0.026
TD 11	-0.157	0.974	0.031
TD 12	-0.157	0.974	0.031
TD 13	0.244	0.905	-0.172
TD 16	0.117	0.720	0.624
TD 17	0.167	0.980	-0.433
TD 18	0.222	0.837	0.121
TD 19	-0.144	0.976	-0.034
QM 2	0.000	0.000	1.000

****
* Latent variable coefficients *
****

R-squared coefficients

M/E/I/M	TD	QM2
		0.265

Adjusted R-squared coefficients

M/E/I/M	TD	QM2
		0.250

Composite reliability coefficients

M/E/I/M	TD	QM2
0.999	0.923	1.000

Page 2

```
                                                  QM 2ALL
Cronbach's alpha coefficients
-----------------------------

M/E/I/M TD      QM2
0.999   0.900   1.000

Average variances extracted
---------------------------

M/E/I/M TD      QM2
0.988   0.635   1.000

Full collinearity VIFs
----------------------

M/E/I/M TD      QM2
1.332   1.096   1.361

Q-squared coefficients
----------------------

M/E/I/M TD      QM2
                0.271
******************************************************
* Ccorrelations among latent variables and errors *
******************************************************

Correlations among l.vs. with sq. rts. of AVEs
----------------------------------------------

        M/E/I/M TD      QM2
M/E/I/M 0.994   0.234   0.488
TD      0.234   0.797   0.273
QM2     0.488   0.273   1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations
-------------------------
        M/E/I/M TD      QM2
M/E/I/M 1.000   0.019   <0.001
TD      0.019   1.000   0.006
QM2     <0.001  0.006   1.000
```

10.SEM analysis results of Increase in Lean/Kaizen projects of the equipment from Focussed Improvement pillar

```
                                          FI 1 ALL
********************************
* General SEM analysis results *
********************************
General project information
---------------------------
Version of WarpPLS used: 4.0

Model fit and quality indices
-----------------------------
Average path coefficient (APC)=0.391, P<0.001
Average R-squared (ARS)=0.973, P<0.001
Average adjusted R-squared (AARS)=0.972, P<0.001
Average block VIF (AVIF)=3.588, acceptable if <= 5, ideally <= 3.3
Average full collinearity VIF (AFVIF)=4.097, acceptable if <= 5, ideally <= 3.3
Tenenhaus GoF (GoF)=0.907, small >= 0.1, medium >= 0.25, large >= 0.36
Sympson's paradox ratio (SPR)=1.000, acceptable if >= 0.7, ideally = 1
R-squared contribution ratio (RSCR)=1.000, acceptable if >= 0.9, ideally = 1
Statistical suppression ratio (SSR)=1.000, acceptable if >= 0.7
Nonlinear bivariate causality direction ratio (NLBCDR)=1.000, acceptable if >= 0.7

General model elements
----------------------
Number of data resamples used: 100
Number of cases (rows) in model data: 100
Number of latent variables in model: 4
Number of indicators used in model: 19
Number of iterations to obtain estimates: 5

**********************************
* Path coefficients and P values *
**********************************
Path coefficients
-----------------
        M       TD      I/MA    FI 1
M
TD
I/MA
FI 1    1.000   0.063   0.109

P values
--------
        M       TD      I/MA    FI 1
M
TD
I/MA
FI 1    <0.001  0.204   0.079

****************************************
* Combined loadings and cross-loadings *
****************************************
        M       TD      I/MA    FI 1    Type (a SE      P value
L  11   0.988   -0.043  -0.150  -0.059  Reflect 0.076   <0.001
L  12   0.997   0.017   -0.037  -0.076  Reflect 0.076   <0.001
L  13   0.997   0.017   -0.037  -0.076  Reflect 0.076   <0.001
L  14   0.997   0.017   -0.037  -0.076  Reflect 0.076   <0.001
L  15   0.957   -0.009  0.270   0.297   Reflect 0.076   <0.001
TD 11   -0.314  0.925   -0.083  0.085   Reflect 0.076   <0.001
TD  12  -0.436  0.958   0.143   0.038   Reflect 0.076   <0.001
TD  13  0.482   0.652   0.172   0.185   Reflect 0.076   <0.001
TD  15  -0.334  0.606   -0.124  -0.588  Reflect 0.076   <0.001
TD  16  0.454   0.800   -0.611  0.278   Reflect 0.076   <0.001
TD  17  0.171   0.699   0.129   -0.302  Reflect 0.076   <0.001
TD  18  0.137   0.828   0.366   0.133   Reflect 0.076   <0.001
                                        Page 1
```

						FI 1 ALL		
IM	12	-0.177	-0.243	0.909	0.124	Reflect	0.076	<0.001
IM	13	-0.053	0.240	0.960	0.078	Reflect	0.076	<0.001
MAI	11	1.209	-0.029	0.841	-0.296	Reflect	0.076	<0.001
MAI	12	1.209	-0.029	0.841	-0.296	Reflect	0.076	<0.001
MAI	13	-1.045	0.023	0.872	0.178	Reflect	0.076	<0.001
MAI	14	-1.045	0.023	0.872	0.178	Reflect	0.076	<0.001
FI 1		-0.000	-0.000	0.000	1.000	Reflect	0.076	<0.001

****
* Normalized combined loadings and cross-loadings *
****

		M	TD	I/MA	FI 1
L	11	0.601	-0.035	-0.125	-0.049
L	12	0.587	0.016	-0.034	-0.070
L	13	0.587	0.016	-0.034	-0.070
L	14	0.587	0.016	-0.034	-0.070
L	15	0.569	-0.015	0.430	0.473
TD	11	-0.256	0.704	-0.068	0.069
TD	12	-0.352	0.700	0.115	0.031
TD	13	0.884	0.459	0.315	0.340
TD	15	-0.228	0.895	-0.085	-0.402
TD	16	0.396	0.560	-0.534	0.243
TD	17	0.234	0.657	0.176	-0.412
TD	18	0.251	0.529	0.672	0.244
IM	12	-0.143	-0.196	0.624	0.100
IM	13	-0.066	0.299	0.587	0.098
MAI	11	0.971	-0.023	0.514	-0.238
MAI	12	0.971	-0.023	0.514	-0.238
MAI	13	-0.540	0.012	0.721	0.092
MAI	14	-0.540	0.012	0.721	0.092
FI 1		-0.000	-0.000	0.000	1.000

****
* Latent variable coefficients *
****

R-squared coefficients

M	TD	I/MA	FI 1
			0.973

Adjusted R-squared coefficients

M	TD	I/MA	FI 1
			0.972

Composite reliability coefficients

M	TD	I/MA	FI 1
0.995	0.919	0.955	1.000

Cronbach's alpha coefficients

M	TD	I/MA	FI 1
0.993	0.894	0.943	1.000

FI 1 ALL

Average variances extracted

M	TD	I/MA	FI 1
0.974	0.625	0.781	1.000

Full collinearity VIFs

M	TD	I/MA	FI 1
6.511	2.724	3.970	3.183

Q-squared coefficients

M	TD	I/MA	FI 1
			0.737

****

correlations among latent variables and errors *

****

Correlations among l.vs. with sq. rts. of AVEs

	M	TD	I/MA	FI 1
M	0.987	0.738	0.830	0.822
TD	0.738	0.791	0.774	0.544
I/MA	0.830	0.774	0.884	0.636
FI 1	0.822	0.544	0.636	1.000

Note: Square roots of average variances extracted (AVEs) shown on diagonal.

P values for correlations

	M	TD	I/MA	FI 1
M	1.000	<0.001	<0.001	<0.001
TD	<0.001	1.000	<0.001	<0.001
I/MA	<0.001	<0.001	1.000	<0.001
FI 1	<0.001	<0.001	<0.001	1.000

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L.V. Muralikrishna Reddy, PhD,

CERTIFICATE

This is to certify that the following paper has been presented in the technical paper session of the 26th Indian Engineering Congress 2011, Bangalore, India.

Paper Title: Role Of Total Productive Maintenance In Lean Manufacturing

Authors: Suresh.P.K, Dr. Mary Joseph

Presented by: ...Suresh.P.K...............................

Hall: 5 ~~A~~/ B/ C/ D   Date: 16/~~17~~/18, December 2011   Time: 12:45-13:30

Dec. 17, 2011
Session Chairman

Dr. L. V. Muralikrishna Reddy

Appendix -2

ROLE OF TOTAL PRODUCTIVE MAINTENANCE IN LEAN MANUFACTURING

SURESH .P.K[1], Dr. MARY JOSEPH[2]

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Total Productive Maintenance (TPM) is a very popular manufacturing philosophy , aims at creating a system for achieving and maintaining 'Zero breakdown' ,'Zero defect', 'Zero accident', and 'Zero pollution'. In 1970 Seiiji Nakajima came out with 'Total Productive Maintenance' (TPM) concept for achieving high plant maintenance efficiency through a comprehensive system, based on respect for individual and total employee participation. Japan also established 'PM' prize by 1964,which is much sought after by TPM practitioners now.

