

Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars

Case: Nile sole Factory

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A Thesis submitted to the School of Graduate Studies of Addis Ababa University
in partial fulfillment of the Degree of Masters of Science in Mechanical
Engineering (Industrial Engineering Stream)

**ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY**

April, 2019

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING
INDUSTRIAL ENGINEERING STREAM

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DECLARATION

I hereby declare that the work which is being presented in this thesis entitled **“Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars ”** is original work of my own, has not been presented for a degree of any other university and all the resource of materials used for this thesis have been accordingly acknowledged.

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Acknowledgement

First of all, thanks to the Almighty GOD for giving me the patience to start and finalize this thesis work. He has always been with me, led my path and helped me to achieve my goals.

Secondly, I am deeply extending my sincere appreciation to my advisors Dr. Kassahun Yimer and Haileleul Mamo together with team of advisors lead by Dr.Kassu Jilcha for their valuable advice, constant support, commitment, dedication, encouragement and precious guidance, creative suggestions and critical comments from the beginning to the end of the project. Without their urge, no doubt, this work would not have been possible at all. Thirdly, a word of thanks must also go to all production Technical, and Quality team leaders and also technicians and machine operators of Nile Sole factory, for their cooperation in providing data, filling out questionnaire. Special thanks should also be addressed to production and Technical manager of Nile sole factory Ato Ermiyas Habte for his support for allowing me get necessary information from the company.

Abstract

Large number of framework of Total Productive Maintenance (TPM) pillars have been proposed by different authors in TPM literature. However, most of them are based on studies done in countries such as Japan, Italy, USA, China and India. Thus, this study aims to evaluate selected TPM pillars contribution towards manufacturing performance on Nile Sole Factory. Production, Downtime, reasons of downtime, scrap level, and rework data is collected from the Nile sole factory and analyzed to see the current performance of the company. A survey methodology is used where questionnaires are distributed to 35 employees of the factory with the resulting response rate of 97 %. Using descriptive statistics tools, the correlation between TPM Pillars and manufacturing performance dimension has been calculated. The Pillar most emphasized on the survey is planned maintenance while the least emphasized Pillar is on office TPM. To support the result from the output of descriptive statistics, AHP (analytic Hierarchy Process) is used. The study reveals that the TPM Pillar – focused improvement, planned maintenance, autonomous maintenance and Training and education have significant contribution towards manufacturing performance such as lower cost, higher equipment availability, strong delivery and increased Flexibility. A new model has been developed in which the last Pillar Safety Health and environment (SHE) diffused in all the four pillars. This pillar has an intangible benefits in making employers safe and well and indirectly impact the productivity. All selected four pillars have activities that help safety of the shop floor when fully implemented. Sustaining safety activities in all the pillars will play significant role in making the working environment safe working place.

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Acronyms

FMEA - Failure mode Effect Analysis

JIPM - Japan institute of Plant maintenance

JIT- Just in time

MTBF- Mean Time between failures

OEE - Over all Equipment effectiveness

OPL- One point lesson

PU- Polyurethane

PVC- Polymerizing vinyl chloride

RCFA- Root cause failure analysis

SGA- Small group activity

SME -Small and medium size enterprises

SPSS-Statistical Package for the Social Sciences (software)

TPM - Total Productivity Maintenance

TQM- Total Quality Management

VCG - Volvo car gent

AHP – Analytic hierarchy process

MP1- Cost

MP2- Availability

MP3- Delivery

MP4- Flexibility

Chapter One

Introduction

1.1 Introduction

The concept of TPM provides quantitative metric OEE for measuring the effectiveness of equipment in production line. TPM is an exceptional method which is developed from preventive maintenance concept for plant maintenance and management. The actions of TPM eliminate the equipment related losses and improve availability, performance rate and quality rate (S.nallusamy & Gautam majumdar 2017). In the earlier days, when ‘mass production’ was at its peak, the primary function of operation was to get the equipment running. Once it has broken down, it will be repaired and rectified by the maintenance people. Generally the operations department would not want the equipment to stop as it was more focused on meeting the daily targets. Since breakdown maintenance tends to keep the shop floor idle for a longer time, the concepts of scheduled maintenance and routine maintenance were introduced. Routine maintenance can be considered as a cyclic operation recurring periodically, where outlines are established by defining the frequency of the tasks and the time taken to complete the task. Scheduled maintenance on the other hand is defined as the ‘periodic replacement of parts based on their age’ Alorom,.M. (2016).

As the competition in market started increasing, organizations found out a different way to carry out maintenance leading to the next phase: i.e. ‘Preventive Maintenance (PM)’. This approach to maintenance was based on the belief that if the equipment was occasionally stopped and maintenance was performed regularly as per schedule, the catastrophic breakdowns could be avoided. Mostafa (2004) defined PM as the practice that encompasses all planned, scheduled and corrective actions before the equipment fails. In other words, PM can be defined as follows: “actions performed on a time or machine-run based schedule that detect, preclude, or mitigate degradation of a component or system with the aim of sustaining or extending its useful life through controlling degradation to an acceptable level”.

Breakdown maintenance or reactive maintenance is the idea of repairing equipment after failing. This method can lead to major impacts on the production depending on the severities of the

failure mode. Primary failure modes such as boiler or compressor breakdown will lead to a complete shutdown of the entire factory which will lead to large profit loss and thereby creating a need for scheduling PM. However, it is not possible to schedule PM to all the equipment in the entire plant due to scarcity of resources, especially to industries that do not practice PM traditionally. Total Productive Maintenance (TPM) is an innovative approach employs to maximize equipment effectiveness by establishing a comprehensive productive-maintenance system covering the entire life-span of the equipment. TPM brings maintenance as a vital part of the business. (Tan Ching et al 2017).

Since performance of facilities and equipment is critical to a manufacturer's ability to produce low-cost, high-quality products; an effective maintenance became increasingly important. Managers too slowly recognized the criticality of the maintenance function to organizational success. This recognition of equipment's role in manufacturing led to the development and growing implementation of a comprehensive concept of equipment repair, service and maintenance. In response to it, the Japanese in 1971 introduced the concept of Total Productive Maintenance (TPM).

TPM is a techniques and an effective tool which aimed at increasing the productivity and quality by reducing the rejection, proper maintenance and availability of equipment and focusing toward no defect. TPM is a lean tool which establishes a system of productive maintenance, covering the entire life cycle of equipment, covers all departments, involves participation of all the employees from the top to bottom i.e., from management to the shop floor (Kholopane, P.A. 2008). The concepts of the TPM were first introduced in Japan by Seiichi Nakajima who is the father of TPM who gives a fundamental concept and also explains the steps for implementing TPM in Industry. The first implemented of TPM strategy in M/S Nippon Denso co. Ltd of Japan in the year 1971. TPM is method of a tool which wholly depends on the OEE which was proposed by Nakajima. Therefore, TPM can be considered as treatment to improve the performance of machines. TPM is a maintenance program for maintaining plant and equipment.

1.2 Back ground and Justification

Maintenance is a function in an organization that operates in parallel with production. The primary output of production is the desired product and its secondary output is demand for maintenance, which is in turn an input for the maintenance function. Maintenance results in a

secondary input to production in the form of production capacity. While production manufactures the product, maintenance produces the capacity for production. Therefore maintenance affects production by increasing production capacity and controlling the quality and quantity of output (Prabowo, H. et al. 2015).

The TPM concept addresses itself to the maximization of overall plant and equipment effectiveness through the elimination or minimization of losses, creating a sense of ownership for plant and equipment operators through a process consisting of training, involvement and promoting continuous improvement through small group activities involving production, engineering and materials personnel. (Narender and A. Gupta 2012)

The manufacturing systems are often operated at less than that of full capacity, resulting in low productivity and high operating costs. The cost of operating and maintaining equipment has become a significant factor in the production of goods in an increasing competitive global environment. Now days, consumers expect manufacturers to provide highest quality, reliable delivery and competitive pricing. This demands that the manufacturer's machines and machining processes are highly reliable. In order to maintain highly reliable machines, there is a need of smooth manufacturing process. Many organizations have been implemented Total Productive Maintenance (TPM) as the enabling tool to maximize the effectiveness of equipment by setting and maintaining the optimum relationship between people and their machines (Kishor Kumar Aroor, et.al 2015).

This thesis will focus on Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars in Nile Sole factory. The company produces different kinds of sole and supply to local market. It operates 24 hours a day through three shifts. In all the shifts corrective maintenance team attend to handle breakdown. No other approaches are used to minimize loses or to improve the production efficiencies of the machines other than fixing after break down. Maintenance in TPM is recognized as an important and valuable resource. Maintenance group now has a role in making the business more profitable and the manufacturing system more competitive by continuously improving the capability of the equipment, as well as making the practice of efficient maintenance. To gain the full benefits of TPM, it must be applied in the proper amounts in proper way and should be integrated with the production system and other improvement initiatives.

Effectiveness and efficiency of equipment plays a major role in modern manufacturing industry to determine the performance of the organizational production function as well as the level of success achieved in the organization. (Prabowo, H. A et al 2015).

Apart from this, the production scenario is highly challenging, often faced with huge losses and wastage that occur on the production floor. Some of the reasons for this wastage can be attributed to the operators skill set, inadequate knowledge of the maintenance personnel, inappropriate process flow, non-availability of components when required and poor infrastructure. Other forms of waste include frequent equipment failures, idle equipment and equipment running below the desired capacity. There are clear maintenance and production problems in Nile Sole and shoe factory reflected as low equipment utilization, low quality rate and high amount of rework.

Quality related wastes have significant impact on the industry due to wastage of raw material invested and monetary commitments. There are also other invisible wastes, like operating the equipment below the rated speed (speed losses), startup losses, and unplanned break down of the equipment in bottle neck processes. All these losses and wastages on the production floor need to be measured and quantified. The quantified data will allow taking timely, necessary corrective action in reducing the losses and wastages.

There is a saying in the industry that “what cannot be measured cannot be managed effectively.” Therefore, every company needs to measure their maintenance performance in order to remain competitive (Parida and Kumar, 2006).

In today’s competitive and fast moving environment, companies are looking for quicker and faster results. To achieve this, a fast-track TPM implementation approach is required. However many companies have attempted to implement TPM programs, less than 10% of companies succeeded in implementing TPM (Mora, 2002). Given the wide scope of TPM program (8 pillars), it can be a difficult task to carry all the 8 pillars of TPM at one go. Also, it can be a big challenge for local firms to roll out TPM since there are already other existing practices. This situation prompts us to see new ways and methods of doing things. Therefore a new approach was needed for TPM program so that companies could see fast results that would impact their performance

1.3 Problem statement

One of the efforts of the government of Ethiopia is to decrease the imported items that can be produced and covered by local companies. It approves many stimulating policies for investors to invest in manufacturing; not only initiate new investments but also there is a need for the operating companies to be efficient in their businesses. One of the locally capable businesses is manufacturing of sole and shoe. Nile sole factory is one of such companies operated in this business since 1993.

Nile sole factory has corrective maintenance personals that correct machines during breakdown. The maintenance team function is to respond for calls from machine operators whom their machine is failed. In other words operate until failure is considered to be the most practical maintenance strategy. The team is organized in such a way that it adequately respond to the failures occurred during each production shift. No other approaches are used to minimize machine downtime and enormous rework. But this situation leads to more resource, spare part and manpower requirement. The cost of maintenance is usually overlooked from being calculated, reported and documented.

Operator's activity is limited to manipulate the machine and shows no sign of ownership. From three active machines followed for three days the recorded average MTBF (mean time between failure) is 125min and the average mean time to repair (MTTR) is 24min which indicates significant amount of unavailability in the production machines this figure does not include major breakdowns happened which took days for the machine to resume operation. The average rework or failed PVC soles per shift is 23kg/ three machine it equals 50 pair of soles. By looking relative bench marks which is the best observed throughput of the machines; the throughput is very low. The best observed historical throughput for a single machine is good 140 pair per shift/machine. The observation shows throughput of 80.96 pair per machine per shift which is 67.5% of the bench mark.

Using pillars of TPM will revert such a problem (Gupta, P. and Vardhan, S. 2016).Successful utilization of TPM will keep production machines in basic condition, improves product quality and equipment up time. Therefore this paper will find out how using TPM improves manufacturing performance in the case company.

Mora, (2002) wrote on the challenges of TPM, Many companies have attempted to implement TPM program but less than 10% of the companies succeeded in implementing TPM. There are

many factors for this but the relatively wide scope of TPM program is one of the main factor. Therefore we need to see options for successful utilization of the program by focusing on the scope.

1.4 Research Question

1. What manufacturing performances should be addressed to solve the current problem of the company?
2. What are the main aspects of TPM to be considered to improving manufacturing performance in the case company?
3. How does using Selected TPM tools improve manufacturing performance In Nile Sole factory?

1.5 Objective of the Research

1.5.1 General Objective.

- Main objective of this research is to investigate the current manufacturing performance of the case company and improve using selected TPM pillars.

1.5.3 Specific Objective

- To investigate current manufacturing performance problems
- To minimize TPM implementation cost.
- To identify TPM pillars significantly affecting current manufacturing problems.
- To develop new TPM model.

1.6. Scope of the research

This research focuses on the manufacturing performance of Nile sole factory shop floor in order to boost them to increase production and limited on Sole the production wing of the factory which also has other types of products in its premises like PVC pipe production. The paper also has limited to research the main problems of hindering manufacturing performance in the case company and their counter remedy from the view of TPM pillars and has limited chance of to test the practicality of the Pillars proposed.

1.7. Benefit of the Research

- The research can reflect Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars.
- The research can help and encourage small manufacturing companies to use important TPM tools with less implementation cost to improve their performance.
- The result can show the gap of the company and at least initiate some measures for improvement.

1.8 Organization of the Research

The first chapter gave a brief overview of the research objectives, the problems and issues addressed in the research and motivation for the research. The second chapter contains a literature review of the research work performed in the areas of maintenance optimization, maintenance planning, maintenance modeling, followed by a brief note on types of maintenance policies. The third chapter deals with maintenance practice in the case companies. The fourth chapter presents with the validation, simulation and application of the hypothesis and presenting the gaps in the maintenance practice in the case companies. The fifth chapter provides the conclusions and recommendation.

Chapter Two

Literature Review

2.1. Introduction to TPM

The literature has revealed that the manufacturing organizations worldwide are facing many challenges to achieve successful operation in today's competitive environment. Modern manufacturing requires that to be successful, organizations must be supported by both effective and efficient maintenance practices and procedures. Over the past three decades, manufacturing organizations have used different approaches to improve maintenance effectiveness (Boateng,K.A. et.al 2016). One approach to improving the performance of maintenance activities is to implement and develop a TPM strategy. The TPM implementation methodology provides organizations with a guide to fundamentally transform their shop floor by integrating culture, process, and technology (Moore, 1997).

TPM is a methodology originating from Japan to support its lean manufacturing system, since dependable and effective equipment are essential pre-requisite for implementing Lean manufacturing initiatives in the organizations (Ravi .N and Pavan. M.2015). While Just-In-Time (JIT) and Total Quality Management (TQM) programs have been around for a while, the manufacturing organizations off late, have been putting in enough confidence upon the latest strategic quality maintenance tool as TPM.

TPM is a production-driven improvement methodology that is designed to optimize equipment reliability and ensure efficient management of plant assets (Pandy D. &Raut N.2016). TPM is a change philosophy, which has contributed significantly towards realization of significant improvements in the manufacturing organizations in the West and Japan (Alorom,,M. 2016).