To assess the degree of relationship between the TPM implementation factors and performance parameters. To assess the difference in the level of implementation of TPM among large scale and SME's, among the industries in Kerala and outside Kerala, among public sector and private sector companies, among process plants and production units etc. The previous researchers of this topic have identified the following factors which influences the successful implementation of TPM Leadership for improvement; Human Resources Management, education and Training; Information architecture; Equipment and process management ; House keeping, Safety, Health and Environment 1. The level of correlation among parameters of implementation and the achieved results to be evidenced. 2. Among public sector and private sector, and region wise difference if any to be monitored. 3. Among process industries and engineering industries any difference to be assessed. 5. Identify the factors of any failure of TPM implementation in industries.

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International Conference on Quality & Reliability Engineering
Recent Trends & Future Directions
Theme : Quality - New Frontiers
20 - 22 December 2011

Certificate of Participation

This is to certify that Prof./ Dr./ Mr./ Ms./ P. K. Suresh.,
of Cochin University of Science & Technology has attended
the International Conference organized by SQC & OR Unit, Indian Statistical Institute, Bangalore Center and
presented the paper titled Role of Total Productive Maintenance
in Lean Manufacturing.

Place : Bangalore
Date : 22.12.2011

(Boby John)
Organizing Secretary, ICQRE 2011

(Somnath Ray)
Head, SQC & OR Unit
Indian Statistical Institute

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A Study on TPM Implementation: Factors and Performance

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Keywords: *Lean Manufacturing, TPM Pillars, Quality Management Principles, JIPM, Objectives, Training.*

1. INTRODUCTION

Globalization in Indian context has started in the first half of 1990's with the opening of Indian economy. Till then, the Indian industry, business and other key vehicles of the economy were well protected by various government rules and regulations. However, with the opening of the economy, the Indian industry faced global challenges of competition and survival. After initial hiccups, the industry soon realized that competitive pricing and quality alone were the means for its survival and growth. Liberalization and opening of the economy to global competition has brought new challenges of the industry in the realism of productivity, reliability and total quality management. The globalization of the economy was putting terrific pressure on industries to have increased adaptability, innovation and process speed.

There is mind-boggling development going on throughout the world. Continuous development and innovations have become order of the day. Technical advancement has made the world today a border less society. Today's competition is ruthless and survival depends upon not only on continuous improvement and invention of new products but also on their availability at low cost, timely delivery, courteous sales and prompts after sales service.

Quality factors, and cost depend upon the quality of the raw material, equipment precision, condition of the methods adopted and on the total involvement and capability of the people who carried out the work. Today's competitive global market helps for availing the quality materials for processing and with the technological advantages helps for sensitive equipments which gives sensitive products and which can operate by a semi skilled operator.

We are now helped by this technological advancement. We have now many precision equipments and devices which help in monitoring and controlling raw material quality and consistency, functional efficiency of equipment and their accuracy, auto operational systems to minimize and or to avoid variations in the methods used and POKA YOKE/mistake proofing system to eliminate human errors. But they are not going to do away with human labour completely. Only output can be automated, maintenance still depends upon human beings.

Upkeep of equipment has become an additional responsibility. The rapid technological advancement, leads to the importance of equipment for market survival. Care for equipment has become a great need. The concept of Total Productive Maintenance (TPM) meets this need.

Quality tools are the buses towards the journey for Total Quality Management (TQM). Quality tools include ISO standards, statistical tools, JIT, Quality circles, TPM, etc.

TPM is a part of Total Quality Management (TQM). Just as Quality Circle activities are carried out in small group, TPM also is carried out as small group activities on a company—wide basis with equipment maintenance as its main aim. This guides the importance of management of equipments, in surviving in the competitive market.

Total Productive Maintenance (TPM) is a very popular manufacturing philosophy and well accepted the world over. TPM aims at creating a system for achieving and maintaining 'Zero breakdown', 'Zero defect', 'Zero accident', and 'Zero pollution'.

Even though basically TPM is meant for manufacturing industries, it can be adapted to service industries also. Many companies in India have adopted TPM and gained lot of benefits.

TPM activity is not an activity restricted to production area alone. It has now a new direction in the function of the entire organization. As mentioned earlier modern tough competition as well as technological advancements has brought in automation and robotization. Now not only quality but also product cost, inventory, safety, health, etc. are dependent on equipment.

2. HISTORICAL BACKGROUND OF TPM CONCEPT

Seiiji Nakajima, a Japanese engineer, came out with this concept in 1971. Till 1950's organizations were carrying out only breakdown maintenance *i.e.*, wherever equipment goes out of order the maintenance crew will attend to that and put it back to operation.

In 1950's a major change came in this method in the form of 'Preventive Maintenance' in USA. This was something revolutionary at that time. Preventive maintenance work was carried out either during holidays or taking a planned shutdown. Preventive maintenance helped to create an awareness and recognition about the importance or reliability and economic efficiency in plant design, etc.

Such awareness led to 'Productive maintenance' concept by 1954. Under this system of day-to-day checkup of the tightness of the nuts and bolts, leakages, etc. were done. This helped to reduce the wear and tear, proper upkeep of the alignment, setup, etc. resulting in minimum breakdown.

By 1957 'Maintainability Improvement' system was developed *i.e.*, improvement of design parameters based on experience, additional control system for timely detection of problems, etc.

All these resulted in considerable reduction in maintenance activities.

3. DEFINITION OF TOTAL PRODUCTIVE MAINTENANCE

TPM is a methodology for maximizing equipment efficiency by establishing a Total system for Productive Maintenance (PM) for the entire life of equipment Participation by all departments, including equipment planning, operating, maintenance departments. Involving all personnel, including top personnel to first line operators. Promoting PM by motivation management, namely by autonomous small group activities.

It can be considered as the medical science of machines. Total Productive Maintenance (TPM) is a maintenance programme which involves a newly defined concept for maintaining plants and equipment. The goal of the TPM programme is to increase production while, at the same time, increasing Employee morale and Job satisfaction.

TPM brings maintenance into focus as a necessary band vitally important part of the business. It is no longer regarded as non-profit activity. Down Time for maintenance is scheduled as a part of the manufacturing day and in some cases and an integral part of the manufacturing process. The Goal is to hold emergency and unscheduled maintenance to a minimum.

4. WHY TPM

TPM was introduced to achieve the following objectives. The important ones are listed below.

- Avoid wastage in a quickly changing economic environment
- Producing goods without reducing product quality
- Reduce cost
- Produce a low batch quantity at the earliest possible time
- Goods send to the customers must be non defective.

5. SIMILARITIES AND DIFFERENCE BETWEEN TQM AND TPM

The TPM programme closely resembles the popular Total Quality Management (TQM) programme. Many of the tools such as employee empowerment, bench marking, documentation etc. used in TQM are used to implement and optimize TPM.

Following are similarities between the two. Total commitment of the programme by upper level of the management is required in both programme.

Employees must be empowered to initiate corrective action and a long range outlook must be accepted as TPM may take a year or more to implement and is an ongoing process. Changes in employee mind set toward their job responsibilities must take place as well.

The difference between TQM and TPM are summarized below.

Category	*TQM*	*TPM*
Object	Quality (Output and effects)	Equipment (input and cause)
Means of attaining goal	Systematize the management. It is software oriented	Employees participation and it is hardware oriented
Target	Quality for PPM	Elimination of losses and wastes

6. BENEFITS OF TPM

TPM Targets

P-Performance: Obtain minimum 80% OPE (Overall plant Efficiency)

Obtain minimum 90% OEE (Overall Equipment Effectiveness).

Q-Quality: Operate in a manner so that there are no customer complaints.

C-Cost: Reduce the manufacturing cost by 30%.

D-Delivery: Achieve 100% success in delivering the goods as required by the customer.

S-Safety: Maintain an accident free environment.

M-Mastermind: Increase the suggestions by 3 times. Develop Multi-skilled and flexible workforce.

Direct benefits of TPM:

- Increase productivity and OPE (Overall Plant Efficiency) by 1.5 or 2 times.
- Rectify customer complaints
- Reduce the manufacturing cost by 30%
- Satisfy the customers need by 100% (Delivering the right quantity at the right time, in the required quality)
- Reduce accidents
- Follow pollution control measures.

Indirect benefits of TPM:

- Higher confidence level among employees
- Keep the work place clean, neat and attractive
- Favourable change in the attitude of operators
- Achieve goals by working as a team
- Horizontal deployment of a new concept in all areas of the organization
- Share knowledge and experience
- The workers get a feeling of owning the machine.

7. MOTIVES OF TPM

Adoption of life cycle approach for improving the overall performance of production equipment. Improving productivity by highly motivated workers which is achieved by job enlargement. The use of voluntary small group activities for identifying the cause of failure, possible plant and equipment modifications.

8. UNIQUENESS OF TPM

The major difference between TPM and other concepts is that the operators are also made to involve in the maintenance process. The concept of "I (Production operators) Operate, You (Maintenance Department) fix" is not followed.

9. TPM OBJECTIVES

Achieve zero defects, zero breakdown, and zero accidents in all functional areas of the organization.

Involve people in all levels of organization.

Form different teams to reduce defects and self maintenance.