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

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

Table 2.1TPM development in Japan source (Nakajima, 1989)

Era	1950's	1960's	1970's
Emerging Concepts	Preventive Maintenance – Establishing scheduled maintenance functions	Productive Maintenance (PM) – Recognizing the importance of equipment reliability, maintenance	Total Productive Maintenance (TPM) – Achieving PM efficiency through a comprehensive approach
Supporting Theories	Preventive Maintenance (PM) 1951 - Productive Maintenance (PM) 1954 - Maintainability Improvement (MI) 1957	- Maintenance Prevention (MP) 1960 - Reliability Engineering 1962 - Maintainability Engineering 1962 - Engineering Economics	Behavioral Science - Management by Innovation and Creation (MIC) - Performance Analysis and Control (PAC) - Systems Engineering - Ecology - Terotechnology - Maintenance Logistics
Significant historical events	1951 – Toa Nenryo Kogyo 1st Japanese company to adopt PM 1953 – 20 Japanese companies form a PM research group which later became JIPM 1958 – American George Smith visits Japan to promote PM	1960 – Japan hosts the first international maintenance convention 1962 – Japan Productivity Association sends an envoy to the U.S. to study equipment engineering 1963 – Japan attends the International Convention on Equipment Maintenance in London 1964 – the first PM prize is awarded to Nippondenso in Japan 1969 – Japan Institute of Plant Engineers (JIPE) established, later to become Japan Institute of Plant Maintenance (JIPM)	1970 – the annual International Convention on Equipment Maintenance held in Japan 1973 – the United Nations Industrial Development Organization sponsors a Maintenance Repair Symposium in Japan

TPM represents a radical change in the way maintenance is being look at. It is a methodology and philosophy of strategic equipment management focused on the goal of building product quality by maximizing equipment effectiveness. Originally introduced as a set of practices and methodologies focused on manufacturing equipment performance improvement, TPM has matured into a comprehensive equipment-centric effort to optimize manufacturing productivity (Ahuja and Pankaj, 2009). The goal of TPM or also known as Total Productive Manufacturing is to continuously improve all operational conditions of a production system by stimulating daily awareness of all employees (Nakajima, 1989). It is not something that is only implemented and contributed by top level management. Rather it involves from the very top of the organization till the shop level workers. An effective TPM implementation program provides for a philosophy based upon the empowerment and encouragement of personnel from all areas in the organization (Davis and Wilmott, 1999). TPM is a system or culture that takes advantage of abilities and skills of all individuals in an organization (Patterson et al., 1996).

Two different approaches towards the definition of TPM can be found from the Japanese approach represented by Nakajima (1989), Tajiri and Gotoh (1992) and Shirose (1996) while the Western approach is represented by Willmott (1994), Wireman (1991) and Hartmann (1992) although there are significant commonality within the two (Bamber et al., 1999). The differences in the Japanese and Western approach to defining TPM are subtle, with commonality highlighted more than significant variation. The Japanese approach emphasizes the role of teamwork, small group activities and the participation of all employees in the TPM process to accomplish equipment improvement objectives. The Western approach focuses on the equipment while understanding that operator involvement and participation in the TPM effort is required. While very similar, the Japanese approach seems to be more people and process focused while the Western definition approaches first from equipment improvement objectives, “which moves the emphasis away from both maintenance and teamwork and towards equipment management and utilization with operator participation” (Pandy D. &Raut N.2016).

According to Shingo (2007), TPM has these 5 basic precepts. Firstly, to build a profitable operation by making production more economical through the elimination of accidents, quality defects in products and breakdowns of machines. Next, practice prevention rather than cure

through initiatives such as maintenance prevention, preventive maintenance and corrective maintenance. TPM also has to involve everyone in the organization and practices participatory management. It uses hands on or shop floor approach by bringing the equipment into its ideal state, introduce extensive visual control and create clean, uncluttered and well organized workplaces. Lastly, TPM aims to create a virtuous circle of workplace expertise by developing a self-sustaining, continuously evolving culture of self-directed workplace management.

Nakajima (1989), a major contributor of TPM, has defined TPM as an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns, and promotes autonomous maintenance by operators through day-to-day activities involving the total workforce (Soliman, Saurin & Anzanello, 2018). The emergence of TPM is intended to bring both production and maintenance functions together by a combination of good working practices, team-working and continuous improvement (Pandy D. & Raut N. 2016). Willmott (1994) portrays TPM as a relatively new and practical application of TQM and suggests that TPM aims to promote a culture in which operators develop “ownership” of their machines, learn much more about them, and in the process realize skilled trades to concentrate on problem diagnostic and equipment improvement projects. TPM is not a maintenance specific policy, it is a culture, a philosophy and a new attitude towards maintenance. TPM is a system (culture) that takes advantage of the abilities and skills of all individuals in an organization (Patterson et al. 1995). An effective TPM implementation program provides for a philosophy based upon the empowerment and encouragement of personnel from all areas in the organization (Alorom, M. (2016). Strategic TPM implementation can also facilitate achieving the various organizational manufacturing priorities and goals as depicted below:

Productivity (P):

Reduced unplanned stoppages and breakdown that improves equipment availability and productivity also provide customization with additional capacity, quick change-over and design of product.

Quality (Q)

Reduce quality problems from unstable production and reduced in field failures through improved quality. Provide customization with additional capacity, quick change-over and design of product

Cost (C)

Reduce Life cycle cost, use efficient maintenance procedures, supports volume and mix flexibility and reduced quality and stoppage-related waste.

Delivery (D)

Support of JIT efforts with dependable equipment, Improve efficiency of delivery, speed, and reliability and Improve line availability of skilled workers

Safety (S)

Improved workplace environment, realizing zero accidents at workplace and eliminates hazardous situations.

Morale (M)

Make significant improvement in kaizen, increase employees' knowledge of the process and product, Improve problem-solving ability increase in worker skills and knowledge and employee involvement and empowerment (A.huja and J.S. Khamba 2008).

2.2. TPM Eight Pillars

The key elements of TPM are known as “pillars” and sometimes they are called activities (Sulistyoadi. Y et al 2016). The naming and the number of the pillars are slightly different from author to author, however, they all based on Nakajima's TPM pillars. Accordingly, each company that intends to apply the maintenance starts the application of these pillars as commensurate with its status. Mishra, Pandey D. & Raut N. (2016) had discussed about TPM pillars as elements of TPM frameworks and said that the literature of TPM have listed a large number of them proposed by different consultants and authors. Most of these frameworks were developed by consultants based on their consultancy experience with different organizations. These frameworks were studied and it was found that just few frameworks are unique while in others, the naming and the number of pillars differ slightly (Sulistyoadi. Y et al 2016).

In accordance with the assessment criteria of Japan Institute of Plant Maintenance depends on the category of the reward. Companies that have introduced TPM and are applying for TPM

award, they must achieve eligibility and requirements for each category. The main two eligibilities include deployment activity based on the five pillars of TPM and focusing on the production site (individual improvement, autonomous maintenance, and planned maintenance, education and development, safety, sanitation and environment control) for category B. The second eligibility is deploying activity based on the eight pillars of TPM by all staff members of the plants (individual improvement, autonomous maintenance, planned maintenance, initial management, quality maintenance, administrative and supervisory department, education and development, safety, sanitation and environment control) for category A (Soliman. M et al 2018) As a result of these classifications, it was evident that worldwide companies fulfilled at least five pillars and in some cases went beyond the original Japanese model by building additional customized pillars (Cigolini and Turco, 1997). According to Davis (1997), cited in Bamber, Sharp, and Hides (1999), the successful implementation of full TPM pillars needs to allow sufficient time.

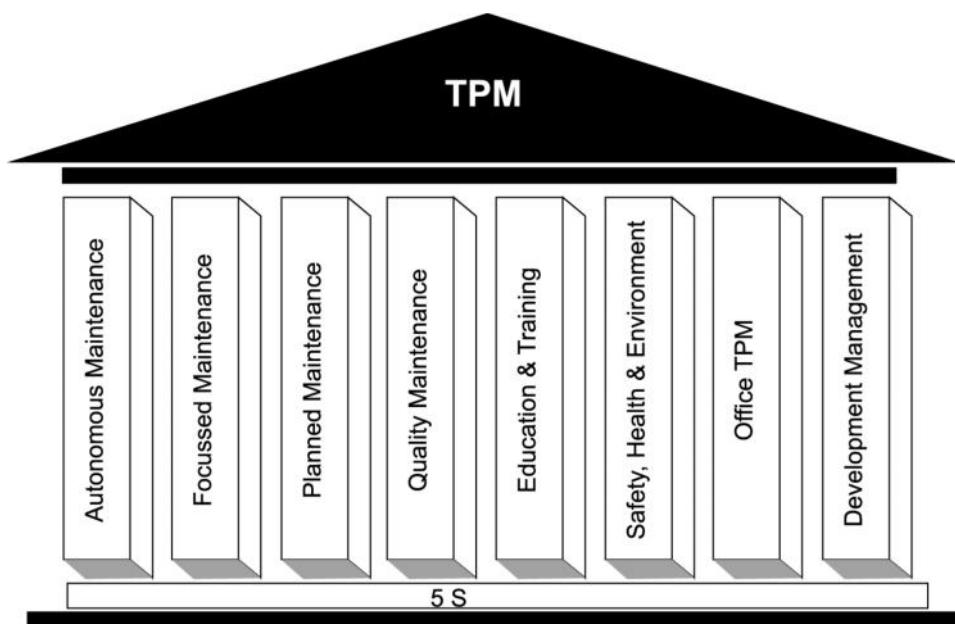


Figure 2.1 eight pillars approach for TPM implementation (Nakajima 1988)

The Japan Institute of Plant Maintenance (JIPM) classified the TPM activities to eight pillars as follows

1. Focused Improvement (Kobetsu Kaizen): Focused improvement it is also referred to as (FI), it includes all activities that aim to maximize the overall effectiveness of the equipment (OEE) and the overall efficiency of the plant (OEP) through fighting all the causes of losses and eliminating them permanently, and, also, the achievement of the zero proportion in losses in all activities and reducing costs and improving performance. The term Kaizen consists of two words “Kai” which means change, and “Zen” which means to the better, and the term “Kobetsu which means focused. So, focused improvement means all activities that maximize the equipment effectiveness through the complete elimination of losses and enhancement of performance (Nakajima, 1988).

2. Autonomous Maintenance (Jishu Hozen): It is also referred to as (AM). It means that the operators do some minor maintenance for their own equipment such as inspection, lubrication, and cleaning. It is a unique feature of TPM done by operators. In order to implement autonomous maintenance correctly, the seven steps’ approach and the 5s are recommended (Nakajima, 1988). The implementation of Autonomous maintenance takes place after conducting operator training and rehabilitation in order to be able to perform some basic maintenance tasks for the equipment and to keep them under good operation condition as well as to prevent any deterioration of the equipment. The training also includes performing the daily routine maintenance work and knowledge of some simple repair works. This will make the workers able to identify faults and eliminate them without having to stop work and wait for long periods for the technicians. Therefore, autonomous maintenance is a self-maintenance efficient approach that depends on the level of training and capabilities of workers who operate the equipment, also it needs a degree of cooperation between different sections and departments of operation and maintenance.

3. Planned Maintenance (Keikaku Hozen): It is also referred to as (PM). It means maintaining the equipment to have defect free products and high plant availability (JIPM, 2010). It also means implementing the maintenance work through planning, control and organising the information related to maintenance activities, including methods, materials, labour and the required times. The aim of planned maintenance is to ensure equipment performance at its best with a minimum of maintenance costs and enabling equipment to work at an optimal level at all times.

4. Quality maintenance: It is also referred to as (QM). It means maintenance focusing on tasks that keep machines producing quality and defect-free products based on the basic idea that says maintaining perfect equipment to maintain perfect quality of products, and hence ensuring all operations run at a consistent level of quality (J.Reyes et al 2018). The JIPM defines quality maintenance as the creation of conditions which prevent defects in the product and control these circumstances to get to the stage of zero defects.

5. Training and Education: It is also referred to as (TE). It means improving the abilities of individuals to be multi-skilled employees (J.Reyes et al 2018). Education and training aims to provide operators with different skills so that they can accomplish all the tasks required of them very effectively and independently. The operators may not understand the main operating principles of the equipment, and also the maintenance crew may not know some of the modern methods of maintenance, so it must include training on the basic requirements for the maintenance of overall productivity, and improve the skills of all employees in the field of maintenance.

6. Early equipment and process management: It is also referred to as Maintenance prevention (MP), it is also known as early management (Suzuki, 1994). It is improvements to the equipment before normal operation can begin as part of a comprehensive approach to maintenance prevention and maintenance free design which is performed by production engineering and maintenance personnel (Nakajima, 1988). Early equipment management aims to develop a new design of the equipment, so that it works to reduce maintenance to a minimum or eliminate it, so, in general that enhances the competitiveness of the organization. The early equipment management is to develop the maintenance systems and the introduction of the concept of quality maintenance during the design phase, in order to improve the operational reliability of the equipment. The new design can be made to the current equipment, so that they can produce new products in high quality, through cooperation and coordination between the manufacturer of the equipment, engineers and specialists in the organization (J.Reyes et al 2018)

7. Safety, health, and environment: It is also referred to as (SHE). It means focusing on the workplace and surrounding area's safety to achieve an accident free workplace. Nakajima (1988) "Ensuring equipment reliability, preventing human error, and eliminating accidents and pollution are the key tenets of TPM". This pillar of total productive maintenance confirms that all the

improvements which have been developed in the organization by the rest of TPM pillars do not diminish the overall performance of safety, health and environment criteria in the organization (M. M. Jafari and Ghavam, 2014).

It also confirms that the actions and resources used to make substantial improvements in the performance of the manufacturing process are also in place to make similar improvements in the field of safety, health and environment. TPM is interested to preserve the safety, human health and the environment by providing a safe working environments free of the causes of accidents, injuries and occupational diseases (Narender and Gupta, 2012).

8. Office TPM: It is related to the activities that improve the efficiency and effectiveness of logistic and administrative functions (E Y T Adesta et al. 2018). Implementing total productive maintenance not only in the field of production, but also applied in the administrative work of the organization in order to get rid of losses and to improve productivity and efficiency in administrative jobs and tasks as well as to diagnose and remove losses. This includes the analysis of processes and procedures. All the problems and losses in administrative work must be eliminated or minimized to a large extent. There are losses in communication, disruption of office equipment, breakdown in communication channels, losses of time spent in data retrieval, and expenses purchases or emergency shipments (Pandy D. &Raut N.2016)

2.3 Overall Equipment Effectiveness and six big losses

Performance of a productive system is measured using a core quantitative metric called OEE or Overall Equipment Effectiveness. OEE is often used as the core metric of measuring TPM implementation program (J.Reyes et al 2018). OEE methodology incorporates metrics from all equipment manufacturing guidelines into a measuring system that helps manufacturing and operations teams improve equipment performance and therefore reduce equipment cost of ownership (Ravi .N et al 2015)

Nakajima (1988) stated that OEE is an effective way of analyzing the efficiency of a single machine or an integrated manufacturing system. It is a function of availability, performance rate and quality rate which are actually measures of equipment losses. Nakajima (1988) defines the losses into six major categories which are breakdown losses, setup and adjustment losses, idling and minor stoppage losses, defect and rework losses, speed losses and start-up losses. Based on

the above losses, OEE is calculated by obtaining the product of availability of equipment, performance efficiency of the process and rate of quality products as shown below (Ravi .N et al 2015). The calculation of OEE by considering the impact of the six major losses on the production system is also indicated in Figure 2.2 (McKellen, 2005).

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

Where:

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

Loading time is the planned time available per day (or month) for production operations and downtime is the total time during which the system is no operating because of equipment failures, setup/adjustment requirement etc.

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

Processed amount refers to the number of items processed per day (or month) and operating time is the difference between loading time and downtime.

$$\text{Quality Rate (Q)} = \frac{\text{Processed amount} \times \text{Defect amount}}{\text{Processed amount}} \times 100$$

Defect amount represents the number of items rejected due to quality defects of one type or another and requires rework or become scrapped.

Downtime losses

Equipment failure: It is the time loss when the equipment breaks down due to some problem. It is often referred to as sudden failure in which the machine stops completely (Nakajima, 1988).

Setup and adjustment: It is the periods in which the equipment was stopped to make some changes to the product or the tools. It may include cleaning and making adjustment to the equipment to get stable quality in the product (Ravi .N et al 2015).

Speed losses

Small stops (Idelling): It is the idling and minor stoppages. In other words, it is the events of interrupting the production flow without actually making the equipment fail like a production jam or a warning given to an operator. The losses in this area can be considerable in some cases more than losses caused by breakdown losses (Ravi .N et al 2015).