10. TPM HAVE THE FOLLOWING PILLARS

1. Autonomous Maintenance
2. Focused Improvement
3. Planned Maintenance
4. Quality Maintenance
5. Development Management
6. Education and Training
7. Safety, Health and Environment
8. Office Improvement.

1. *Autonomous Maintenance:* This pillar is geared towards developing operators to be able to take care of small maintenance activities, thus freeing up the skilled maintenance people to spend time on more value added activity and technical repairs.
2. *Focused Improvement:* Target is to achieve and sustain zero losses with respect to minor stops, measurement and adjustments, defects and unavoided down times.
3. *Planned Maintenance:* It is aimed to have trouble free machines and equipments producing defect free products for total customer satisfaction. It breaks maintenance down into 4 families or groups as: a. Preventive maintenance b. Breakdown maintenance c. Corrective maintenance d. Maintenance prevention.
4. *Quality Maintenance:* Quality maintenance activities are to set equipment conditions that preclude quality defects, based on the basic concept of maintaining perfect equipment to main perfect quality products.
5. *Development Management:* Planning project strategies, analyzing the factors influencing project decision. Design new products with customer focus; reduce lead time from design to production to market.
6. *Education and Training:* It is aimed to have multi skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently.
7. *Safety, Health and Environment:* Focus on targets, actual data and gaps in implementation of systems for ensuring safety, occupational health and clean environment through continuous training.
8. *Office Improvement:* 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.

11. RESEARCH PAPERS REFERRED

1. Dr. S. Muthu, Principal, P.S.G. College of Technology, Bharatheeyar University had conducted research work in 2002 under Dr. S.R. Devadasan on the topic 'Design and Exploration of Strategic Maintenance Quality Engineering Model'. This model was designed by integrating the chosen 'Strategic Quality Management model' with TPM principles.

This model recommends:

- Long term and short term Quality Objectives
- Suggestion schemes, small group activities, quality circle and other similar techniques to attain maintenance quality through human knowledge
- System for continuous maintenance quality system
- Programme for continuous approach towards target
- System for continuous transfer of customer feedback
- Programme for continuous training on maintenance quality
- System for continuous maintenance quality failure analysis
- System for continuous control of maintenance quality cost
- System for maintenance quality counseling.

Successful maintenance quality planning, maintenance quality implementation and maintenance quality improvement and maintenance quality control and evaluation is done through:

- Maintenance quality through human knowledge nourishment
- Continuous information system for maintenance quality
- Continuously monitored maintenance quality system
- Approach towards maintenance quality target
- Transfer of customer feedback
- Training and education on maintenance quality
- Maintenance quality through failure analysis
- Maintenance quality costing
- Periodical maintenance quality auditing
- Maintenance quality through counseling.

2. Research paper titled 'The impact of total productive maintenance practices on manufacturing performance' by Mr. Kathleen. E. Mckone, Mr. Roger. G. Schroedar and Mr. Kristy. O. Cua from U.S.A. finds that TPM has a positive and significant relationship with low cost, high levels of quality and strong delivery performance. They are considering the factors influencing TPM as:

- House keeping
- Cross training
- Teams
- Operator involvement
- Disciplined planning
- Information Tracking
- Schedule compliance, etc.

3. Research paper titled as 'Relationship between TQM and TPM implementation factors and business performance of manufacturing industry in Indian context' by Mr. Dinesh Seth and Mr. Deepak Tripathi from NITIE, Mumbai, examines the relationship between factors influencing the implementation of TQM and TPM and business performance.

They are considering the factors as:

- Leadership for improvement
- Strategic planning
- Process management
- Education and training
- Information architecture
- Equipment management
- Performance measurement system.

4. Mr. Shari. M. yusuf and Flaine Aspinwall, University of Birminghan, U.K, conductesd a study on 'TQM implementation issues, Review and Case study' which discusses the various issues confronting small businesses when embarking on TQM. First, reviews the subject of TQM and the quality initiatives undertaken by small businesses (which are treated as Small- to Medium-sized Enterprises (SMEs)) such as ISO 9000 and TQM.

Various issues for effective implementation such as management practices, process of implementation, results and outcomes were investigated.

In terms of structure, processes and people, a small business is in an advantageous position when it comes to adopting a new change initiative, provided that the owner/management has the commitment to, and leadership of, the change process, together with a sound knowledge of it. Lee and Oakes (1995) cited financial and technical resource constraints as being the main problems plaguing small businesses.

Moreno-Luzon (1993) reported on the problems faced by small firms in their attempt to develop a quality culture. Some of the difficulties were:

- Resistance to change;
- Lack of experience in quality management;
- Lack of resources.

5. Mr. Noorliza Karia and Muhamed Hasmi of University of Sains Malaysia had conducted study on 'The effects of Total Quality Management' practices on employee related attitudes.

The results indicate that training and education have a significant positive effect on job involvement, job satisfaction, and organizational commitment. Empowerment and teamwork significantly enhance job involvement, job satisfaction, career satisfaction, and organizational commitment.

Continuous improvement and problem prevention significantly enhance job satisfaction and organizational commitment.

Customer focus does not contribute to job involvement, job satisfaction, career satisfaction, or organizational commitment.

12. AWARDS RELATED WITH QUALITY MANAGEMENT

12.1 IMC Ramakrishna Bajaj National Quality Award Progamme

The Criteria are built upon the following set of interrelated Core Values and Concepts:

- Visionary leadership
- Customer-driven excellence
- Organizational and personal learning
- Valuing employees and partners
- Agility
- Focus on the future
- Managing for innovation
- Management by fact
- Social responsibility
- Focus on results and creating value
- Systems perspective.

12.2 The European Quality Award is the European Equivalent of the Baldrige Award

Special Prizes will be given for:

- Leadership and consistency of purpose
- Customer focus
- Corporate social responsibility
- People development and involvement
- Results orientation.

12.3 Malcolm Baldrige National Quality Award (MBNQA)

Embedded in each of these categories or dimensions—the ideal is defined:

- Leadership
- Strategic Planning
- Customer Focus
- Information and Analysis
- Human Resource Development
- Process Management
- Business Results.

12.4 Deming Prize—The Criteria

Broadly, the following considerations are taken into account for the Deming Application Prize:

- Top Management Leadership, Vision, Strategies
- TQM Frameworks

- Quality Assurance Systems
- Management Systems for Business Elements
- Human Resource Development
- Effective Utilisation of Information
- TQM Concepts and Values
- Scientific Methods
- Organisational Powers (Core Technology, Speed, Vitality)
- Contribution to Realisation of Corporate Objectives.

As per ISO 9000: 2005, eight quality management principles have been identified that can be used by top management in order to lead the organization towards improved performance.

- Customer focus
- Leadership
- Involvement of people
- Process approach
- System approach to management
- Continual improvement
- Factual approach to decision making
- Mutually beneficial supplier relationships.

13. RESEARCH OBJECTIVE

- To assess the degree of relationship between the TPM implementation factors and performance levels.
- To compare the performance of equipments with traditional maintenance practices with equipments have TPM level maintenance practices.
- To assess the difference in the level of implementation of TPM and performance among large scale industries and SME's, among the industries in Kerala and outside Kerala, among public sector and private sector companies, among process plants and production units and the performance with respect to the period of implementation, etc.

14. RELEVANCE OF SECTOR BASED STUDY

In large scale industries the employee strength are comparatively high and in small and medium enterprises, that are generally low. In SME's there is better scope for efficient management control and for providing better training, etc.

In public sector enterprises, there may frequent changes in leadership when comparative to private sector. Similarly, the political influence and other factors influences the decision making process.

Similarly, with respect to equipments, the process equipments are generally continuous running and annual shutdown or similar type maintenance practices are going on. But in production units, it can stop and restart at anytime and routine maintenance can be done very effectively.

When comparative to Kerala and other states, the work culture is generally different. The efficiency and effectiveness of workforce in Kerala is appraised everywhere, but there is some bottlenecks exists in effective utilisation of the force, due to some other issues related with influence of politics and general resistance to change the mindset of the people.

Generally any cultural change will occur with some periods of time. So the performance can be measured with respect to the duration of implementation. So a comparison with duration of implementation is also important.

15. IN THIS RESEARCH THE FOLLOWING IMPORTANT FACTORS ARE CONSIDERED FOR ANALYSIS WHICH INFLUENCES THE SUCCESSFUL IMPLEMENTATION OF TPM

By considering the referred research papers and the factors considered by different award criteria's, the following factors are selected as implementation factors which influences the success in attaining TPM objectives:

- Leadership for improvement
- Strategic Planning
- Human Resources Management, education and Training
- Information architecture
- Equipment and process management
- Monitoring and Analysis.

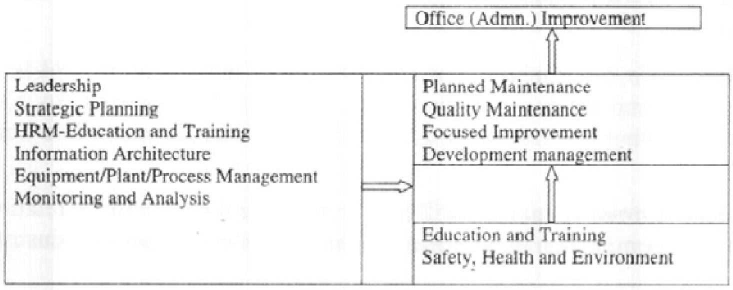
All these factors results the external and internal customer satisfaction.

The identified results areas are:

- Machine speed
- Machine availability
- Innovative products/processes/equipments
- Zero defects areas/zero customer complaint areas
- Zero breakdown areas
- Plant/Machine flexibility achieved for new product manufacturing/small volume of production of multiple items
- Easiness of operation achieved
- Machine accuracy/process streamlining
- Intellectual property rights/patent applications being obtained
- Reduction in pollution
- Reduction in accidents
- Increase in employee suggestions/small group activities.

The core results of TPM are achieved through the five pillars as addressed below and training, safety, health and environment, which are the plinths of TPM which supports these five pillars.

Office TPM is also considered as one of the plinth supporting the five pillars by providing necessary administrative supports. Here, the related results of five pillars is linked with administrative improvement which results cost reduction by man hours saving and through inventory reduction, etc.



16. ADVANTAGES OF THIS ANALYSIS AND RESULTS

1. This research work will help to scientifically prove the relationship between implementation factors and performance parameters and it will guide to take further necessary steps for effective implementation of the system.
2. The category wise analysis will help to identify the specific nature of implementation and results indifferent categories of industries.
3. This research work will help to identify the importance of leadership and strategic planning which includes the determination of long term and short term objectives and systematic allocation of responsibility and authority, etc.
4. The role of education and training in attaining organisational performance also will be revealed.
5. This research work will prove the importance of effective monitoring and analysis of performance (also through internal audits as recommended by Mr. S. Muthu in Strategic Maintenance Quality model research paper) and the importance of implementation of statistical tools in analysis of performance.

Limitation of the Study:

The study does not consider the financial outcomes through TPM implementation.

17. METHODS ADOPTED FOR DESIGNING QUESTIONNAIRE

Japan Institute of Plant Maintenance (JIPM) have a questionnaire for considering the industries for its different criteria of awards. The questionnaire of JIPM includes the categories from 1. TPM policies and objectives 2. Individual Improvement 3. Autonomous Maintenance 4. Planned Maintenance 5. Quality Maintenance 6. Product and Equipment development and control 7. Training and Development 8. Administrative and Supervisory departments 9. Safety, Sanitation and Environment Control 10. Effects and evaluation of TPM.

Based on the questionnaire of JIPM awards and with referance from advanced books of TPM and from different ISO standards related with Quality, environmental and safety, a questionnaire is designed for collecting necessary data in relation with implementation levels of TPM and the results.

18. SAMPLING METHODS

Industries are to be selected already implemented TPM practices and which are in traditional maintenance practices in a convenient sampling basis. Industries in Kerala and from other southern states and industries belong to different sections as large scale and SME's, Public sector and private sector companies, Process industries and production industries, etc.

From these selected industries different machines or process plants to be selected on a sampling basis to collect data.

From TPM club of India, he membership industries who are in practice of TPM is available. But there are other non member industries who already started TPM initiatives. So, a convenient as well as judgment sampling method will be adopted for collecting necessary data from each sector of industries.

So, the correlation, regression analysis will help to measure the strength of relationship and 't' test will help for the comparison on performance in various categories of industries.

19. IMPROVEMENTS OF STUDY AT THE PRESENT LEVEL

Presently data is collected from industries which in the stage of successful implementation of TPM and data is also collected from industries which are in traditional maintenance practices.

The strength of relation ship in implementation factors and performance is measured in both categories of industries and the difference in implementation and performance is done only with TPM companies and Non TPM companies.

20. RESULTS

- The level of correlation among implementation factors and the achieved results evidenced.
- There is significant difference in performance of TPM implemented. companies with industries which are in traditional maintenance practices. (Tables attached)

21. RECOMMENDATIONS WITH THE PRESENT RESULTS

- Internal audits to be strengthened for monitoring performance (As recommended by Mr. S. Muthu, in Strategic Maintenance Quality model).
- Long term and short term objectives to be fixed and reviewed.
- Implementation results are positive, so the awareness among industries to be improved about the importance of TPM.
- Responsibility and authority to be done properly and performance to be monitored.
- Proper training to be done and individual objectives to be done and monitored for performance measurement for increments and rewards.
- Statistical tools with the support of software will strongly support TPM implementation.

22. FURTHER STUDY

The study will be extended to collect more samples from industries with sector wise, process wise and state wise for more elaborate way.

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55th National Convention of
Indian Institution of Industrial Engineering
in association with
Shri Ramdeobaba College of Engineering & Management,
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Total Productive Maintenance- A Tool for Lean Management

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Abstract

The advancement in technology had resulted introduction of sophisticated equipments which supports the productivity, quality and delivery of products and services and also the protection of environment and safety. Total Productive maintenance (TPM) concept helps for the scientific upkeep of plant and equipments. This study conducted among selected industries in South India which is awarded for TPM and other industries from various sectors which already practicing quality management practices. The relationship between the implementation factors and performance is analyzed. This study gives a focus to the industries to introduce the TPM model for improvement which leads to the attainment of lean concepts in manufacturing.

Key words: TPM, Lean, Correlation analysis, PDCA approach

1. INTRODUCTION

In today's industrial situation ,technological advancements has resulted sophisticated, automated equipments by which the operations can be perform by even semi skilled or unskilled operators. So the importance of the upkeep of equipment has its own importance since the condition and performance of the equipment have large role in the quality and availability of the products.

TPM focus on improvement in equipment availability, performance and quality with assuring health and safety of employees and protection of environment.

TPM helps for eliminating equipment breakdown and improving quality performance of equipment, thus the achievement in TPM strongly supports in attaining the lean concepts which includes the elimination of waiting time, defects in process etc.

To attain these results through TPM, the each pillars have its own contributions. According to the book 'TPM Reloaded ' by Joel Levitt, which suggests for each pillar its own objectives .This includes

1 .Autonomous Maintenance Pillar: 1.Reduction of scheduled down time 2.Reduction of unscheduled down time 3. Increase in speed of the machine 4. Decrease in product/process variability 5. Increase in the number of flexible operators to operate and maintain the equipment 6. Reduction in lubrication oil consumption 7. Increase in small group activities etc.

2. Planned maintenance pillar:_1.Reduction in scheduled down time_2. Reduction in schedule miss due to operations 3. Reduction in breakdown 4. Increase in zero breakdown areas etc

3.Quality Maintenance; 1._ Reduction in process defects 2. Reduction in final defects 3.Zero defects areas/zero customer complaint areas identified etc.

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4.Focussed improvements- 1. Increase number of lean/kaizen projects 2.No. of waste areas identified 3.Easiness of operation achieved 4.Reduction in incidents of fire/explosions 5. Plant/Machine flexibility achieved for new product manufacturing /small volume of production of multiple items etc.

5. Development management_ 1. Intellectual property rights/patent applications being obtained, 2.Innovative products/processes/equipments etc.

6.Education and Training___ 1. Reduction in absenteeism of employees 2. Increase in suggestions per employee 3.Increase in quality circle participation 4. Improvements in skills per persons etc.

7.Safety, Health &Environment 1.Reduction in pollution level 2. Reduction in discharges 3. Reduction in accidents 4. Increase in recycling 5. Number of audit failures per total findings etc.

8.Administrative Improvements:_ 1.Reduction in overtime job 2. Reduction in inventory, 3. Reduction in holiday work 4.Improvements in equalizing of work load 5. Improvement of information processing etc.

2. SCOPE OF THIS RESEARCH:

The scope of this research is to identify the system gap in selected industries from different sectors with the TPM level system. The industries is selected based on judgmental sampling which has implemented certain quality management initiatives and have reputation in the society. This study will helps for identifying the gap in their system with that in the TPM level and it will give a clear guidance for improvement on that direction. The relationship between the various implementation factors and performances are also analyzed.

3. OBJECTIVE

1. To identify, whether any significant difference in the existing system and performance in selected industries from different sectors with TPM successfully implemented companies.

2.To identify the relationship between different implementation factors and performance in TPM implemented companies and in other selected industries based on identified TPM objectives.

2. To identify the impact of the implementation of quality, and environmental standards in attaining the TPM objectives.

3. To identify if the nature of the products and processes have influences in attaining TPM objectives

4. QUESTIONNAIRE DESIGN AND DATA COLLECTION

The questionnaire is designed with the reference from previous research papers on similar area and from the input from the questionnaire of Japan Institute of Plant maintenance used for various TPM award criteria.

The questionnaire designed is tested and validated in two TPM award winner companies and found valid. Six industries each from engineering, chemical and food sectors are selected based on the judgemental and convenient random sampling, in which they have permitted to conduct the study inside. From the total equipments the equipments or plants are selected based on simple random sampling from the critical equipments /plants.

The data collection is by direct observation, by interview etc by visiting in the factory premises.

5. DATA ANALYSIS

The difference in the systems and performance between TPM implemented companies with other industries is analysed by t test. The relationship different implementation factors of TPM with performance of selected objectives is analysed by correlation ,Regression analysis.