Reduced speed: They refer to the variance between machine design speed and actual operating speed (Bamber, Sharp, and Motara, 2003). The factors that impact the capacity of the machine are the speed and volume of the output (Boeteng K. et al 2016).

Quality losses

Start-up losses: They are the losses due to low performance in the beginning of the operation of the equipment or the production line till reaching stability (Bamber, Sharp, and Motara, 2003).

Production rejects: They are also known as quality defects and re-work. They are the losses in quality which occur when products are not conforming to the specifications

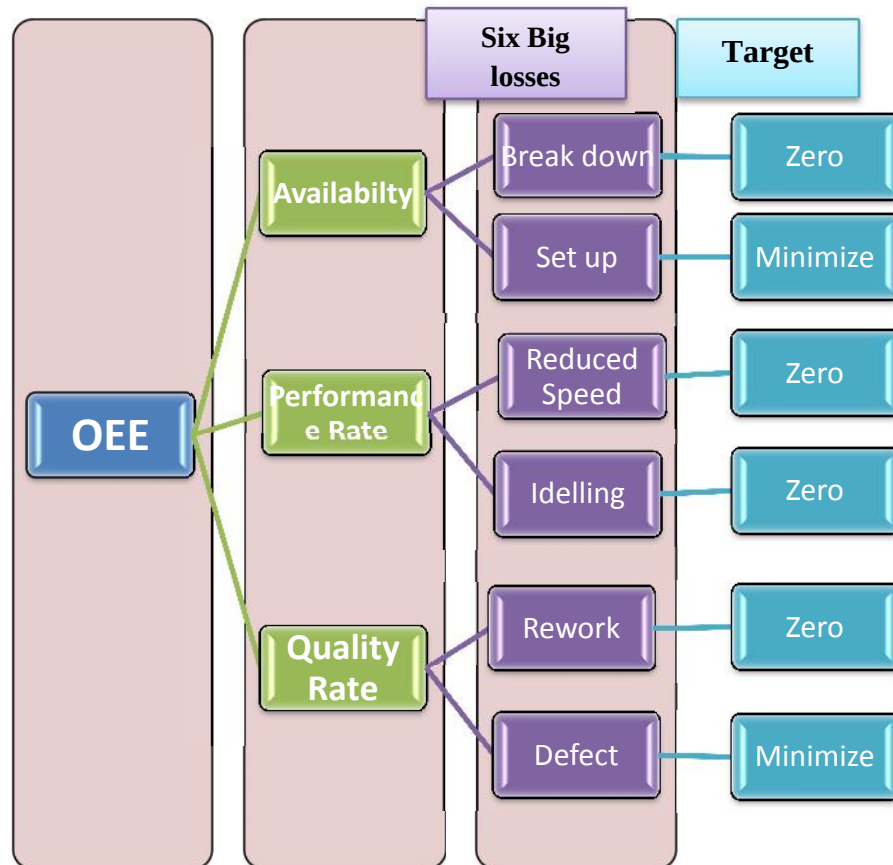


Figure 2.2 Show the OEE Model. (Chetan S. Sethia et.al 2014)

2.4 Tools of TPM

A variety of tools are often used to help the deployment of activities through TPM programs based on these pillars. Among the tools used by TPM to analyze and solve equipment and process related problems are Pareto Analysis, Statistical Process Control (SPC – control charts, etc), problem solving techniques like brainstorming, cause and effect diagrams and 5M Approach, visual control like OPLs, Poka-Yoke Systems, Autonomous Maintenance, Continuous Improvement, 5S, Setup Time Reduction, Waste Minimization, Bottleneck Analysis, Recognition and Reward Program and Simulation ((Boeteng K. et al 2016)

One of the tools mentioned is 5S which is based on a Japanese approach to establishing and maintaining an organized and effective workplace. It is often used during plant cleaning activities and is a systematic method to organize, order, clean, and standardize a workplace and keep it that way (Productivity, 1999). The elements of 5S include Seiri (Organization), Sieton (Orderliness), Seiso (Cleaning), Seiketsu (Cleanliness) and. Shitsuke (Discipline) (Willmott 1994). Figure below shows the key activities to be deployed for effective 5S implementation at workplace.

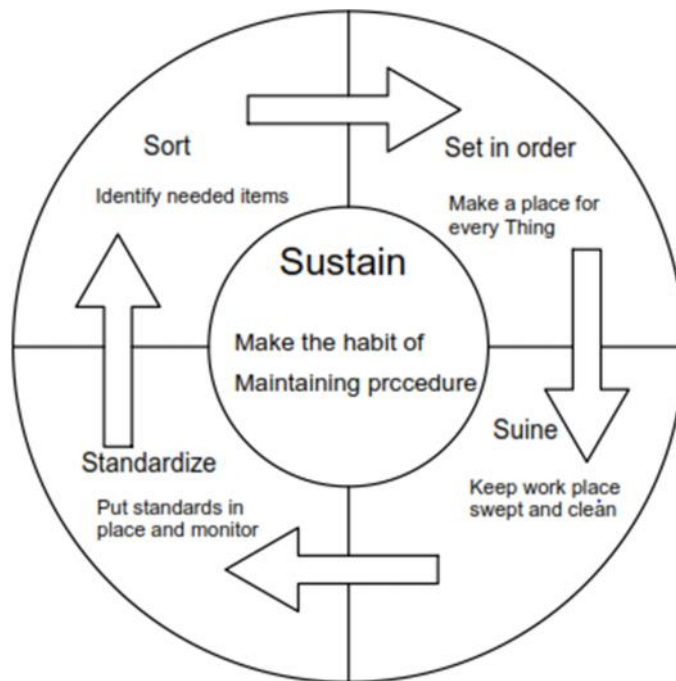


Figure 2.3 Key activities for effective 5S implementation at the workplace (Zahid Habib and Kang Wang 2008)

It is noticeable that there are many instruments supporting the implementation of TPM and helping to unleash full potential of TPM pillars as other lean manufacturing techniques, TPM integrates with the developed and proven maintenance strategies and it borrows techniques and tools from other disciplines. These tools are briefly defined as following:

The overall equipment effectiveness (OEE) is a method to measure TPM success (Prabowo H. et al 2015)

The statistical process control (SPC) is the use of statistical techniques to analyze a process and its outputs to improve the capability of the process (Jostes and Helms, 1994). The SPC and the Computerized Maintenance Management System (CMMS) are a data collection and analysis tools (Pomorski, 2004).

The six sigma is a tool that provides the structure needed to ensure the equipment is working optimally. It means that it brings possibilities identifying, qualifying and eliminating the activities that does not bring benefits for defining the new work standards (Szewieczek, Roszak, and Helizanowicz, 2008).

The visual control (VC) gives an early warning signal and indicates the correct position of equipment gauges (Leflar, 2001).

The plan, do, check, and act cycle (PDCA) is tool to drive TPM program to affect enhancement in the maintenance function (Ahuja and Khamba, 2008c).

Poka-yoke (mistake proofing) is a key tool to eliminate defects and accidents (Szewieczek, Roszak, and Helizanowicz, 2008).

Problem solving techniques are those techniques that use to get to the root cause of the problem, for example, brainstorming, fishbone diagrams, why-why analysis, and the 5m approach (Jostes and Helms, 1994).

PM analysis consists of the following: define the problem; proceed with physical analysis; list the conditions causing the problems; assess the equipment, materials, and methods; develop investigation techniques; eliminate negative factors; submit improvement proposals (Nakajima, 1988).

The one point lesson (OPL) is a training tool that takes from 5 to 10 minutes to enhance the operators' skills. This form is a tool that helps to effectively and efficiently communicate TPM training concepts to participants and employees. The One Point Lesson form is structured to motivate the trainer to establish all important activities onto one simple and easy to use. (Sun, Yam, and Wai-Keung, 2003).

Brainstorming is a tool used to help with the difficulty of managing the views of a large group and to run the meeting effectively (Prabowo H. et al 2015)

The why-why analysis or the 5-whys Analysis is a tool which seek to find the roots cause of the problem's by asking 5 why. Root Cause Failure Analysis (RCFA) is used to understand the core reason of problems. It is not a tool to fully eliminate equipment failure by overhaul, repair or replace new equipment, but we could prevent from reoccurrence of the problems by analyzing through RCFA. By doing RCFA, at least we can prevent or predict the timing of failure (MTBF). RCFA can anticipate, delay, prolong or control the process failure. There are several tools can be used to do RCFA likes Fishbone Diagram, FMEA, Pareto Analysis, Fault Tree Analysis and others. Maintenance people traditionally have culture to have fast solution by jumping into repairing and modification without knowing or tackle the root cause of problems (Pandy D. & Raut N.2016).

The single minute exchange of die (SMED), or quick changeover, is a method to reduce downtime caused by any process of change from one product to another. It measures the total time from the moment of completion of the last unit of the first product to the time of commencement of the first unit of second product.

Spare parts management is one of the key processes which supports effective world class maintenance scheduling and planning and machines reliability improvement (Pandy D. & Raut N.2016).

2.4.1 Summary

Tools that use to run and facilitate TPM are very important to sustain it. They are a means to lay in practice all the edifices of TPM. Without using these tools almost we cannot run TPM and get the advantages of it. The more and consistently use of this tools properly defines how the company is effective in implementation of the TPM.

2.5 Effectiveness of TPM

Total Productive Maintenance has been practiced and examined for a period of time in many factories worldwide and most of the results indicate that it has worked well (Davis, 1997). Also, the benefits of implementing TPM are ten times more than the costs incurred Alorom,.M. (2016). In fact, the correct application of TPM will increase productivity, raise morals, save energy and increase job satisfaction for workers (Shen, C. C., 2015) mentioned that the actual targets of TPM are fixed more concretely in terms of Production, Quality, Cost, Delivery, Safety and Morale (Shen, C. C., 2015). On the other hand, Wireman (2004) indicated that the average cost of conventional maintenance is about 28% of the total production cost, and the average of the technicians' actual work is about 2-3 hours per day in the companies that relies by about 50% on reactive maintenance, while they spend the remaining time involved in non-productive activities. Whereas, The TPM program puts the maintenance function at the center of attention as a vital and essential part of any project, which is no longer seen as a non-profit function but considered in the development of the production scheduling and maintenance and has become in many cases an integral part of the productivity process itself.

Practicing TPM tasks can significantly enrich the operators work, gives them new experiences, strengthens their skills, and generates a feeling of property and ownership Hence, TPM program is not just a production strategy, but a new philosophy of continuous development and collective action which creates a sense of ownership among the employees at all levels and the assets of the company and creates new directions for their commitment and responsibility. The idea behind implementing TPM is not just for achieving a zero defect product, zero breakdown, and zero accident for a period of time, but about how to keep this rate of achievement as long as the organization is working. The benefit of TPM can be divided into tangible and intangible benefits. (Alorom,.M. 2016)

Tangible benefits:

Increase in overall equipment effectiveness (OEE), reduce the life cycle cost of equipment., eliminate unplanned downtime, minimize planned downtime, increase customers' satisfaction and decrease their complains, reduce the manufacturing cost (maintenance and production) and reduce accidents and scraps are tangible benefits.

Intangible benefits:

Improve in the ideas submitted, employees' confidence level went up, employees get the feeling of machines' ownership, working as a team cheers the employees up, sharing the experience, Clean workplace provides psychological comfort and job enrichment are some of the intangible benefits.

2.6 TPM relationship with manufacturing performance

TPM has a strong positive impact on multiple dimensions of MP. While TPM directly impacts MP, there is also a strong indirect relationship between TPM and MP through JIT. Maintenance programs have long been used as a means to control manufacturing costs. TPM does more than control costs, it can improve dimensions of cost, quality, and delivery. TPM can be a strong contributor to the strength of the organization and has the ability to improve MP (Kathleen et al 2001)

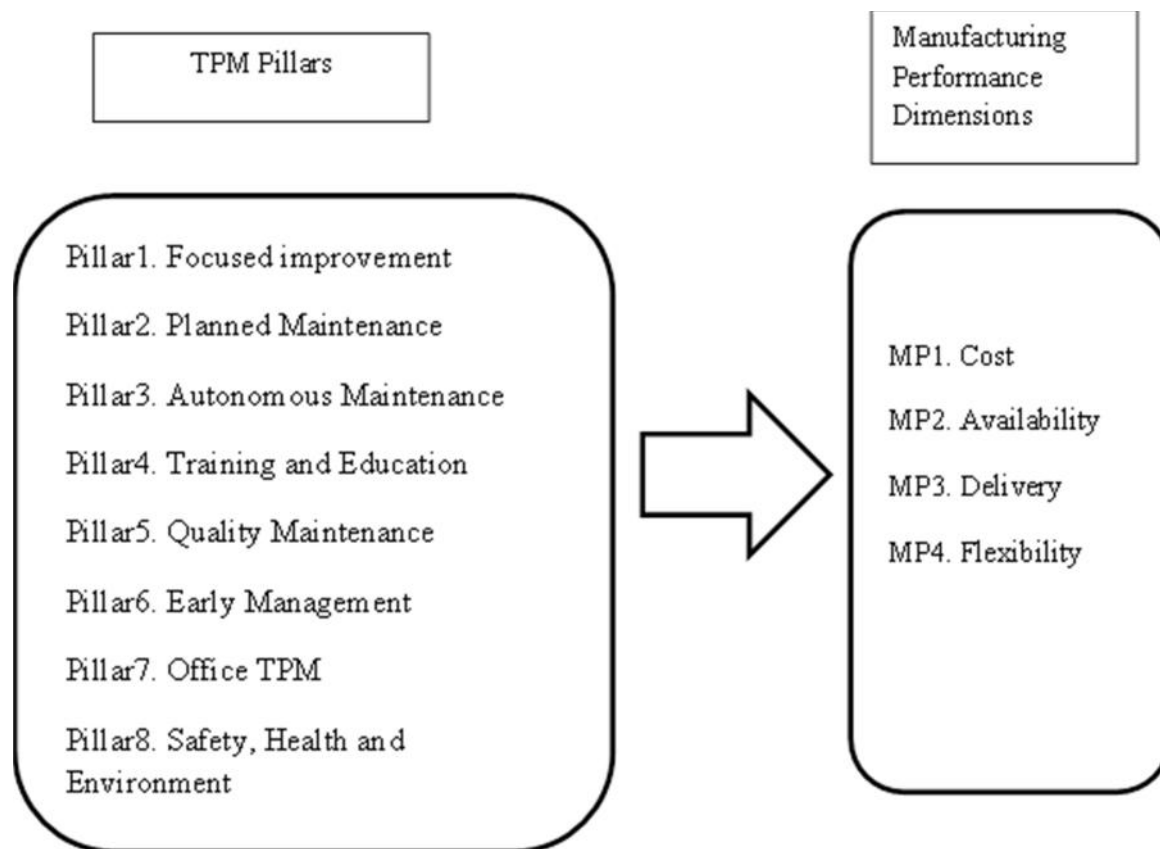


Figure 2.4 TPM pillars relation with manufacturing performance (Kathleen et al. 2001)

2.7 Total Productive Maintenance Elements and measures

In Japan, early TPM programs follows a strict implementation process by Japan Institute of Plant Maintenance (JIPM) which led to many plants winning TPM awards (Nakajima, 1988). From then on, many literatures can be found on TPM framework model such as Kathleen et al. (2001) who have investigated the relationship between TPM and manufacturing performance through structural equation modeling and Ireland and (A.Sivanantham et al 2017) who has elaborate implication of TPM in various manufacturing organization. TPM Club India has also produced frameworks of TPM elements which only differ in naming from Nakajima's framework (TPM Club India, 2003). Shen, C. C., (2015) on the other hand, places importance on maintenance prevention in his framework and also emphasis on training to improve the skills of the people involved in TPM.

From this exhaustive literature review, Nakajima's Eight TPM Pillars or elements have been taken investigation on the shop floor to identify the pillars which contributes significant role towards manufacturing performance.

Pill1. Focused improvement	Pill5. Quality Maintenance
Pill2. Planned maintenance	Pill6. Early Management
Pill3. Autonomous Maintenance	Pill7. Office TPM
Pill4. Training and Education	Pill8. Safety, Health and Environment

Focused improvement (Pillar1) complements this by using why-why and P-M analyses to eliminate losses and improve equipment reliability ((Shen, C. C., 2015). Focused improvement includes all activities that maximize the overall effectiveness of equipment, processes, and plants through uncompromising elimination of losses and improvement of performance (Suzuki, 1994). The driving concept of Focused Improvement is Zero Losses. Maximizing equipment effectiveness requires the complete elimination of failures, defects and other negative phenomena – in other words, the wastes and losses incurred in equipment operation (Nakajima, 1989). Focused Improvement has been, and still is, the primary methodology for productivity improvement in the fabrication process and the key metric for Focused Improvement is Overall Equipment Effectiveness (OEE) 1 (Thomas 2003). Focused Improvement includes three basic

improvement activities. First, the equipment is restored to its optimal condition. Then equipment productivity loss modes (causal factors) are determined and eliminated.

Planned maintenance (Pill2) typically requires discipline planning process for maintenance task, good information tracking systems to capture data for problem solving and schedule compliance as an indicator of the health of the planned maintenance management system (Kathleen et al., 2001). The key to effective Planned Maintenance is to have a PM plan for every tool. The PM plan is based on the history and analysis of failure modes to determine preventive practices. The PM plan consists of:

Five elements which are as follows (Leflar, 1999):

1. A set of checklists for PM execution.
2. A schedule for every PM cycle.
3. Specification for every PM cycle.
4. Procedure for every checklist item.
5. Maintenance and parts logs (equipment maintenance history) for every machine.

Investigating how well these tasks are executed in permanent bases will measure the impact of the pillar on the manufacturing performances.

Autonomous maintenance (AM) (Pill3) goals are to develop equipment competent operators and also to empower operators to look after their own equipment (Shingo, 2007). TPM through AM enables operator to learn more on their equipment function, identify common problems and how to prevent them through early detection and treating of abnormal conditions (Kathleen et al., 2001). TPM also embraces empowerment to production operators, establishing a sense of ownership in their daily operating equipment. This sense of ownership is an important factor that underpins TPM to its continual success with every operator being responsible to ensure their machine is clean and maintained (Shen, C. C., 2015). AM enables operators to perform basic maintenance task such as housekeeping task which includes cleaning and inspection, lubrication, precision check and other light maintenance task.

The final TPM Pillar that would be emphasized is Education and training (Pillar4) which involves not only transforming organization culture and redefining of roles but also skills and technical upgrade for everyone in operation, maintenance and support group (Tsang and Chan, 2000). Training and educational issues has become one of the critical factors to establish successful TPM implementation, where proper education begins as early as during TPM introduction and initial preparation stage (A.Sivanantham et al 2017). Training and education provide the necessary skill, knowledge and the ability to make it happen, (Gupta, P. & Vardhan, S.,2016). Wiremen (1991) also emphasized on training to improve the skills of the people involved in TPM and have classified it into two major components. One is soft skill training, such as how to work as teams, diversity training and communication skills. The second is technical training, which ensures that the employees have the technical knowledge to make improvements to the equipment's (Shen, C. C., 2015).

In order to evaluate the manufacturing performance dimensions accrued as a result of effective emphasis of TPM tools, a five point scale will be used in this study (Rating mechanism: 1 – no correlation at all, 2 – nominal impact, 3- some impact, 4 – reasonable impact, 5 – extensive impact/correlation).

2.8 Manufacturing Performance elements and measure

In this study, the paper focuses on manufacturing performance at the plant level. Since the plant does not control sales or costs outside the plant, overall financial measures of plant performance are not appropriate. Rather, the basic dimensions of plant performance which are controlled by the plant are used: cost, availability, delivery, and flexibility (Skinner, 1969; Schroeder, 1993; Ward et al., 1995). I discuss the measurement of each of the four dimensions of plant performance in this section. Appendix 1 has the details of survey questions on selected TPM Pillars and Manufacturing performance.

Cost is interpreted to mean not only the traditional accounting cost of manufacturing, but we cost, the measurement taken is maintenance cost; the scrap level, amount of break down and machine down time. A high scrap level indicates a high cost position.

Availability from manufacturing point of view is the probability that a component is performing its required function at a given point in time when used under the stated operating conditions.

Availability of a component or subsystem governs the uptime of a machine system. it accounts for both repairs and failures which directly influenced by the skill of maintenance personals and the follow up on machines which includes the execution of planned maintenance cleaning and inspection done on regular basis by the operators.. Through focused improvement the causes of breakdowns would be analyzed and counter measures implemented to prevent the reoccurrence of the same failure.

Delivery performance includes two different measures: the percentage of orders delivered on time (or filled from stock) and the manufacturing lead-time from when an order is placed until it is delivered. These measures are indicative of a plant's ability to deliver quickly and as promised.

Finally, flexibility can be measured in a number of different ways. It is chosen to use two measures: the length of time that it takes to change the production schedule mainly the time taken for a machine to produce anther product and the capability to add a new product in the existing mix. Most plants have a frozen production horizon inside of which they do not take additional orders or make changes to existing orders. This production horizon measures a plant's capability to make changes and, of course, a shorter horizon offers more flexibility.

2.9 Frame works of TPM

A framework can act as a guide and it provides a structured way to achieve certain objectives. A review of literature revealed that different frameworks of TPM are available. Among them, very few frameworks were proposed by academicians, while most of them were proposed by consultants who have developed these frameworks based on their consultancy experience with various organizations. In all these frameworks, the principal activities of TPM are organized as 'pillars/elements'.The elements of different frameworks are shown below.

Table 1.2 Different frameworks of TPM (R.P Mishra et.al 2008)

1 Seiichi Nakajima 1 Focused improvement (Kobetsukaizen) 2 Autonomous maintenance(Jishuhozen) 3 Preventive maintenance 4 Training and education 5 Maintenance prevention (Initial flow control) 6 Quality maintenance 7 Administrative TPM 8 Safety and environmental Management	2 TPM Club India 1 Individual improvement 2 Autonomous maintenance 3 Planned maintenance 4 Education and training 5 Development management 6 Quality maintenance 7 Office TPM 8 Safety, health and environment
3 Aramis Management System 1 Safety and environmental management 2 Focused equipment and process improvement 3 Work area management 4 Operator equipment maintenance 5 Maintenance excellence for TPM 6 Education and training 7 Human resource management 8 Administration and support systems improvement 9 New equipment management 10 Process quality management	4 Strategic Work Systems Inc. 1 Improving equipment effectiveness by targeting the major losses 2 Involving operators in daily runtime maintenance of their equipment 3 Improving maintenance efficiency and effectiveness 4 Training for everyone involved 5 Life-cycle equipment management and maintenance prevention design 6 Winning with teamwork focused on common goals
5 Volvo Cars Gent 1 Customer-ordered production 2 Individual improvement 3 Autonomous management 4 Planned maintenance 5 Quality management 6 Early product management 7 Early equipment management 8 Logistics 9 People management 10 Office management 11 Safety and environment 12 Supplier support 13 Integration in society	6 Yeomans and Millington 1 Increase equipment effectiveness 2 Training 3 Autonomous maintenance 4 Early equipment management 5 Planned preventive maintenance system

7 Terry Wireman 1 Maximize equipment effectiveness 2 Improve maintenance efficiency and effectiveness 3 Train to improve the skills of all people involved in TPM 4 Involve operations personnel in daily maintenance of equipment 5 Manage equipment in order to prevent maintenance	8 The Centre for TPM (Australasia) 1 Safety and environmental/risk management 2 Focused equipment and process improvement (Macro and Micro) 3 Work area management 4 Operator equipment management 5 Maintenance excellence management 6 Logistics and support improvement 7 New equipment/product management 8 Education and training 9 People support systems improvement 10 Process quality and innovation management
9 Imants BVBA Consulting and Services 1 Autonomous maintenance 2 Equipment and process improvement and overall equipment effectiveness 3 Planned maintenance 4 Early management of new equipment 5 Process quality management 6 TPM in administrative and support departments 7 Education and training 8 Safety and environmental management	10 Australian Die Casting Association 1 Operator equipment management (autonomous maintenance) 2 Equipment and process improvement (equipment improvement) 3 Planned maintenance 4 Education and training 5 Process quality management (quality maintenance) 6 New equipment management (maintenance prevention) 7 Administration system improvement (TPM in the office) 8 Environmental and safety management
11 Cayman System 1 Autonomous maintenance 2 Quality maintenance 3 Planned maintenance 4 Individual improvement 5 Training, people development 6 Environment Health and Safety (EHS) 7 Early equipment management 8 5S's	12 Phillips 66 (Borger and Sweeny Complexes) 1 Team running maintenance 2 Focused improvement 3 Planned maintenance 4 Support, service and training 5 Total quality conditions 6 Teamwork

13 Society for Maintenance and Reliability Professionals 1 Restoring equipment to a new like condition 2 Operator involvement in maintaining equipment 3 Improving maintenance efficiency and effectiveness 4 Training people to improve their job skills 5 Equipment management and maintenance prevention 6 Effective use of preventive and predictive maintenance technology	14 Advanced Productive Solutions (S.L. Barcelona) 1 Focused improvement 2 Autonomous maintenance 3 Effective maintenance 4 Quality maintenance 5 TPM in administration 6 Safety, health and environment 7 Training and education 8 Early maintenance
15 Promaint Inc. 1 Focused improvement 2 Autonomous maintenance 3 Planned maintenance 4 Training and education 5 Initial phase management 6 Quality maintenance 7 Efficient administration 8 Safety and environment	16. MAX International Engineering Group 1 Small group activities to eliminate the major equipment losses 2 Integrated maintenance system 3 Planned maintenance system 4 Improving education and skills 5 Feedback process for product, process and equipment improvement 6 Quality maintenance system 7 Administrative system 8 Safety, hygiene and environmental system
17. Steinbacher and Steinbacher 1 Maintenance prevention 2 Predictive maintenance 3 Autonomous maintenance 4 Corrective maintenance 5 Preventive maintenance	18 Society of Manufacturing Engineer 1 Improve equipment effectiveness 2 Involve operators in daily maintenance 3 Improve maintenance efficiency and effectiveness 4 Education and training 5 Designing and managing equipment for maintenance prevention
19 Shekhar Jitkar 1 Individual improvement 2 Planned maintenance 3 Initial control 4 Education and training 5 Autonomous maintenance 6 Quality maintenance 7 Administration 8 Safety, health and environment	20 Venkatesh 1 5S 2 Autonomous maintenance (Jishu hozen) 3 Kobetsu kaizen 4 Planned maintenance 5 Quality maintenance 6 Training 7 Office TPM 8 Safety, health and environment

It was also found that, among the frameworks surveyed; only very few frameworks are unique, while most of them are more or less similar. Only the naming and the number of pillars/elements differ slightly ,(Gupta, P. & Vardhan, S.,2016)

Yeomans and Millington (1997) who has developed their model based on the theory of classic Japanese TPM approach, which is built on five strategic pillars which is no 6 on the table. The other similar simplified model is shown in on no 17 on the table (Steinbacher and Steinbacher, 1993).This framework model also comprises of five pillars. This is the model followed by Western countries and the authors have emphasized on training and education as an integral element of their pillars rather than a stand-alone pillar as in the Nakajima model (Steinbacher and Steinbacher, 1993).

However, there are also a few models that are totally different from JIPM such as Aramis Management System, Volvo Cars Gent, and the Centre for TPM Australasia. One example is the implementation of TPM at Volvo Cars Gent (VCG) which is based upon 13 committees or development pillars. Some of the unique pillars in this framework are: customer ordered production, early product management, logistics, supplier support and integration in society (Volvo Cars Gent, 1998).

2.10 Simplified Pillars from the literature.

As stated above Some Western TPM practitioners have simplified the Nakajima model by eliminating pillars. #6 on the above table 2.2 for example, presents a five-pillar model those maps to five of Nakajima's pillars. (Yeomans and Millington 1997)

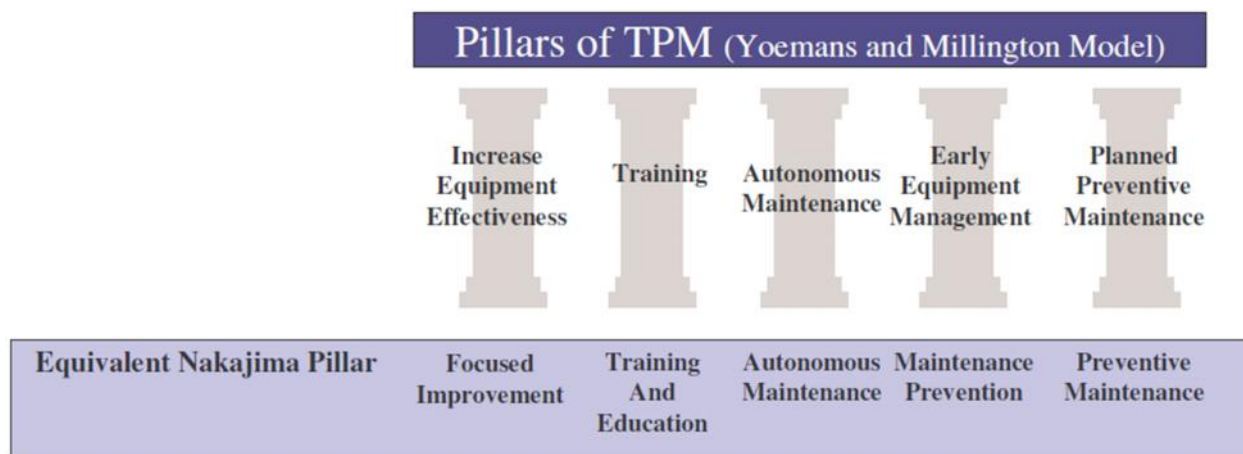


Figure 2.5 TPM Pillars (Yoemans and Millington Model 1997)

Here Yoemans and Millington select five of the most important pillars from Nakajima's eight pillars that directly influence the performance on the shop floor.

A similar simplified Western pillar model is presented in Figure 2.6. (Steinbacher and Steinbacher 1993) In this model, Training and Education are an integral element of the other pillars rather than a stand-alone pillar as in the Nakajima Model.