The various implementation factors are identified as 1.Leadership &Strategic planning (L& SP)2. Plant / Equipment /Process management (P/E/P) 3. Human Resourse Management (HRM) 4. Information Architecture (IA) and 5. Measurement, Analysis & Improvement (MAI) etc

Table1: Sample analysis .Obj-Reduction in scheduled down time

Correlation between the objective with different factors		
	Correlation	p - value
Leadership and Strategic Planning	0.661**	0.000
Plant/Equipment/Process Management	0.637**	0.000
Human Resource Management	0.636**	0.000
Information Architecture	0.560**	0.000
Measurement, Analysis and Improvement	0.659**	0.000

6. FINDINGS: AUTONOMOUS MAINTENANCE PILLAR AS SAMPLE

1. The t test shows the p value of 0.072 ,in the performance of the objective -3 of increase in speed of the machine from the samples from the food sector industries ,which means that ,this samples have no significant difference with the TPM implemented companies samples.

All other objectives and implemantation factors from all the sectors shows significant difference with TPM samples.

2. While analysing the samples from TPM implemented companies, all the samples shows high level of performance in the implementation of various factors of TPM and the results are also achieved. The results of objective shows significant positive correlation at .01 and0.05 levels with the implementation factors.The regression analysis shows the factors Information architecture and Measurement ,analysis and Improvement have significant positive effect on attaining the objective of reduction in unscheduled down time.

7. RECOMMENDATIONS

The P.D.C.A approach in TPM implementation starts from the initiatives from the top management. The strategic decision making and planning by fixing objectives and targets and by assigning responsibilities etc. Implementing the necessary steps for plant/process management and by providing necessary supports by providing necessary information and by proper training to employees. Top management have to review the progress of implementation at frequent intervals and to take proper corrective measures for overcoming the hurdles.

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5th International & 26th All India Manufacturing Technology, Design and Research Conference

AIMTDR 2014

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Department of Mechanical Engineering, IIT Guwahati, Assam, India

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participated and presented a paper under poster presentation category in the ***5th International & 26th All India Manufacturing Technology, Design and Research Conference AIMTDR 2014*** *held at Indian Institute of Technology Guwahati, Assam, India.*

Paper Title: "TPM-A PDCA Approach"

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5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India

"TPM-A PDCA APPROACH"

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Abstract

India as a rising economic power, has not achieved its potential as Technology, Globalization, and International Competitiveness. Today's competition is ruthless and survival depends on the availability of products and services at low cost, timely delivery, courteous sales and prompts after sales service. The precision equipment and devices helps in monitoring and controlling raw material quality, consistency and functional efficiency of equipment and their accuracy, auto operational systems etc minimizes or avoidsdefects.But even themaintenance of equipment has become an additional responsibility and maintenance still depends upon human beings. The concept of Total Productive Maintenance (TPM) meets this need.Total Productive maintenance (TPM) concept helps for the scientific upkeep of plant and equipments. This study conducted among selected industries in South India from various sectors which already practicing certain quality management tools and also done in TPM awarded companies. The relationship between the implementation factors and performance are analyzed. The P.D.C.A approach in TPM implementation starts from the initiatives from the top management. Top management has to review the progress of implementation at frequent intervals and to take proper corrective measures for overcoming the hurdles.

Key words:TPM,Lean, PDCA approach

1.Introduction:

India is a rising economic power, but one which has not yet integrated very much with the global economy and still has not achieved its potential as Technology, Globalization, and International Competitiveness.Technical advancement has made the world today a border less society and survival depends upon not only on continuous improvement and invention of new products but also, on their availability at low cost, timely delivery, courteous sales and prompts after sales service. We have now many precision equipment and devices which help in monitoring and controlling raw material quality and consistency, functional efficiency of equipment and their accuracy, auto operational systems to minimize and or to avoid variations in the methods used and POKA YOKE/mistake proofing system to eliminate human errors. But the care and upkeep of equipment has become an additional responsibility.
Maintenance still depends upon human beings.The concept of Total Productive Maintenance (TPM) meets the needof scientific upkeep of plant and equipments.

2.Methodology:

This study conducted among selected companies in South India from various sectors which already started practicing TPM and alsodone in TPM awarded companies. The relationship between the implementation factors and performance are analyzed. This study give a focus to the industries to introduce the TPM model for improvement through a Plan –Do –Check-Act (P.D.C.A) approach,which leads to the attainment of lean concepts in manufacturing.

2.1 TPM Pillars and performance indicators:

The results, fromthe followingselected pillars of TPM haveidentified for this study. According to the book 'TPM Reloaded ' by Joel Levitt, which suggests for each pillar its own objectives.It

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TPM-A PDCA APPROACH

includes1.Autonomous Maintenance Pillar: 1.Reduction of scheduled down time 2.Reduction of unscheduled down time 3. Increase in speed of the machine 4. Decrease in product/process variability 5.Reduction in lubrication oil consumption

2.Planned maintenance pillar:1.Reduction in scheduled down time 2.Reduction in unscheduled down time 3.Reduction in schedule miss due to operations 4. Reduction in breakdown

3.Quality Maintenance; 1.Reduction in process defects 2. Reduction in final defects

5.Development management1. Innovative products/processes/equipments.

2.2 Identified factors which influences the TPM implementation:

The previous research papers on TPM and similar areas and the different awards criteria related with Quality have identified some common factors which influence the successful implementation of any quality management system practices.

It includes1.Leadership &Strategic Planning (L&SP) 2. Equipment/process management (EM)3.Training &Development (T&D)4. Information Management (IM) 5.Measurement, Analysis and Improvement system(MAI)

2.3.Research objectives;

1.To assess the impact of top management commitment on performance of equipments from various manufacturing companies.

2.To assess the impact of Equipment/process management practices on performance of equipments from various manufacturing companies.

3.To assess the impact of Training and development practices on on performance of equipments from various manufacturing companies.

4.To assess the impact of Information management practices on performance of equipments from various manufacturing companies.

5.To assess the impact of Measurement, Analysis and Improvement practices on performance of equipments from various manufacturing companies.

2.4.Research hypothesis;

1.Leadership and strategic planning have significant positive effect on performance of equipments from various manufacturing companies.

2.Equipment/process management practices have significant positive effect on performance of equipments from various manufacturing companies.

3.Training and development practices have significant positive effect on performance of equipments from various manufacturing companies

4.Information management practices have significant positive effect on performance of equipments from various manufacturing companies

5.Measurement, Analysis and Improvement practices have significant positive effect on performance of equipments from various manufacturing companies.

2.5 Collection of data;

The questions regarding these implementation factors are derived from the previous research questionnaire in this area and also the inputs from the questionnaire of JIPM (Japan Institute of Plant maintenance), and with references from books of TPM.

The designed schedules is validated with the experts in the field (Academicians and experts from Industries). The data collection is by direct interview with officials, by observing the plants, verifying the secondary data etc

2.6 Sampling:

The companies are identified on a judgement sampling method which includes both TPM awarded companies as well as which are already started implementing the TPM practices. The identified samples are equipments from various companies. The equipments are selected by simple random sampling from the selected companies. 60 samples are identified from 4 TPM awarded companies and 60 samples are identified from other companies which already started TPM practices.

2.7 Data Analysis:

Partial least squares (structural Equation Modelling) is used for analysis.The analysis done combinely and separalety with TPM awarded and TPM practicing industry samples.

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Table :1 Overall samples

Analysis of results from total 120 sample equipments								
		L&SP	EM	T &D	IA	MAI	AARS	GOF
AUTONOMOUS MAINTENANCE								
1	Reduction in scheduled down time	β =0.62 P<0.01	β =0.02 P=0.39	β =-0.13 P=0.03	β =-0.14 P<0.01	β =0.09 P=0.10	0.410 P<0.001	0.585
2	Reduction in unscheduled down time	β =1.74 P<0.01	β =0.35 P<0.01	β =-0.04 P=0.28	β =2.88 P<0.01	β =-0.01 P=0.44	-	-
3	Increase in speed of the machine	β =1.18 P<0.01	β =-0.38 P<0.01	β =0.10 P–0.08	β =-1.1 P<0.01	β =-0.64 P<0.01	-0.737 P<0.001	-
4	Decrease in product/process variability	β =0.13 P=0.04	β =-0.23 P<0.01	β =-0.30 P<0.01	β =-0.02 P=0.37	β =-0.37 P<0.01	-0.695 P<0.001	-
5	Reduction in oil consumption	β –0.96 P<0.01	β –0.02 P=0.39	β –-0.09 P=0.10	β –0.15 P=0.02	β –0.06 P=0.21	1 P<0.001	0.913
PLANNED MAINTENANCE								
1	Reduction in scheduled down time	β =0.82 P<0.01	β =0.16 P=0.04	β =0.03 P=0.35	β =-0.14 P=0.03	β =0.15 P=0.02	0.95 P<0.001	0.864
2	Reduction in unscheduled down time	β =0.48 P<0.01	β =0.69 P<0.01	β =-0.49 P<0.01	β =-1.02 P<0.01	β =0.22 P<0.01	0.23 P<0.001	0.423
3	Reduction in schedule miss due to operations	β =-0.13 P=0.03	β =-0.72 P<0.01	β =-0.60 P<0.01	β =0.66 P<0.01	β =0.41 P<0.01	0.67 P<0.001	0.731
4	Reduction in breakdown	β =-0.36 P<0.001	β =0.781 P<0.001	β =0.87 P<0.001	β =0.72 P<0.001	β =-.50 P<0.001	0.550 P<0.001	0.649
QUALITY MAINTENANCE								
1	Reduction in process defects	β =-2.78 P<0.01	β =3.46 P<0.01	β =-0.05 P=0.23	β =0.00 P=1	β =0.00 P=1	0.67 P<0.001	0.731
2	Reduction in final defects	β =-2.78 P<0.01	β =3.46 P<0.01	β =-0.05 P=0.23	β =0.00 P=1	β =0.00 P=1	0.76 P<0.001	0.833
DEVELOPMENT MANAGEMENT								
1	Innovation on processes/equipments	β =0.00 P=1	β =-0.00 P=0.50	β =0.00 P=0.50	β =0.00 P=1.0	β =1.00 P<0.01	1.00 P<0.001	0.963