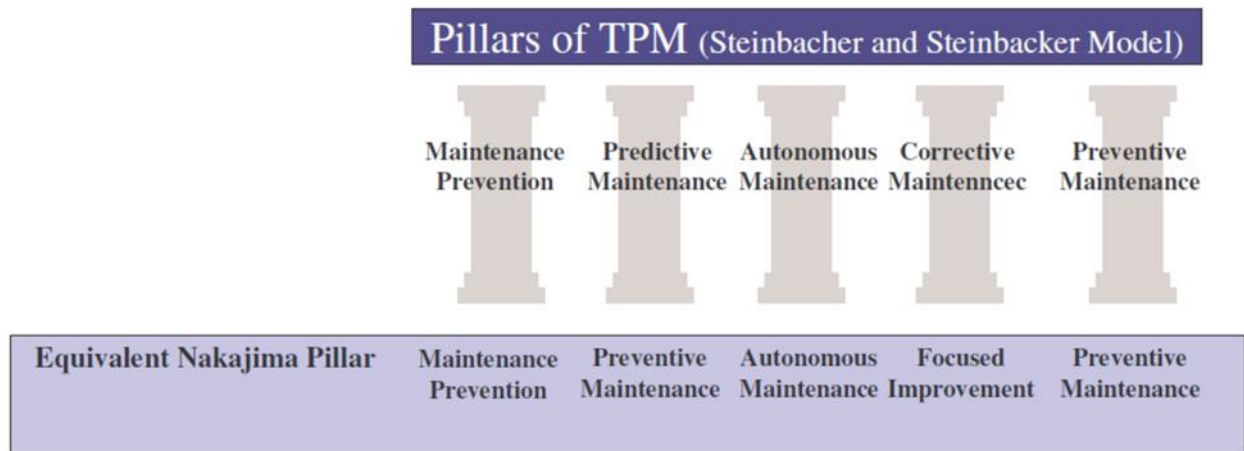


Figure 2.6 TPM Pillars (Steinbacher and Steinbacher Model 1993)

And in Figure 2.7: (Society_of_Manufacturing_Engineers 1995)

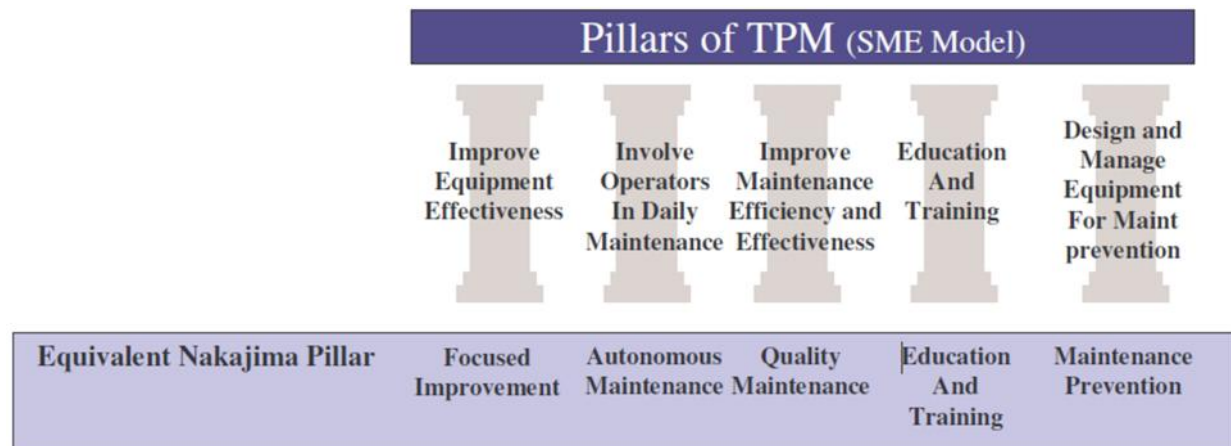


Figure 2.7 TPM Pillars (SME Model) Society_of_Manufacturing_Engineers 1995)

Since implementation of TPM program is a strategic decision, it is necessary that managers should identify a suitable framework and they cannot afford to make a mistake in the selection process. But a greatest hurdle in this selection process is the availability of large numbers of frameworks in the literature ,(Gupta, P. & Vardhan, S.,2016).

From Table 2.2 and Figure 2.5, 2.6 and 2.7 we can take a notice that some of the Nakajima Pillars are common across most of the frame works. They are Focused improvement, Autonomous maintenance, planned maintenance and Training and education. These pillars are the core of the TPM since they are a direct effect on the manufacturing performance of an industry. Thus, it is important to study the right emphasis of TPM implementation strategies or elements and its correlation with manufacturing performance dimension.

Table 2.2 TPM concept summery (S.Vigneshwaran et.al 2015)

Motives of TPM	1. Adoption of life cycle approach for improving the overall performance of production equipment. 2. Improving productivity by highly motivated workers, which is achieved by job enlargement. 3. The use of voluntary small group activities for identifying the cause of failure, possible plant and equipment modifications.
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.
TPM Objectives	1. Achieve Zero Defects, Zero Breakdown and Zero accidents in all functional areas of the organization. 2. Involve people in all levels of organization. 3. Form different teams to reduce defects and self-Maintenance.
Direct benefits of TPM	1. Increase in productivity and OEE (Overall Equipment Efficiency) 2. Reduction in customer complaints. 3. Reduction in the manufacturing cost by 30%. 4. Satisfying the customers'`+ needs by 100 % (Delivering the right quantity at the right time, in the required quality.) 5. Reduced accidents.
Indirect benefits of TPM	1. Higher confidence level among the employees. 2. A clean, neat and attractive work place. 3. Favourable change in the attitude of the operators. 4. Achieve goals by working as team. 5. Horizontal deployment of a new concept in all areas of the organization. 6. Sharing knowledge and experience. 7. The workers get a feeling of owning the machine.

2.11 Literature Gap

In the above literature papers, the authors clearly highlighted the importance of TPM methodologies to be followed in the organization. The literature authors listed above focused implementation of TPM and focused on ways to improve performance efficiency and effectiveness. And also they addressed the issue faced during the implementation of TPM in the organization. They have calculated the various losses which affects directly the productivity of an organization. They also suggested how to improve the Overall Equipment effectiveness by eliminating the various losses. Melesse Workeneh wakjira,(2012) presents his case research on the contribution of TPM on manufacturing performance by evaluating its impact against OEE. But in his research he didn't mention the separate significance or impact of the pillars on the improvement achieved.

On the other hand some TPM consultants and practitioners have simplified the Nakajima model by eliminating some pillars. One of them is Yeomans and Millington (1997) who has developed their model based on the theory of classic Japanese TPM approach, which is built on five strategic pillars which are focused improvement, training, maintenance prevention, preventive maintenance and autonomous maintenance. Other models have only few pillars that differ from the JIPM model and pillars that cover only the basic definition of TPM like Strategic Work Systems, Society for Maintenance and Reliability Professionals and Society of Manufacturing Engineers (Mishra et al., 2008). There are also few models that are totally different from JIPM such as Aramis Management System, Volvo Cars Gent, and Centre for TPM Australasia. One example is the implementation of TPM at Volvo Cars Gent (VCG) which is based upon 13 committees or development pillars. Some of the unique pillars in this framework are: customer-ordered production, early product management, logistics, supplier support and integration in society (Volvo Cars Gent, 1998).

However, selecting pillars which have most affecting the manufacturing performance and embark TPM has not been studied specially on local firms. Given the wide scope of TPM program (JIPM) (8 pillars), it can be a difficult task to carry all the 8 pillars of TPM at one go. Therefore this paper will study the eight pillars of TPM contribution to the manufacturing performance and select the most affecting ones for an ease of implementing and improve vital manufacturing performances.

Chapter Three

Research methodology

3.1 Introduction

This section outlines the methodology on how data and information relevant to the research were gathered and analyzed in order to achieve the objectives of the study. It discusses the description of study procedures and the methods employed in the study. Areas covered include the research design, sources of data, and instruments of data collection, population and sampling procedures, methods of data analysis.

3.2 Research Design

There are many definitions of research design; one definition that Kelliher (2005) uses is that "research design is the blueprint for fulfilling research objectives and answering questions where it aids the researcher in the allocation of limited resources by posing crucial choices in the methodology". Other definitions are that research design is an activity- and time-based plan and a guide for selecting sources and types of information to obtain answers to research questions (Blumberg, et al. 2005).

Though it can be complicated in selecting an appropriate research design, Cooper and Schindler (2008) are of the view that, by creating a research design which uses a combination of methodologies, researchers can achieve greater insight than if they were to follow methods which used frequency or methods which have been mentioned the most in media.

This research will be conducted in a descriptive method of research called survey studies to assess Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars in the factory under study. The descriptive research method helps to draw a valid general conclusion, and it is the most popular and widely used research method. This idea is strengthened by using a decision tool AHP. It is an effective tool for dealing with complex decision making.

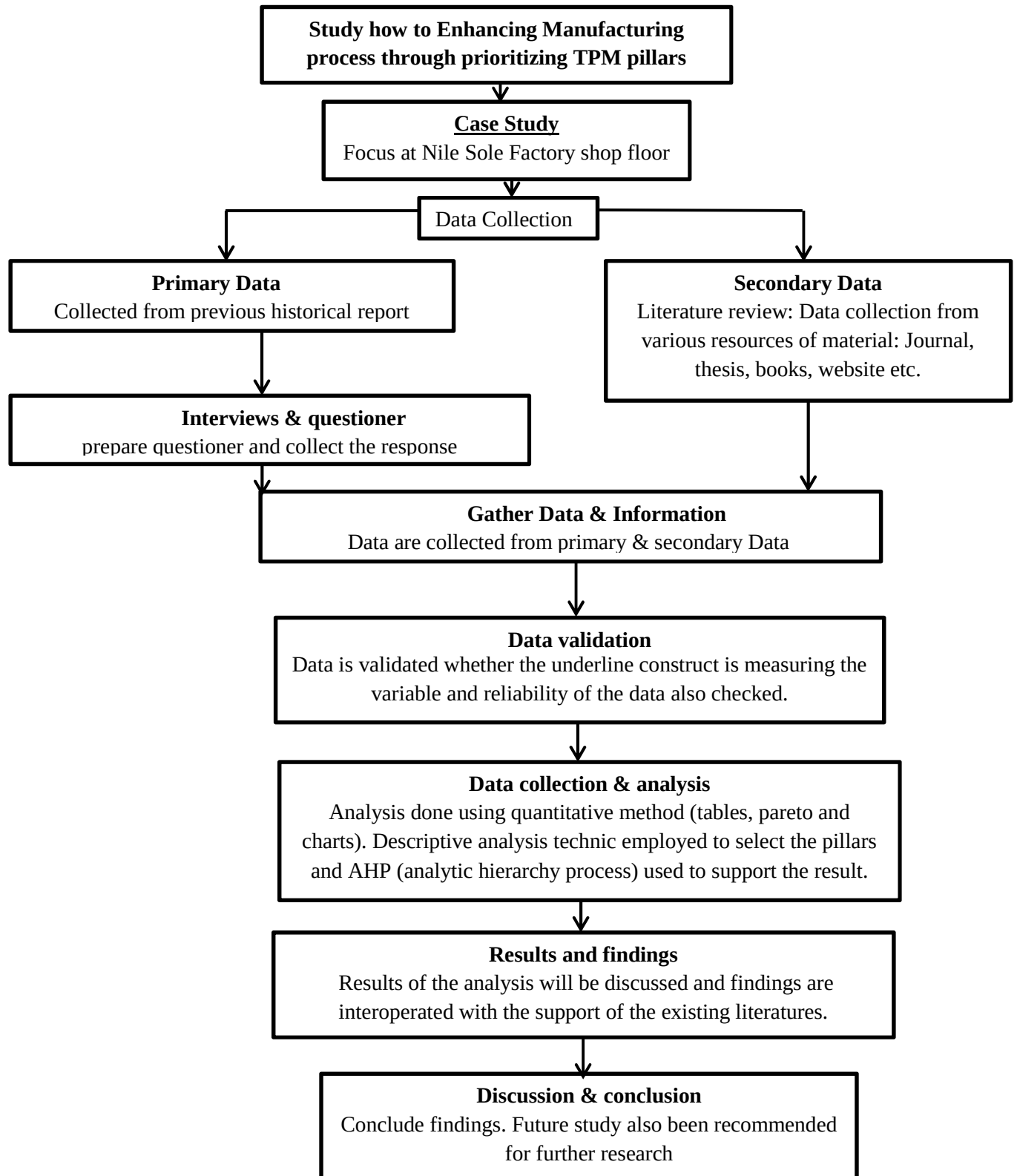


Figure 3.1: Methodology used for this study

3.3 Source of Data

The main sources of data for this research were both primary and secondary data.

Primary data:- In relation to primary data, Trochim (2003:) argues that alternative forms are designed to be equivalent to the types of questions that leads to the outcome. Likewise, Kothari (2006) describes that the collection of primary data is either through questionnaire or through interviews. Accordingly, for this study, the primary data have been collected directly from the sample respondents through the selected instruments discussed in the following sub-sections.

Secondary sources: - Besides primary data, secondary data were obtained from different books, newspapers, magazines, academic papers, reports, etc. In addition to these, authentic and reliable online scholarly written literatures were used to supplement the information. To assess Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars.

The researcher has referred to the monthly production reports and compared the factory's productivity.

3.4 Instruments of Data Collection

The researcher collected data by administering a questionnaire and structured interview questions. The questionnaire used structured questions, divided into two parts. Part I consisted of the demographical background of respondents. Part II discusses about respondents' opinion on practice how effective was the factories and impacts of Implementing selected TPM pillars based on key dimensions questions to answer the research questions. The structured interview questions were prepared for the researcher to collect the data through interview.

Most of the structured questions were the close-ended type and respondents were asked to mark the appropriate box matching the correct answer.

Interview: - it is verbal form of data gathering instrument. "Interview is a form of verbal questioning and it is a principal means of data gathering. It is one of the most popular techniques in survey research" Robson, A, (1993). The research has used unstructured interviews to collect more detail information about the topic. The 3 shift production supervisors and 2 maintenance supervisors will be interviewed to gather first-hand information regarding the how the selected TPM pillars affect manufacturing performance in the factory.

Questionnaire: - is a written question in the form of text (Sarantakos, 1993; Robson, A., 1993) defining it as “questionnaires are written question, which can be self-administered by the researcher or could be sent by mails. Information is offered by the respondent” The researcher used closed - ended questions prepared and presented for maintenance supervisors, production supervisors, machine operators and technicians.

Observation: - the researcher conducted observation on factory production and production related departments’ general environment, the factory production store organization, main production and machine outline of the factory, the factory production records before and after implementing selected pillars.

Document analysis: - the factory’s production and improvement related documents of different years and final annual reports will be analyzed.

3.5 Research Population and Sampling Procedures

Population refers to the group about whom the researcher wants to know more and from whom a sample will be drawn. This is often defined in terms of demography, geography, occasion time, etc.

Though the total number of employees in the factory is more than 100, the target population taken for this study is listed on the table below, focused on the top management and shop floor workers. The others are supporting staffs like securities, drivers etc.

• Production Team leaders	4
• Maintenance supervisors	4
• Machine operators	45
• Technicians	12
• Quality inspectors	<u>3</u>
	68

According to L. R. Gay (2008) who suggests that "10% of large populations and 20% of small populations as minimums can be taken as sample size". However, the researcher has taken 30% of the target population in order to get more reliable data from different respondents.

Accordingly, 4 production team leaders from production department, 4 maintenance supervisors were selected through probability sampling that represents 100% because of small population. In addition to this, 20 machine operators' 6 technicians and 1 quality inspector were taken as sample respondents for interview questions.

Table 3.1 : Total Population and Sample Size

NO	Type of respondent	Population	Sample size ≥ 30%	Set of sampling technique
1	Production Team leaders	4	4	Simple random sampling
2	Maintenance supervisors	4	4	Simple random sampling
3	Machine operators	45	20	Simple random sampling
4	Technicians	12	6	Simple random sampling
5	Quality inspectors	3	1	Simple random sampling
	Total	68	35	

3.6 Method of Data analysis

Data analysis in descriptive methods research relates to the type of research strategy chosen for the procedures. For the analysis process, version SPSS.24.0 software was used to maintain the database and is used for the descriptive data analysis. As indicated in the sampling strategy section, the data collected from different sources have been summarized, categorized and coded to suite for analysis. The qualitative or the open-ended questions have been summarized and presented as they are, while the closed-ended questions have been coded and analyzed using both descriptive and inferential statistics by using correlation, percentages, frequencies, T-test and measure of central tendency and desperation. The outputs of the data were presented appropriately depending on the respondents' response. Accordingly, the T-test was used to determine the level of significance of the difference in response of the respondents. In addition to the descriptive analysis analytic hierarchy process is used to prioritize the pillars and help the decision of selecting the more significant pillars. The end result has been presented in a written form and in the form of table. Finally, presentation, analysis, and interpretation of data and conclusions and recommendations will be drawn using analysis and data outcomes into a text format.

Table 3.2 Method of analyzing

No	Item of data	Method of analyzing	
		Tools	
1	Open ended interviews for the production and maintenance supervisors	Description	These qualitative data will be entertained qualitatively based on their frequency
2	Closed ended questioner team leaders, quality inspectors, technicians and operators	SPSS 24.0	Correlation, Percentage, mean, standard deviation and t-test will be treated quantitatively
4	Observation check list of the factory production and breakdown down time related documents	Tables and charts	Here researcher observed the factory workshop, production machine out late and documents related to productivity and Analysis will be done using quantitative method (tables, Pareto and charts.
5	Pillars of TPM and manufacturing performance dimensions.	Analytic hierarchy process	Prioritizing the pillars to support the result drawn from descriptive analysis.

3.7 Reliability and validity test

This section presents the results collected from the survey which were distributed to a sample of 35 employees of the company. Employees randomly selected from the category of their status. Respondent are of the company comprises of Production team leader, Maintenance supervisors, maintenance engineer, quality inspectors, technicians and machine operators which are most suitable to answer the survey questionnaires. Although initial response rate was not encouraging, efforts were made to increase response personally calling up the relevant personnel in respective shifts and attend in person. As a result, the final response rate is 97 % based valid responses. The responses were then analyses using SPSS Version 20 statistical package and are tabulated in the Appendix.

3.7.1 Reliability Test

Reliability analysis or also known as internal consistency was performed to access the reliability of the measurements (eight constructs) depicting the degree to which they indicate a common latent (unobserved) construct. It relates to the extent to which an experiment, test or any measuring procedure yields the same results on repeated trials (Cramer, 1998). Cronbach's Alpha (α) is commonly used for this purpose, where values of alpha range from between 0 and 1.0, with higher values indicating higher reliability. Thus, Cronbach's Alpha values for the various categories of TPM Pillars and manufacturing performance dimension were calculated to ascertain the reliability of the input and output data collected from the survey questionnaire.

The alpha values range from 0.5 to 0.826 as shown in Table 3.3, which indicates an internal consistency with the alpha value of more than 0.50, so no items were dropped from each variable. These also indicate the significantly high reliability of data for various inputs and output categories and are a reliable measure of construct.

Table 3.3: Internal consistency test result

Factor	TPM Pillars and Manufacturing performance dimensions	No of Items	Cronbach's α value
Pillar1	Focused improvement	6	0.724
Pillar2	Planned Maintenance	7	0.717
Pillar3	Autonomous Maintenance	6	0.780
Pillar4	Training and Education	5	0.721
Pillar5	Quality Maintenance	5	0.699
Pillar6	Early Management	5	0.763
Pillar7	Office TPM	5	0.722
Pillar8	Safety, health and Environment	5	0.784
MP1	Cost	5	0.712
MP2	Availability	7	0.733
MP3	Delivery	4	0.706
MP4	Flexibility	5	0.772

Table 3.4: overall Cronbach Alpha value

Reliability Statistics	
Cronbach's Alpha	N of Items
.959	65

3.7.2 Validity Test

Construct validity is used to measure that the factor or items in question are really able to measure the underlying construct that it is designed to measure. For this study, the validity of the factors for each TPM elements will be tested using confirmatory factor analysis approach (Bagozzi, 2001). Factor analysis is used for structure detection which purpose is to examine underlying (or latent) relationship between the variables. The factor analysis test used is the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) which is a statistic that indicates the proportion of variance in the variables that might be caused by underlying factors and for construct validity. For KMO test, high values (close to 1.0) generally indicate that a factor analysis may be useful with the data. If the value is less than 0.50, the results of the factor analysis probably won't be very useful. Kaiser (1994) also recommends either to collect more data or to exclude certain variables if the value is below 0.5. For this study, the KMO values for each factors range from 0.601 to 0.774 as seen in Table 3.5 which were considered satisfactory

Table 3.5 Validity test with principal component analysis and KMO test

Factor	TPM Pillars and Manufacturing performance dimensions	Item Deleted	Factor Loading	KMO Value
Pillar1	Focused improvement	None	0.659 – 0.808	0.651
Pillar2	Planned Maintenance	None	0.583 – 0.781	0.687
Pillar3	Autonomous Maintenance	None	0.549 – 0.715	0.761
Pillar4	Training and Education	None	0.503 – 0.657	0.629
Pillar5	Quality Maintenance	None	0.513-- 0.825	0.603
Pillar6	Early Management	None	0.603 – 0.875	0.732
Pillar7	Office TPM	None	0.535 – 0.886	0.616
Pillar8	Safety, Health and Environment	None	0.486 – 0.690	0.708
MP1	Cost	None	0.512 – 0.622	0.736
MP2	Availability	None	0.509 – 0.779	0.674
MP3	Delivery	None	0.517 – 0.800	0.606
MP4	Flexibility	None	0.512 - 0.716	0.663

Chapter Four

Data Presentation, Analysis and Interpretation

4.1 Introduction

This chapter will present statistical analysis of the production data and downtime from the nine machines. The chapter will attempt to fully understand the production situation and identify the problems in order to address them, questionnaires and interviews data analysis will be presented in the rest of this thesis. It presents the results collected from the survey which were distributed to a sample of 34 company workers. Respondents were selected according to the sample required for this research. Respondent are comprises of maintenance and production supervisors, maintenance manager, quality supervisors, Machine operators and technicians suitable to answer the survey questionnaires. Although initial response rate was not encouraging, efforts were made to increase response by personally calling up the relevant personnel and contacting in person. As a result, the final response rate is 97 %. The responses were then analyses using SPSS (PASW) Version 24 statistical package and are tabulated in the following pages. In addition, Multi Criterion decision making tool (AHP) used and presented to support the result obtained from the SPSS analysis.

4.1.1 Process overview

Injection molding is a process by which plastic raw materials are converted into useful products meeting acceptable standards (Beaumont, Nagel, & Sherman, 2002). Each plastic material, based on type and grade, can be correctly processed within a certain range of temperatures and pressures (Whelan, Anthon, Craft, 1978). These are the key parameters of plastic processing. The purpose of this section is to review these key parameters and their associated problems that can lead to scrap.

Melt temperature is the temperature at which a resin changes from a solid to a liquid. At this point, the crystalline regions of a plastic material soften and begin to flow (Reinhold, 1991). Melt temperatures range from 248oF to 662oF (Beaumont, Nagel, & Sherman, 2002) and are controlled by barrel temperature, nozzle temperature, screw speed, back pressure, and residence time.

About 70% of the heat needed to melt the plastic is generated from shear heating that occurs within the plastic itself (Beaumont, Nagel, & Sherman, 2002). Therefore, the melt temperature is difficult to measure and cannot be directly controlled by the thermostats on the control panel. The injection molding machine barrel and nozzle temperatures are maintained by electrical heating elements. These elements provide the remaining 30% of the heat required to maintain a plastic temperature high enough to guarantee plastic flow.

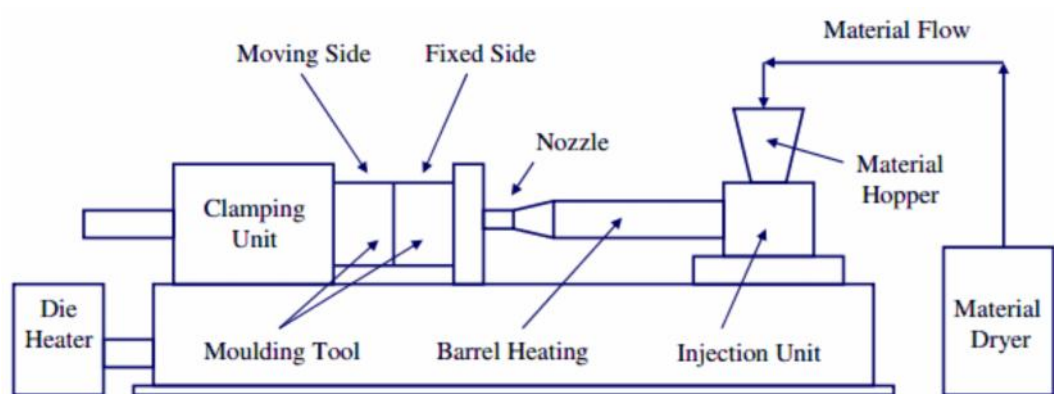


Figure 4.1. PVC sole injection machine (S.R.Vijayakumar & S.Gajendran 2014)

4.2 Productive and Non-Productive Time

In order to understand and evaluate the actual problems facing the company, detailed statistical data was collected from the company, which was then compiled and analyzed. The data represents production between March, 1/2018 to March 31/2018. Table 4-1 presents the downtime of the Nine Machines and its type.

Table 4.1 statistical data of downtime and failure for month of March 2018

Reason for Down time in hours a month of March 2018											
Machine	Working hours target(WHT)	Electrical Failure	Parameter adjustment	Change over	Mechanical failure	Mechanical Adjustment	West by scrap	Lack of material	Power cut	Total hours of Down time (THD)	Proportion of Down time WHT/THD
Injection1	572	38.2	25.5	9.08	53.14	7.62	14.9	1.93	4.08	154.45	27%
Injection2	572	49.3	18.57	14.73	53.23	9.1	11.52	0.83	4.33	161.61	27%
Injection3	572	45.6	21.6	8.32	37.44	5.6	14.97	10.45	4.33	148.31	26%
Injection4	572	23.37	10.5	7.65	33.84	2.25	19.08	1.83	4.33	102.85	18%
Injection5	572	27.62	11.48	12.07	45.38	8.42	2.67	3.55	4.33	115.52	20.2%
Injection6	572	28.18	16	19.77	49.77	2.9	16.78	2.03	4.33	139.76	24.4%
Injection7	572	19.22	15.33	15.7	40.53	13.65	1.95	1.65	4.33	112.36	19.6%
Injection8	572	14.3	8.83	12.67	41.55	11.63	19.77	4.58	4.33	117.66	20.6%
PU Machine	572	17.93	15.47	16.73	27.74	4.07	11.27	0.067	4.33	97.6	17.1%
Total	5148	263.72	143.28	116.72	382.6	65.24	112.91	26.91	38.7	1150.1	22.2%

It is clear from the table that the downtime in March was between 17.1% and 27% .The electricity failure was when the supply of electricity failed which was mainly caused by a problem in the grid and it is outside of the Control of the Company, relatively it is limited number of hours. The majority of nonproductive time, seen on Table 4-1, is mainly caused by Mechanical failure this implies that since there is no preventive maintenance carried on the machines, no action is taken in the early signs of failure and break downs took long hours mainly due to technicians lacks skill to solve the problem in time. As seen in the above table the aggregate from all machines in the month of March is 382.6 hours. The second major down time is electrical failure, this is also mainly due to the failures not repaired in time due to lack of competent skill that is not parallel with the machines sophistication. The reason for scrap or rework is basically caused by the knowledge of the different parameter setting in accordance with the material and type of Sole. It is down to the operational competency of the operators, the second reason is mostly machines are not in their basic condition for example if the scrap is resulted from low pressure of the hydraulic press on the mold and this in turn caused by low level of oil in the reservoir; oil is top up after a failure is reported and further investigation usually did not proceed and returning the machine to basic condition is overlooked.

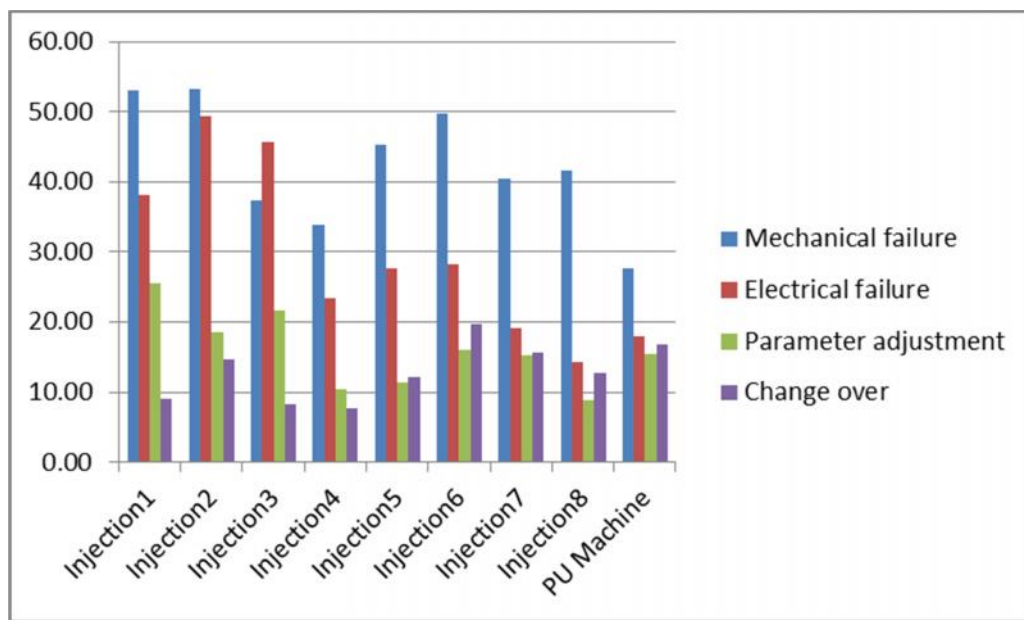


Figure 4.2 Reason for top four downtime across the machines in the month of March 2018

During the period observed, material and supplies suffered no significant lack of availability and did not contribute much to downtime values. Lack of supply of spare parts was not reported

during the observation period and this again had no effect on downtime. There appears to be a considerable amount of down time on Parameter adjustment which is regarded as no written procedure to follow and time wasted for try and error attempts those results have contribution to down time. It also appears significant variation in the distribution of mechanical failure in the nine machines, there are two main reasons observed the first is Injection machines 1 & 2 are longer service time both are above 12 years in operation in the other hand injection machine 6 is less than 5 years in operation it is mainly due to new products and tests are done here. The second reason is more change overs are done on the older machine for easy to make changes on this machine both mechanical and parameter. The more change overs done on the machine the more technical issues arise as a result.

Table 4.2 comparison of Production with target and actual and scrap level of March 2018

Machine	Unit	Design capacity	Target production	Actual Production	Scrap	proportion Scrap	Proportion of actual with	
							Design (%)	Target (%)
Injection1	PCS	11040	8000	5755	1151	20	52.12	72
Injection2	PCS	11040	7800	6000	1153	17.4	54.3	77
Injection3	PCS	11040	7800	6661	811	12.2	60.3	83.2
Injection4	PCS	11040	8500	6800	733	9.8	61.6	80
Injection5	PCS	11040	8500	6278	983	15.7	56.9	73.9
Injection6	PCS	11040	9000	7745	1078	13.9	70.15	86.1
Injection7	PCS	11040	9000	7500	878	10.8	68	83.3
Injection8	PCS	11040	8500	6800	900	12.5	65.6	80
PU Machine	PCS	54740	43000	36805	3329	9	67.2	85.6
Total	PCS	143060	110100	90344	11016	11.9	63.2	82

The amount of scrap is very high considering production in the given period of time. The machines need correct adjustment of parameters like temperature, speed and time of baking in accordance with the sole type, times, size and material composition. During the field visit it is

observed that operators check by try and error until good sole is produced until then Soles with different quality issues scraped. It is also observed that no Chang over procedure is used on any of the machines. Operators only use their unwritten past experience during change overs. The Molds to be changed are not labeled on the shelves and considerable time is wasted for searching the model(mold) currently in need. Operators wait for a technician to come and fix the mold after they bring it to their machine. In most cases the technician has responsibility to fix the mold and make parameter adjustment for the next product.

Lack of preventive measure is the problem that implicates high down time. According to Moghaddam and Usher and Wang and Christer, preventive maintenance involves maintenance tasks such as inspection, monitoring, cleaning, lubrication, adjustment, alignment, repair, replacement and maintenance of building's and systems' components before failures or system breakdowns occur. Meanwhile, preventive maintenance is based on component reliability characteristics and aimed to reduce the probability of component failure, as well as to minimize the system downtime.