AARS=Average adjusted R-SquaredGOF-Goodness of Fit

2.8 Findings from overall samples:

The analysis from overall 120 samples reveals with the significant levels of 0.01 and 0.001 , the factor Leadership and Strategic Planning, have significant impact in attaining the performance on reduction in scheduled down time in autonomous and planned maintenance pillars,and the reduction in unscheduled down time in planned maintenance pillars, increase in speed of the machine, reduction in oil consumption,etc. in autonomous maintenance pillar.

The factor equipment /process management have significant impact on attaining the performance in reducing the unscheduled down time, reduction in breakdown, Reduction in ,inprocess and final defects,

The factor training and development have significant impact on attaining the performance of reduction in breakdown.

The factor information architecture has significant impact on attaining the performance on the reduction in unscheduled down time in autonomus maintenance pillar, reduction in schedulemiss due to operations, and reduction in breakdowns.

The factor Measurement, Analysis and Improvement has significantimpact on attaining the performance of reduction in unscheduled down time in planned maintenance pillar, reduction in schedule miss due to operations, and on innovation on processes / equipments.

Table :2 Samples from TPM awarded companies

Analysis of results from total 60 sample equipments from TPM awarded companies								
		L&SP	EM	T &D	IA	MAI	AARS	GOF
AUTONOMOUS MAINTENANCE								
1	Reduction in scheduled down time	0	β =-0.0 P=0.5	β =-0.5 P<0.001	β =1.52 P<0.001	β =0.00 P=0.5	0.96 P<0.001	0.948
2	Reduction in unscheduled down time	β =-6.21 P<0.01	β =-0.0 P=0.5	β =3.19 P<0.01	β =3.99 P<0.01	β =-0.0 P=0.5	1.00 P<0.001	0.944
3	Increase in speed of the machine	β =6.098 P<0.001	β =-0.0 P=0.5	β =-5.13 P<0.001	β =0.00 P=0.5	β =0.00 P=0.5	1.00 P<0.001	0.965
4	Decrease in product/process variability	β =0.00	β =-0.0 P=0.5	β =0.55 P<0.001	β =1.519 P<0.001	β =0.00 P=0.5	0.96 P<0.001	0.948
5	Reduction in oil consumption	β =0.00	β =-0.0 P=0.5	β =0.55 P<0.001	β =1.519 P<0.001	β =0.00 P=0.5	0.96 P<0.001	0.948
PLANNED MAINTENANCE								
1	Reduction in scheduled down time	β =0.00	β =-2.2 P<0.01	β =0.00	β =3.14 P<0.001	β =0.00	0.96 P<0.001	0.98
2	Reduction in unscheduled down time	β =-0.00 P=0.5	0	0	β =0.62 P<0.001	β =-5.3 P<0.001	1.00 P<0.001	0.997
3	Reduction in schedule miss due to operations	0	β =1.00 P<0.001	0	0	0	1.00 P<0.001	0.998
4	Reduction in breakdown	0	β =1.00 P<0.001	0	0	0	1.00 P<0.001	0.998
QUALITY MAINTENANCE								
1	Reduction in process defects	β =-4.7 P<0.001	β =5.52 P<0.001	0	0	0	1.00 P<0.001	0.997
2	Reduction in final defects	β =-4.7 P<0.001	β =5.52 P<0.001	0	0	0	1.00 P<0.001	0.997
DEVELOPMENT MANAGEMENT								
1	Innovation on processes/equipments	0	0	0	0	β =1.00 P<0.001	1.00 P<0.001	1.0

2.9 Findings from TPM awarded companies;

The analysis from overall 60 samples reveals that at the significant levels of 0.01 and 0.001 the factor Leadership and Strategic Planning, have significant impact in attaining the performance on increase in speed of the machine.

The factor equipment /process management have significant impact on attaining the performance in reduction in schedule miss, reduction in breakdown, and the reduction in ,inprocess and final defects.

The factor training and development have significant impact on attaining the performance of reduction in unscheduled down time, reduction in product/process variability,and reduction in oil consumption .

The factor information architecture has significant impact on attaining the performance on the reduction in scheduled and unscheduled down time, reduction in product/process variability, and reduction in oil consumption.

The factor Measurement, Analysis and Improvement has significantimpact on attaining the performance of innovation on processes / equipments.

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5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India

Table :3 Samples from TPM practicing companies

Analysis of Results from total 60 sample equipments from TPM implementing companies								
		L&SP	PM	T &D	IA	MAI	AARS	GOF
AUTONOMOUS MAINTENANCE								
1	Reduction in scheduled down time	0	0	0	0	β –1.0 P<0.001	1 P<0.001	0.913
2	Reduction in unscheduled down time	β =-0.75 P<0.001	β =0.22 P<0.01	β =0.74 P<0.001	β =-0.7 P<0.001	0	-0.491 P<0.001	0
3	Increase in speed of the machine	0	0	0	0	β =1.0 P<0.001	1 P<0.001	0.913
4	Decrease in product/process variability	0	0	0	0	β =1.0 P<0.001	1 P<0.001	0.913
5	Reduction in oil consumption	β =-1.22 P<0.001	β =0.35 P<0.001	β =-1.5 P=0.35	β =0.09 P=0.15	β =-2.11 P<0.001	-4.2 P<0.001	0
PLANNED MAINTENANCE								
1	Reduction in scheduled down time	β –0.82 P<0.001	β –0.16 P<0.01	β –0.03 P<0.01	β –-0.13 P=0.03	β –0.155 P<0.01	0.947 P<0.001	0.864
2	Reduction in unscheduled down time	β =0.484 P<0.001	β =0.69 P<0.001	β =-0.49 P<0.001	β =-1.02 P<0.001	β =0.23 P<0.001	0.2 P<0.001	0.423
3	Reduction in schedule miss due to operations	β =-0.13 P=0.032	β =-0.72 P<0.001	β =-0.6 P<0.001	β =0.66 P<0.001	β =0.41 P<0.001	0.66 P<0.001	0.731
4	Reduction in breakdown	β =-0.4 P<0.001	β =0.78 P<0.001	β =0.87 P<0.001	β =0.71 P<0.001	β =-0.05 P<0.001	0.55 P<0.001	0.65
QUALITY MAINTENANCE								
1	Reduction in process defects	0	β =0.71 P<0.001	β =-0.02 P=0.43	0	0	β =0.48 P<0.001	0.674
2	Reduction in final defects	0	β =0.71 P<0.001	β =-0.02 P=0.43	0	0	β =0.48 P<0.001	0.674
DEVELOPMENT MANAGEMENT								
1	Innovation on processes/equipments	0	0	0	0	0	0	0

3.0 Findings from TPM practicing companies:

The analysis from overall 60 samples with the significant levels of 0.01 and 0.001, the factor Leadership and Strategic Planning, have significant impact in attaining the performance on reduction in scheduled and unscheduled down time from planned maintenance pillar.

The factor equipment /process management have significant impact on attaining the performance in reduction in unscheduled down time in autonomous maintenance pillar, reduction in scheduled and unscheduled down time in planned maintenance pillar, reduction in oil consumption,reduction in breakdown, and the reduction in inprocess and final defects

The factor training and development have significant impact on attaining the performance of reduction in un scheduled down time in autonomous maintenance pillar,and the reduction in breakdown.

The factor information architecture has significant impact on attaining the performance on the reduction in schedulemiss due to operations, and the reduction in breakdown.

The factor Measurement, Analysis and Improvement has significantimpact on attaining the performance of reduction in scheduled down time,reduction in unscheduled down time in planned maintenance pillar,increase in speed, reduction in product/process variability,reduction in schedule miss due to operations etc. .

3.1Analysis of Findings:

All the hypotheis are analysed with the samples as overall and separately with TPM awarded companies and TPM practicing companies

In all the analysis the factor plant and process management shows significant impact on attaining the performance on reducing the breakdown, inprocess and final defects etc.

TPM-A PDCA APPROACH

In the TPM awarded companies, the results shows, the leadership and strategic planning factor, as identifying the long term and short term targets , allocation of necessary resourses, review by top management etc supports in attaining the performance on increase in speed or performance of the equipment.

The factor equipment/process management by suitable equipment diagnostic techniques,usage of sensors,weaknessimprovement of machine parts ,set up of equipment for zero defects , sensors for detecting the defects etc supports in attaining reduction in schedule miss due to operations, reducing the breakdowns,and for reducing the in process and final defects .

The factor training and development by organizing the training by equipment manufactures, from retired employees, lubricant suppliers, from cooperate companies, developing internal instructors, etc supports in attaining the performance on reducing the process / product variability , reducing the oil consumption, reducing the unscheduled down time

The factor information architecture, as speedy information processing, introducing the operator's minimanual, one point lessons, information on the problem areas by tags etc,supports in attaining the performance in reducing the scheduled and unscheduled down time, reducing the product /process variability, reducing the oil consumption etc.

The measurement analysis factor as reviewing the programmes, design review and debugging etc supports in attaining the performance on innovation on equipments.

In TPM practicing companies the the impact of various factors on performance is analysed and identified the factors.

3.2 Recommendations:

The TPM practicing companies have to implement the practices done in TPM awarded companies as mentioned above,which have significant impact on the results.

It is based on leadership and strategic planning., plant process management, information architecture, training and development, measurement, analysis and improvement for attaining the performance from various pillars.

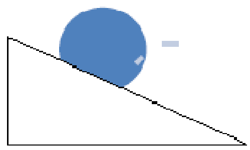

Figure 1 PDCA Approach in TPM

TPM system implementation-

Plan-Leadership & strategic Planning

Do-Plant/equipment/Procesmanagement with the support of HRD & Information architecture'

Check&Act-Monitoring,analysisand improvement

This PDCA approach in implementing the various practices based on the various factors will lead the industries for improving the equipment performance through TPM.

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Suresh.P.K

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Peeyush Mehta
(President, SOM)

Debabrata Ghosh

Debabrata Ghosh
(Conference Chair, SOM)

XIX Annual International Conference of the Society of Operations Management

IIM Calcutta (Dec 11 – 13, 2015)

This booklet contains the abstracts of the papers which were presented in the XIX Annual International Conference of Society of Operations Management (Dec 11 – 13, 2015) held at Indian Institute of Management Calcutta.

TPM PRACTICES AND ITS EFFECT ON EQUIPMENT PERFORMANCE

Suresh P.K, Dr.Mary Joseph T and Dr.Jagathy Raj V.P.

Abstract:

Introduction to the study; In today's industrial scenario, the technological advancements have resulted introduction of sophisticated equipment which supports for the productivity, quality and delivery of products and services and also to the protection of environment and safety.The upkeep of equipment has its own importance since the condition and performance of the equipment has large role in getting its performance. Total Productive maintenance (TPM) concept helps for the scientific upkeep of plant and equipment. This study has the aim give more insights in the concept of total productive maintenance.

Relevance of this study :TPM is originated in Japan and a number of companies in Japan and outside Japan have achieved the prestigious Japan Institute of Plant Maintenance (JIPM) award. India stands for the first out side Japan , where large number of companies are attained this award. A large number of companies in India is engaged in practicing the TPM concepts , but several companies are not succeeded in effectively implementing TPM. A number of studies are undertaken so far relates to the various implementation factors and performance of TPM on an industry basis. There is however a research gap identified about the various implementation factors and performance of TPM on equipment basis. Hence the relevance of the present study.Theoretical framework Dinesh Seth and Deepak Tripathi , National Institute of Industrial Engineering (NITIE), in their study on the "Relationship between TQM and TPM implementation factors and business performance of manufacturing industry in Indian context" have identified the factors which are critical for the effectiveness of TPM as leadership, process management , strategic planning; equipment management ,education and training, information architecture and performance management system etc. Their study considered manufacturing industry as a whole and as per these researchers, their study has opened many research avenues on the interfacial aspects of TQM and TPM . They recommended intensive case studies to be carried out on various modes of TQM and TPM implementation, that the outcome of such studies will definitely be valuable to both Indian and global practitioners, who want to focus attention on manufacturing centric improvement drives.

The performance of TPM is measured based on the productivity, quality, delivery , safety , morale and environment. The improvements in productivity, quality and delivery etc are achieved mainly through the improvements on equipment's overall equipment effectiveness, The overall equipment effectiveness are through the availability of equipment, performance of equipment (increase in quantity of production) and through the production of quality products(reduction in defects of products from equipment etc).

The emphasis on extracted factors which directly influence the results of TPM through overall equipment effectiveness will help companies in realizing the factors which have impact on getting the

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results of TPM through the successful implementation of various TPM pillars. The various independent factors identified in this study: Based on the review of these research papers , the various factors are identified as factors influencing the implementation of TPM. In this research study the various implementation factors as identified are: They are 1.Management Commitment 2. Equipment/process management 3.Training & Development 4. Information Management 5.Monitoring, Analysis and Improvement system The dependent variable is the results of TPM from various pillars. The identified various dependent variables from various pillars are

1.From Autonomous Maintenance pillar:1.Reduction in scheduled down time 2.Increase in speed/ output from the equipment 3. Increase in accuracy level of the equipment 4. Reduction in lubrication consumption
2. From Planned maintenance pillar:1. Reduction in scheduled down time 2.Reduction in breakdown 3.Reduction in scheduled miss due to operations
3. From Quality maintenance pillar:1. Reduction in inprocess defects/ reworks 2.Reduction in final defects
4. From Focussed Improvement pillar: 1. Increase in lean/Kaizen projects on the equipment

Research objective
1. To assess the impact of the factor management commitment on performance of equipment from various manufacturing companies.
2. To assess the impact of of the factor Equipment/process management practices on performance of equipment.
3. To assess the impact of the factor Training and development practices on performance of equipment.
4. To assess the impact of the factor Information architecture practices on performance of equipment.
5. To assess the impact of the factor Monitoring, Analysis and Improvement practices on performance of equipment.

Hypothesis of the study
1. Management commitment has a significant positive effect on performance of the equipment
2. Equipment/process management practices has a significant positive effect on performance of the equipment .
3. Training and development has a significant positive effect on performance of the equipment .
4. Information Architecture has a significant positive effect on performance of the equipment
5. Monitoring, Analysis and Improvement has a significant positive effect on performance of the equipment

Research Design :Empirical survey-based research on a sample size of 100 Critical Equipment from TPM practicing companies

Sample design :The companies are selected based on convenient sampling which includes both awarded for TPM as well as which are in the stage of implementing the TPM practices. From the selected companies, the equipment is selected on a simple random sampling method from the population of critical equipment . A total number of 100 sample equipment is selected from 19 manufacturing companies. A minimum of 10% of the critical equipment are selected from each company..The numbers are generated by a pure random process so that any number has an equal probability of appearing in any position.

Analysis Design :he partial least square, statistical analysis technique is used for analysis. The used statistical tool is Warp PLS 4.0 . PLS-SEM is advantageous when used with small sample sizes (e.g., in terms of the robustness of estimations and statistical power; Reinartz etal., 2009). Primarily, PLS is a non- parametric regression- based estimation method whose focus is on the prediction of a specific set of hypothesized relationships.(Albers 2010; Hair et al.2011a).

Conclusion of findings: As per the findings, the significant positive correlation is evidenced between the identified TPM factors with most of the performance indicators from various TPM pillars and no significant correlation is evidenced for a few performance indicators. The management commitment, individually and together with various factors proved the positive effect on maximum performance indicators of TPM from various pillars.

The study contributes to TPM by validating the relationship between the different factors of TPM implementation and its effect on equipment performance.

It gives more focus to the companies which are implementing TPM to implement the best practices of TPM to get benefited with the results from the equipment. The designed schedule can be used for evaluating the implementation of TPM in a simple way. The performance indicators mentioned in the schedule give clear direction to measure the performance of the equipment. Some of the reviewed literature, support the positive effect of these factors on TPM performance on an industry basis. Management commitment is identified as one of the main factors for the success of TPM in almost all the studies.

Recommendations;

The management commitment as the fixing of long term and short term objectives, assigning the duties and responsibilities, providing the resources including training, the periodic review of the progress in implementation and the continuation of the practices even with the changes in leadership etc strongly supports in getting the results of performance of the equipment. Other factors as Equipment plant/process management practices, Training & motivation, Information architecture and Monitoring, Analysis & improvement etc individually and together with various factors showed significant positive effect on certain performance indicators .So the mentioned various TPM implementation factor's importance on achieving the results are evidenced. The effective implementation of these practices can show the results on the equipment. So the TPM practicing companies can effectively implement these practices for attaining results from equipment.

Limitations and scope for further research: This study did not include any cost return factor which indicates the cost of TPM implementation and its return by the improved performance of the equipment. Also the TPM pillars as Development Management,Safety, Health , Environment etc. are not assessed in this study. The time period of implementation of TPM in the selected samples are also not assessed in this study.

Further empirical research should be conducted to assess the cost return factor of TPM based on the nature of the equipment, and also studies can be done on other performance of TPM as on development of products and equipment , and on the performance on environment and safety.

Assessing the impact of human behavior on workflow policies in production flow lines: A simulation approach

Vinay Kalakbandi.