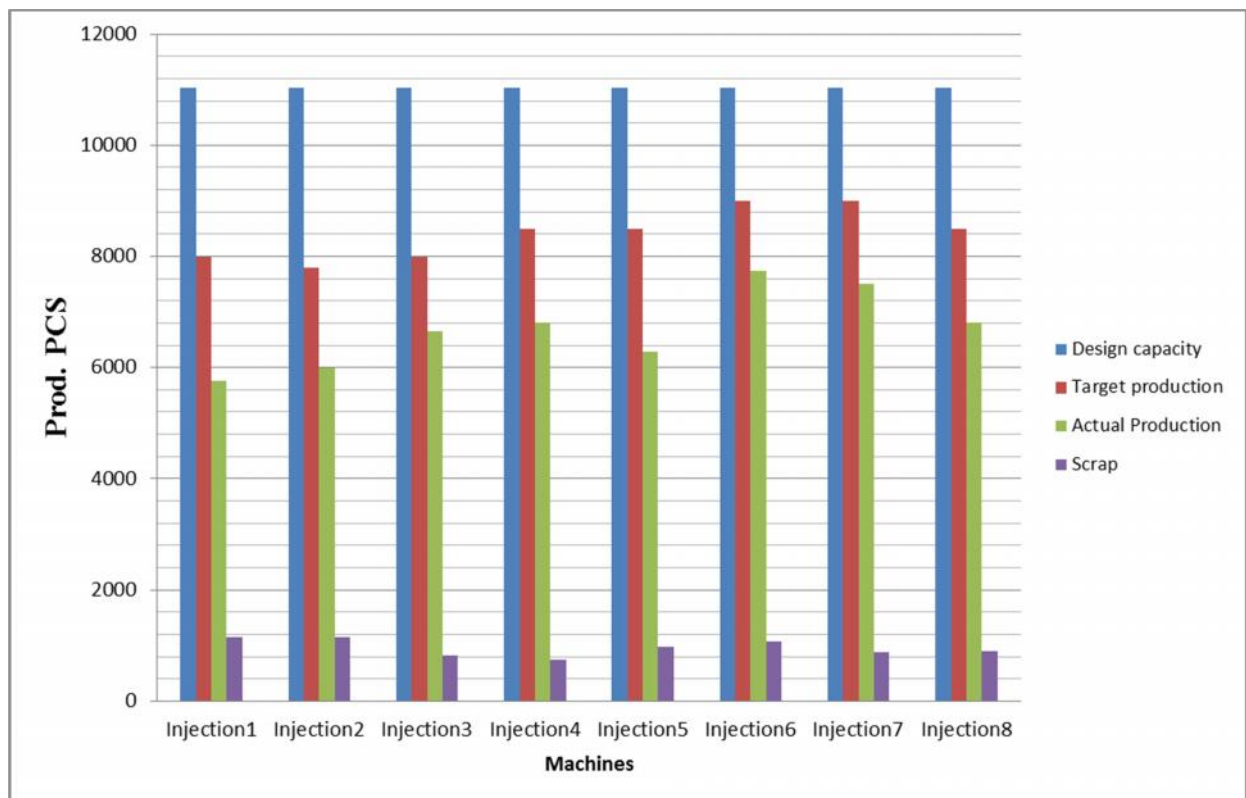


Figure 4.3 Design, Target, actual and Scrap level of March 2018

It can be seen that the target production is intended to be far from the design capacity this is because the design capacity didn't consider the change overs, whereas the target is including the number of change overs that can be done on the specific machine. However, none of the machines managed to achieve the Target even.

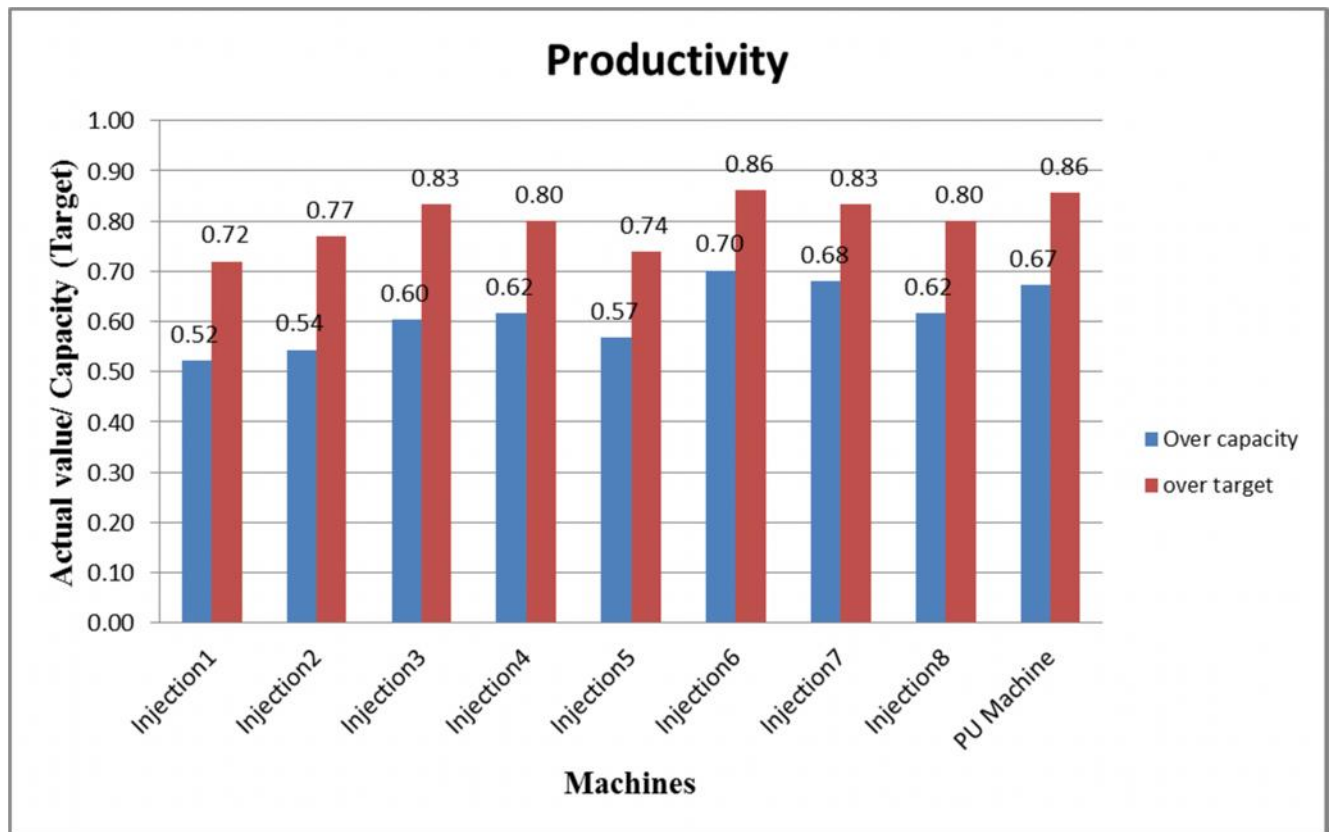


Figure 4.4 Productivity as Production/capacity/Target

From the above Figures, it is clear that injection1 and injection2 has the lowest productivity this is because relatively there are more changeovers than the other machines. The others have similar productivity but still much less than the target production. This issue will be investigated during the course of this research work.

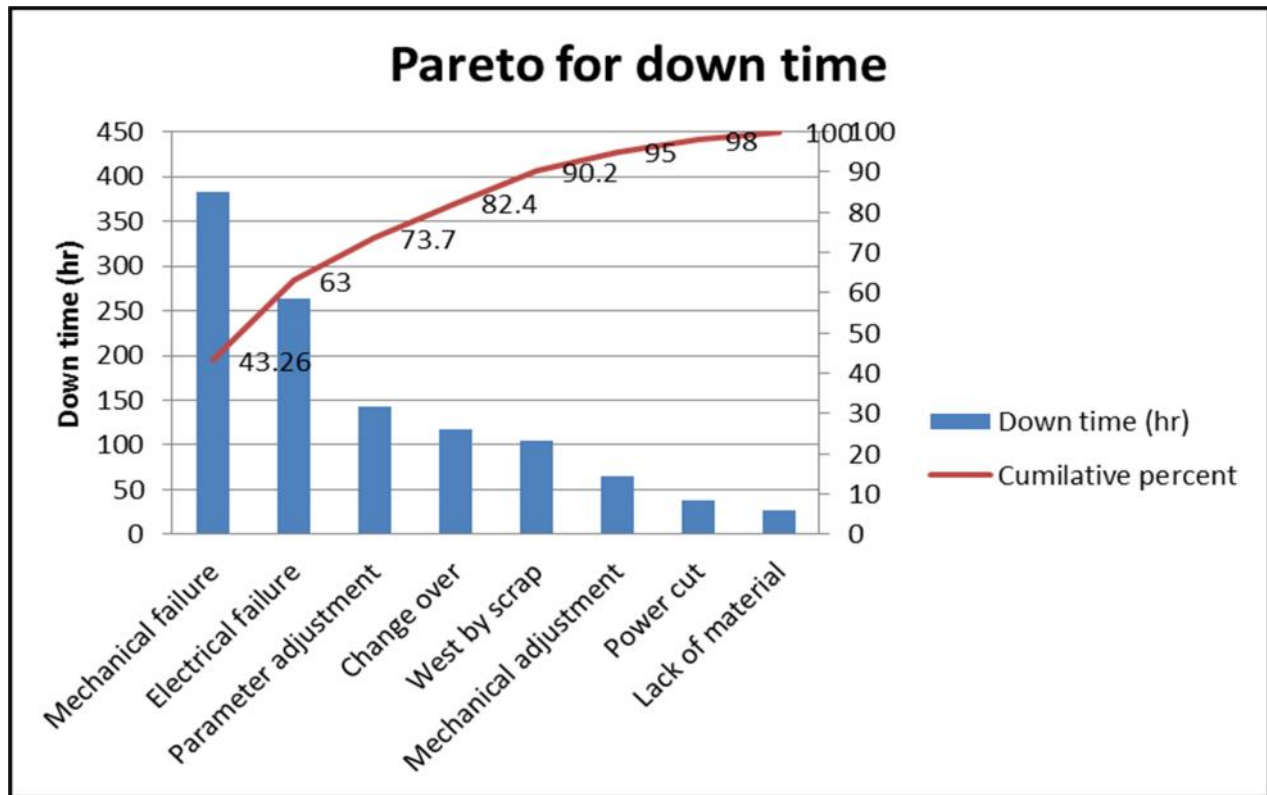


Figure 4.5 Pareto for down time reasons

From the Fig.5.3 it was observed that the major losses contributing the machine downtime were Mechanical failure, Electrical failure, parameter adjustment and change overs and constitutes more than 80% of the down time. The scrap losses are two fold first the unproductive time due to scrap and the second is the rework or the lost materials, But the sources of the scrap are mainly incorrect parameter adjustment and technical failures (mechanical and electrical) therefore the working on the first three major reasons of down time will affect the scrap level and its associated down time.

Therefor from the above data analysis presentation the company need to focus on the following particular manufacturing performance parameters in order to improve its performance and be competitive on the market.

Cost: as shown in Table 4.1 the down time across all machines is between 17% - 27% of its target production hour. . This shows the cost of production loss during machine stoppage is too much. The scrap amount also reaches 20% in some machines that increases the rework and the waste raw material.

Availability: a total of 382.6 hours of unavailability registered in one month which limits machine utilization and productivity. Hence this criteria or parameter should take attention in order to increase the productivity.

Delivery: Hence the company is straggling to fulfill its promises to deliver on the due date because of the reasons mentioned above, it is necessary to work on improving its delivery promises to keep customers satisfied.

Flexibility: One of the challenges of the company with the costumer's satisfaction beside its short of delivery is the limitation on its flexibility to meet the changing product request.

Therefore in order to improve its productivity and to be competitive in market the company should focus on these four manufacturing performance parameters.

4.3 Level of Emphasis of TPM Pillars

After initial studying the background of the respondents and also performing analyses on the reliability of the results, the next part analyses the level of emphasis of TPM Pillars. To further understand this, a summary of the mean values for each TPM Pillar was calculated as shown in Table 4.3, where the higher the value indicating a higher level of emphasis.

Table 4.3 The mean of TPM pillars

Factor	TPM Pillars	Over all mean	Std. Dev.	Rank (based on overall mean)
Pillar1	Focused improvement	4.0098	0.76084	1
Pillar2	Planned Maintenance	3.7437	0.77824	3
Pillar3	Autonomous Maintenance	3.94118	0.71100	2
Pillar4	Training and education	3.70588	0.79199	4
Pillar5	Quality Maintenance	2.11765	0.62939	7
Pillar6	Early Management	1.89412	0.510834	8
Pillar7	Office TPM	2.13256	0.61615	6
Pillar8	Safety, Health and Environment	2.14118	0.60864	5

The mean score for each TPM elements ranges from 1.8941 to 4.1033 and the variability of each construct is ranges 0.5108 to 0.7919. From the table, the first four TPM Pillars Focused

improvement, Planned Maintenance, Autonomous Maintenance and Training and education have higher emphasis with the high overall mean value of 3.8501 between them. While the remaining four pillars have less emphasize with average mean value of 2.07137. Furthermore, the ability of an organization to conduct basic maintenance activities effectively in an organized and efficient way will determine the success of a TPM implementation program (Ahuja and Khamba, 2008).

4.4 Evaluating of TPM Element Emphasis and their Contribution towards Manufacturing Performance

Based on the responses from Nile Sole factory workers, an assessment has been made of the relationship between various TPM Pillars emphases and their contribution towards different manufacturing performance dimension. To show this relationship, the bivariate correlation procedure is used to compute the Pearson's correlation coefficient between various TPM pillar emphasis and manufacturing performance dimension as shown in Table 4.4. It is useful to determine the strength and direction of association between two scale variables. In this case, Pearson correlation is worked out to define significant TPM element contributing towards realization of different manufacturing performance.

Table 4.4 Pearson's correlation between various TPM Pillars and manufacturing Performance dimension

	MP1	MP2	MP3	MP4	Average
Pill1	0.832**	0.859**	0.751**	0.729**	0.793
Pill2	0.920**	0.941**	0.827**	0.832**	0.88
Pill3	0.845**	0.849**	0.778**	0.795**	0.817
Pill4	0.671**	0.661**	0.675**	0.533**	0.635
Pill5	0.218	0.295	0.287	0.395*	0.299
Pill6	0.249	0.312	0.340*	0.336	0.309
Pill7	0.250	0.369*	0.238	0.225	0.270

4.5 Discussion on Relationship between TPM Pillars and Manufacturing Performance

The Pearson's correlation results show that there exist significant association between the first four TPM pillars and their contribution towards manufacturing performance. Focused Improvement (Pill1), shows significant relationship with improving availability (MP2), lowering cost (MP1) and good level of flexibility (MP3). This is due to the objective of Focused Improvement which is Zero Losses. Maximizing equipment effectiveness requires the complete elimination of failures, defects, and other negative phenomena – in other words, the wastes and losses incurred in equipment operation (Nakajima, 1989).

Next, the results also show similar pattern with planned maintenance management (Pill2) having significant contribution towards improving manufacturing performance by lowering cost (MP1), high levels of availability (MP2) and increased flexibility (MP4). The objective of Planned Maintenance is to establish and maintain optimal equipment and process conditions (Suzuki, 1994). As defined by JIPM, devising a planned maintenance system means raising output (no failures, no defects) which reduces product cost, as well as improve quality of product and increasing plant availability (machine availability) which indirectly affects productivity also.

Autonomous maintenance (Pill3) shows strong relation on the availability (MP2) and flexibility (MP4). This indicates the availability of the equipment increases if minor maintenance are made by operators instantly will reduces the down time of failed machine that waits until a technician come and sorts a problem. The engagement of operators in small maintenance activity also allows them to get experience in doing change overs efficiently, which in turn increase productivity and so significantly affect the delivery. Execution of minor maintenances and cleaning and inspection will give a chance to make immediate measures on any abnormalities and helps the machine to be in basic condition, this will minimize cost of maintenance.

Education and training (Pill4) also shows significant impact on all four manufacturing performance dimension in terms of cost (MP1), availability (MP2), delivery (MP3) and flexibility (MP4). The objective of Training and Education is to create and sustain skilled operators able to effectively execute the practices and methodologies established within the other TPM pillars (Ravi .N et al 2015). It also enables the upgrading and expanding of employees'

technical, problem solving and team working skills (Pandy D. &Raut N.2016). Only by improving the workforce in the organization, would we see improvement in manufacturing performance of the organization. Training and Education focuses on establishing appropriate and effective training methods, creating the infrastructure for training, and proliferating the learning and knowledge of the other TPM pillars. It may be the most critical of all TPM pillars for sustaining the TPM program in the long-term. A test of TPM success is to look at organizational learning, TPM is about continual learning (Ravi .N et al 2015).