Abstract: Production flow lines are the most widely accepted type of production system of discrete manufacturing. Doerr et al (2002) conjecture "no production method has yet been developed that can rival its efficiency". Production line design is therefore of prime importance to a manufacturing company as it is a strategic core activity of the company and directly affects the company's operational costs and throughput. Hence, it is required to utilize and develop the production lines in the most efficient way. With cost reduction wars becoming fiercer in today's competitive markets, manufacturing system designers use every possible trick in the book to achieve higher operational performance in production lines. Manufacturing system designers, however, are notorious for "virtually ignoring" the impact of human behavior on production line performances (Fletcher et al. 2008; Doerr et al. 2002). Incorporation of behavioral nuances in manufacturing system design has therefore been the focus of many recent publications.

QUESTIONNAIRE							
Company name:							
Equipment name:							
AUTONOMOUS MAINTENANCE							
1	Reduction in scheduled down time						
2	Increase in speed /performance of the equipment						
3	Decrease in product/process variability						
4	Reduction in oil consumption						
MANAGEMENT COMMITMENT			1	2	3	4	5
1	Targets fixed on the equipment for improvement						
2	Responsibility is assigned for the equipment						
3	Necessary resources provided like spares, etc ,including training						
4	Reviews of improvement on the equipment done chairedby top management persons						
5	Activities are continued on the equipment with any change in person also						
6	Duties of autonomous and planned maintenance are clearly defined on the equipment						
EQUIPMENT AND PROCESS MANAGEMANT			1	2	3	4	5
1	Operator level actions to remove dirt ,scattered materials, oil leakages, bolt tightening etc on the equipment						
2	Cleaning materials , tools , spares etc are kept near to equipment						
3	Storage procedures for tools, jigs ,etc with routine cleaning etc are available for the equipment.						
4	In the equipment ,lubrication is standardised and monitored, automated						
TRAINING & DEVELOPMENT			1	2	3	4	5
1	Necessary skill requirements identified for the equipment						
2	On job training programmesis available on the equipment operation for upgradation of the skill of staff members						
3	Internal trainers are available on the equipment						
4	Retired staff is engaged with training activity to share their experience on the equipment						
5	Training conducted by lubricant vendors						

	to solve the problems on the equipment						
6	Video technology supported training done on the equipment						
7	Each employee have their own schedule on the equipment operation and maintenance						
8	Training by cooperate companies to lead the level of assessment of the equipment						
9	Own research and by outside consultants like OEM's for better cleaning and lubrication on the equipment						
10	Increase in employee suggestions/,Quality circle participation for the improvement of the equipment						
11	Multi skill training on the equipment for operation and maintenance						
INFORMATION ARCHITECTURE			1	2	3	4	5
1	Speedy information processing and efficient distribution about the performance status of the equipment						
2	Operators mini manual available with description of production system, machine abnormalities, etc about the equipment						
3	One point lessons available with plant description on the equipment						
4	Review of O &M manuals about the equipment done with updated field conditions etc						
5	Tags kept on the equipment in problem areas and the contents are transferred to log books						
MONITORING, ANALYSIS AND IMPROVEMENT			1	2	3	4	5
1	The results are reviewed against the targets at frequent period						
2	Feed back from the stake holders are received						
3	The real problems are analysed and the reasons are identified						
4	Corrective actions done on all the problems						

	PLANNED MAINTENANCE						
1	Reduction in scheduled down time						
2	Reduction in schedule miss due to operations						
3	Reduction in breakdown						
MANAGEMENT COMMITMENT			1	2	3	4	5
1	Targets fixed on the equipment for improvement						
2	Responsibility is assigned for the equipment						
3	Necessary resources provided like spares, etc ,including training						
4	Reviews of improvement on the equipment done chairedby top management persons						
5	Activities are continued on the equipment with any change in person also						
6	Duties of autonomous and planned maintenance are clearly defined on the equipment						
EQUIPMENT AND PROCESS MANAGEMANT			1	2	3	4	5
1	Maintenance time cycle is established for effective weakness improvement of the equipment						
2	Major parts of the equipment prone to wear and tear are put to predictive maintenance						
3	Equipment diagnostic technologies as vibration analysis etc ,and TBM & CBM are used						
4	Equipment analysis by instruments and sensors and maintenance cycle are determined						
5	Equipment improved for ease of autonomous maintenance						
6	Failure analysis done on the equipment to enhance improvement						
TRAINING & DEVELOPMENT			1	2	3	4	5
1	Necessary skill requirements identified for the equipment						
2	On job training programmesis available on the equipment operation for upgradation of the skill of staff members						
3	Internal trainers are available on the equipment						

4	Retired staff is engaged with training activity to share their experience on the equipment						
5	Training conducted by equipment manufacturers						
6	Video technology supported training done on the equipment						
7	Training done on hydraulics, pneumatics, electrical, instruments, etc						
8	Increase in employee suggestions/,Quality circle participation for the improvement of the equipment						
9	Multi skill training on the equipment for operation and maintenance						
INFORMATION ARCHITECTURE			1	2	3	4	5
1	Speedy information processing and efficient distribution about the performance status of the equipment						
2	Operators mini manual available with description of production system, machine abnormalities, etc about the equipment						
3	One point lessons available with plant description etcon the equipment						
4	Review of O &M manuals about the equipment done with updated field conditions etc						
5	Tags kept on the equipment in problem areas and the contents are transferred to log books						
6	Communication of problems of the equipment from other users with vendors						
7	CMMS used in equipment deterioration, breakdown, spares management, etc						
8	Maintenance requirements of the equipment is published well in advance						
MONITORING ANALYSIS AND IMPROVEMENT			1	2	3	4	5
1	The results are reviewed against the targets at frequent period						
2	Feed back from the stake holders are received						
3	The real problems are analysed and the reasons are identified						
4	Corrective actions done on all the problems						

QUALITY MAINTENANCE							
1	Reduction in process defects/reworks						
2	Reduction in final defects						
MANAGEMENT COMMITMENT			1	2	3	4	5
1	Targets fixed on the equipment for improvement						
2	Responsibility is assigned for the equipment						
3	Necessary resources provided like spares, etc ,including training						
4	Reviews of improvement on the equipment done chairedby top management persons						
5	Activities are continued on the equipment with any change in person also						
EQUIPMENT AND PROCESS MANAGEMENT			1	2	3	4	5
1	Monitoring of inward material for identifying the defects						
2	Equipment is monitored regularly for its performance level on quality						
3	Monitoring of production done at frequent periods by sensors etc for identifying the defects						
4	Analytical tools as Pareto analysis, why-why analysis, etc are effectively used in defect analysis						
TRAINING & DEVELOPMENT			1	2	3	4	5
1	Necessary skill requirements identified for the equipment						
2	On job training programmesis available on the equipment operation for upgradation of the skill of staff members						
3	Internal trainers are available on the equipment						
4	Retired staff is engaged with training activity to share their experience on the equipment						
5	Training conducted by equipment manufacturers						
6	Video technology supported training done on the equipment						
7	Necessary training and research to reduce the defects caused by equipment						
8	Increase in employee						

	suggestions/,Quality circle participation for the improvement of the equipment						
9	Multi skill training on the equipment for operation and maintenance						
INFORMATION MANAGEMENT:			1	2	3	4	5
1	Speedy information processing and efficient distribution about the performance status of the equipment						
2	System is established for information on defective products from the equipment and for further tracking						
3	Mistake proofing systems in progress in the equipment						
MONITORING, ANALYSIS AND IMPROVEMENT			1	2	3	4	5
1	The results are reviewed against the targets at frequent period						
2	Feed back from the stake holders are received						
3	The real problems are analysed and the reasons are identified						
4	Corrective actions done on all the problems						
FOCUSSED IMPROVEMENT							
1	Number of lean/kaizen projects						
MANAGEMENT COMMITMENT			1	2	3	4	5
1	Targets fixed on the equipment for improvement						
2	Responsibility is assigned for the equipment						
3	Necessary resources provided like spares, etc ,including training						
4	Reviews of improvement on the equipment done chairedby top management persons						
5	Activities are continued on the equipment with any change in person also						
TRAINING & DEVELOPMENT			1	2	3	4	5
1	Necessary skill requirements identified for the equipment						
2	On job training programmesis available on the equipment operation for upgradation of the skill of staff members						

3	Internal trainers are available on the equipment						
4	Retired staff is engaged with training activity to share their experience on the equipment						
5	Training conducted by equipment manufacturers						
6	Video technology supported training done on the equipment						
7	Increase in employee suggestions/,Quality circle participation for the improvement of the equipment						
8	Multi skill training on the equipment for operation and maintenance						
INFORMATION ARCHITECTURE			1	2	3	4	5
1	Speedy information processing and efficient distribution about the performance status of the equipment						
2	Information on improvements on similar equipments are available						
3	Review of loss from the equipment is performed regularly for zero loss activity.						
MONITORING, ANALYSIS AND IMPROVEMENT			1	2	3	4	5
1	The results are reviewed against the targets at frequent period						
2	Feed back from the stake holders are received						
3	The real problems are analysed and the reasons are identified						
4	Corrective actions done on all the problems						