4.6 Analytic hierarchy process to prioritize the pillars

The Analytic Hierarchy Process (AHP), introduced by Thomas Saaty, T. L. (2012).is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision. By reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. In addition, the AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process. For prioritizing TPM Pillars, the judgment based on observation is fed into AHP for each criterion and sub criterion of all level of hierarchy. Pair-wise comparisons of criterion at each level is done on a scale relative importance

The steps to follow in using the AHP (Roger 1987):

1. Define the problem and determine the kind of knowledge sought.
2. . Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) to the lowest level (which usually is a set of the alternatives).
3. Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.
4. Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for every element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of

weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.

5. Having done all the pair-wise comparisons and entered the data, the consistency is determined using the eigenvalue. To do so, normalize the column of numbers by dividing each entry by the sum of all entries. Then sum each row of the normalized values and take the average. This provides Principal Vector or priority criterion.

The check of the consistency of judgments is as follows:

Let the pair-wise comparison matrix be denoted M1 and principal vector be denoted M2. Then define $M3 = M1 * M2$; and $M4 = M3 / M2$. λ_{max} = average of the elements of M4.

Consistency Index (CI) = $(\lambda_{max} - n) / (n - 1)$

Consistency Ratio (CR) = CI / RI

Where R: Random Index

n: number of elements

Table 4.5 Random index number

n	3	4	5	6	7	8	9	10
RI	0.52	0.88	1.11	1.25	1.34	1.41	1.45	1.49

Table 4.6 Saaty's pairwise comparison scale

Verbal judgment	Numeric value
Extremely important	9
	8
Very Strongly more important	7
	6
Strongly more important	5
	4
Moderately more important	3
	2
Equally important	1

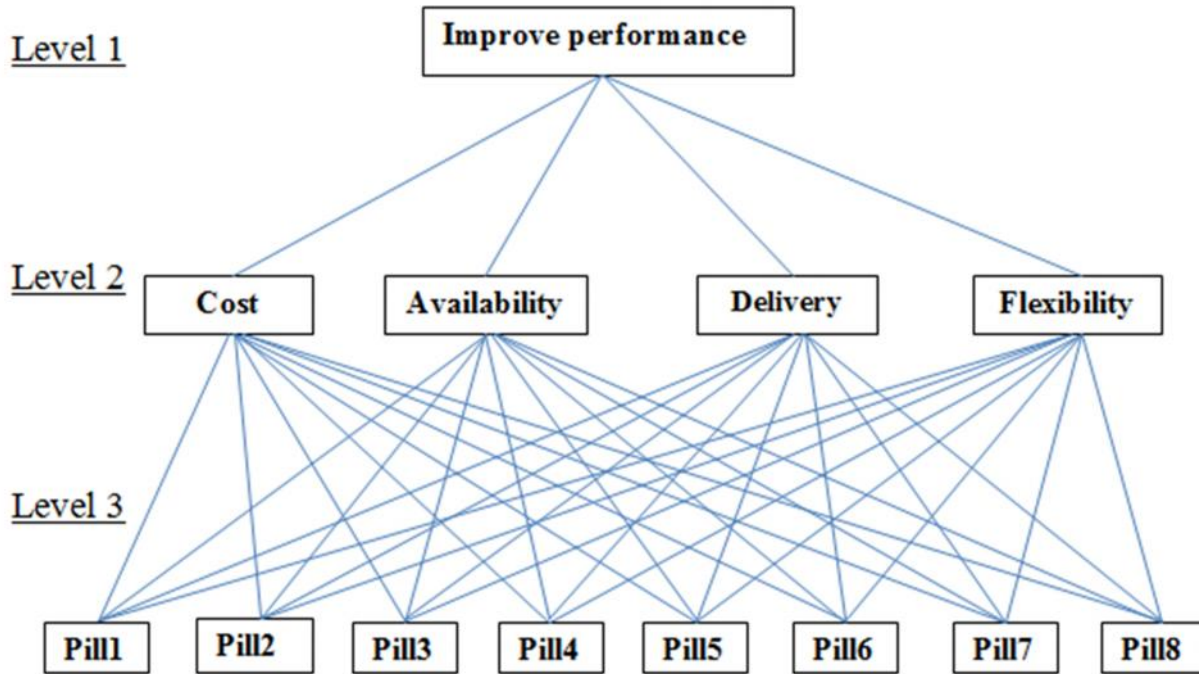


Figure 4.6 Schematic of AHP Process

Table 4.7 Relative comparison of performance parameters

	Cost	Availability	delivery	flexibility
	0.50108	0.26298701	0.1590909	0.0768398
Cost	1	3	3	5
Availability	0.33333	1	3	3
delivery	0.33333	0.3333333	1	3
flexibility	0.2	0.3333333	0.3333333	1

With Consistency index (CI) = 0.0671,
Consistency Ratio (CR) = 0.0745

The priority metrics (Eigen vector) of the criterion or performance dimension is shown on Table 4.7

Table 4.8 priority criterion for level 2

Cost	0.501	The Most important criterion
Availability	0.263	The second important criterion
delivery	0.1591	The third important criterion
flexibility	0.0768	The least important criterion

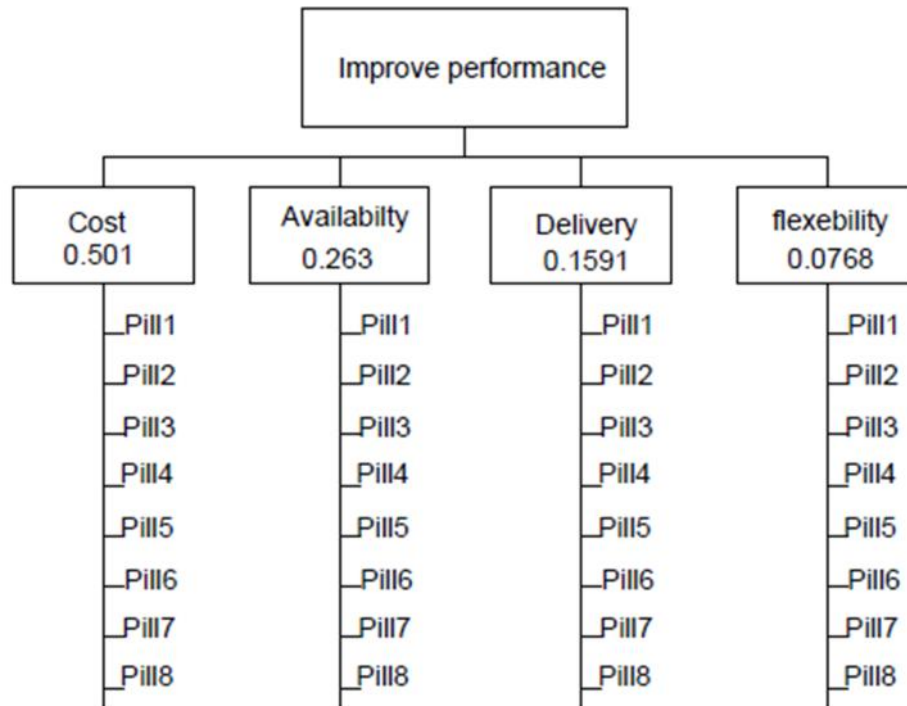


Figure 4.7 Hierarchal tree with criterion weights

In terms of Cost pair wise comparisons to determine the preference of each alternative over the other is depicted on the following table.

Table 4.9 pair wise comparison of alternatives in terms of cost.

	Pill1	Pill2	Pill3	Pill4	Pill5	Pill6	Pill7	Pill8
Pill1	1	0.2	0.333	2	3	5	2	3
Pill2	5	1	3	7	7	9	4	5
Pill3	3	0.333	1	5	5	6	5	3
Pill4	0.5	0.143	0.2	1	1	3	2	2
Pill5	0.333	0.143	0.2	1	1	2	0.333	0.33333
Pill6	0.2	0.111	0.167	0.333	0.5	1	0.333	0.5
Pill7	0.5	0.25	0.2	0.5	3	3	1	2
Pill8	0.333	0.2	0.333	0.5	3	2	0.5	1

Consistency Index (CI) = $(\lambda_{\max} - n) / (n - 1)$

$$CI = 0.0804$$

Consistency Ratio (CR) = CI / RI

Table 4.10 normalized matrix of table 4.9

	Pill1	Pill2	Pill3	Pill4	Pill5	Pill6	Pill7	Pill8	Priorities
Pill1	0.092	0.084	0.061	0.115	0.128	0.161	0.132	0.17822	0.119
Pill2	0.46	0.42	0.552	0.404	0.298	0.29	0.264	0.29703	0.3732
Pill3	0.276	0.14	0.184	0.288	0.213	0.194	0.33	0.17822	0.2254
Pill4	0.046	0.06	0.037	0.058	0.043	0.097	0.132	0.11881	0.07382
Pill5	0.031	0.06	0.037	0.058	0.043	0.065	0.022	0.0198	0.0418
Pill6	0.018	0.047	0.031	0.019	0.021	0.032	0.022	0.0297	0.0275
Pill7	0.046	0.105	0.037	0.029	0.128	0.097	0.066	0.11881	0.07824
Pill8	0.031	0.084	0.061	0.029	0.128	0.065	0.033	0.05941	0.06118

From Random number table for $n = 8$, $RI = 1.41$

$CR = 0.0571$

Similar Procedures in relative to the other performance criterion, Availability, delivery and flexibility will produce the next complete table.

Since the numeric values are derived from the subjective preferences of individuals, it is impossible to avoid some inconsistencies in the final matrix of judgments. The question is how much inconsistency is acceptable. For this purpose, AHP calculates a consistency ratio (CR) comparing the consistency index (CI) of the matrix in question (the one with our judgments) versus the consistency index of a random-like matrix (RI). A random matrix is one where the judgments have been entered randomly and therefore it is expected to be highly inconsistent

Table 4.11 priority weights (principal vectors) for each criterion with respect to the alternative

	Cost	Availability	Delivery	Flexibility
Pill1	0.119	0.1396	0.1162	0.1213
Pill2	0.3732	0.3655	0.2836	0.2946
Pill3	0.2254	0.2033	0.2048	0.2946
Pill4	0.07382	0.0904	0.0871	0.0903
Pill5	0.0418	0.0562	0.0297	0.0335
Pill6	0.0275	0.0539	0.0291	0.0297
Pill7	0.07824	0.0411	0.0672	0.0799
Pill8	0.06118	0.0492	0.0585	0.0559
Consistency Ratio (CR)	0.0571	0.0656	0.0641	0.0634

As shown on the above table all priority weights are calculated with $CR < 10\%$.

If the value of Consistency Ratio is smaller or equal to 10%, the inconsistency is acceptable. If the Consistency Ratio is greater than 10%, we need to revise the subjective judgment (Saaty, T. L. 2012). Computing the priority weights with the criterion weights determines the relative ranking of alternatives under each criterion by the following matrix

$$\begin{array}{c}
 \begin{array}{ccccc}
 & \text{Cost} & \text{Availability} & \text{Delivery} & \text{Flexibility} \\
 \text{Pill1} & 0.119 & 0.1396 & 0.1162 & 0.1213 \\
 \text{Pill2} & 0.3732 & 0.3655 & 0.2836 & 0.2946 \\
 \text{Pill3} & 0.2254 & 0.2033 & 0.2048 & 0.2946 \\
 \text{Pill4} & 0.07382 & 0.0904 & 0.0871 & 0.0903 \\
 \text{Pill5} & 0.0418 & 0.0562 & 0.0297 & 0.0335 \\
 \text{Pill6} & 0.0275 & 0.0539 & 0.0291 & 0.0297 \\
 \text{Pill7} & 0.07824 & 0.0411 & 0.0672 & 0.0799 \\
 \text{Pill8} & 0.06118 & 0.0492 & 0.0585 & 0.0559
 \end{array}
 & * &
 \begin{array}{c}
 \text{Criterion} \\
 \text{weights} \\
 \\
 0.501 \\
 \\
 0.263 \\
 \\
 0.1591 \\
 \\
 0.0768
 \end{array}
 \end{array}$$

Computing the above matrices will give the alternative weights on the next table and that helps the decision.

Table 4.12 relative alternative weights

Relative Alternative weights	
Pill1	0.1241
Pill2	0.3508
Pill3	0.2216
Pill4	0.0815
Pill5	0.043
Pill6	0.0349
Pill7	0.0668
Pill8	0.0572

From above table (4.12) alternative weight we can see that the most preferable pillar is planned maintenance (Pill2) with the weight of 35%. It is better by far from the second alternative, which shows that it is the most important pillar to deal with the current manufacturing problems discussed in the problem section of this research. In the criterion preference seen in the previous section cost is the first criterion or most important parameter to focus. As planned maintenance is

related to the availability and proper function of the machines that in turn will reduce the rework and waste due to defects which reduces cost, as a result it took much of the relative weight.

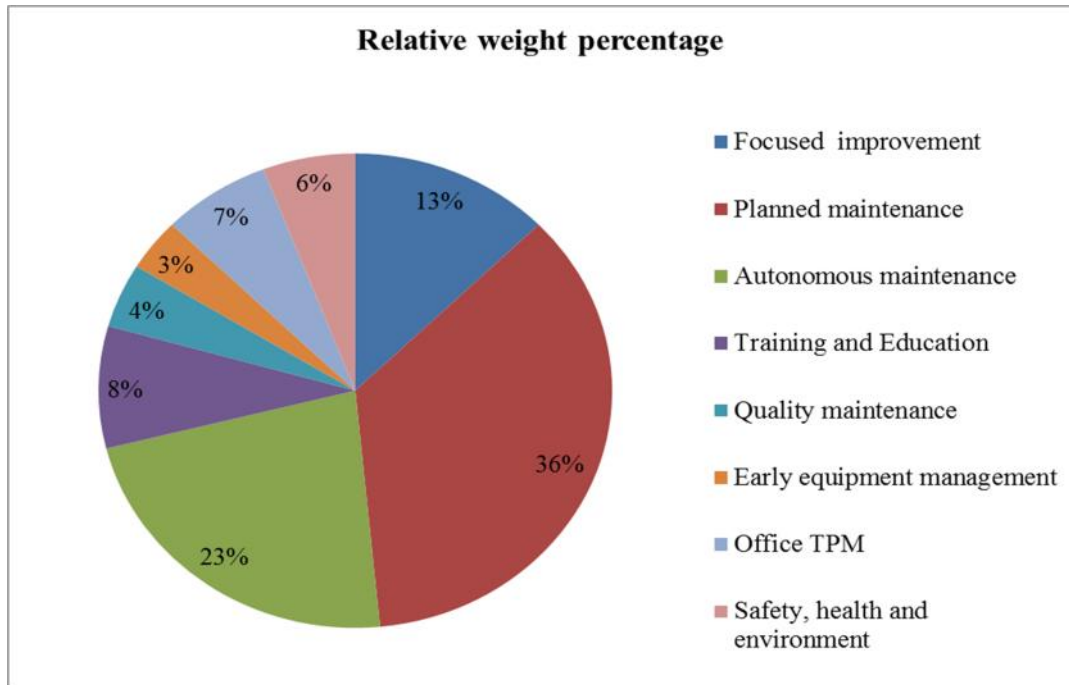


Figure 4.8 Alternative relative weight percentages

The second most important pillar as of the result in table 4.12 is Autonomous maintenance (Pill3) with weight of 23%. As autonomous maintenance is involvement of operators in minor maintenance and increase responsibility in the cleanness of the machine and ownership it increases the effectiveness of the equipment by improving its up time and reducing defects. It is an important pillar in keeping the area clean. Moreover its role in the sustaining of 5S is vital in that by properly keeping the work place conducive to work. Keeping the tools and materials in orderly manner also has indirect good effect on safety. Because it clears unnecessary materials around, 5s and Autonomous maintenance pillar is creating safe environment for the work place. From Figure 4.8 the alternative weight of planned maintenance and Autonomous maintenance is 59% and shows the importance of these pillars over the others. Focused improvement and training and education pillars follow the third and fourth preference. Focused improvement held both tangible and intangible importance in that continuous improvement of the process and the activity will improve the product quality and productivity. Training and education on the other hand is helping the TPM pillars function to be sustainable by giving insight to the employees how to live the talk of TPM.

From the result of descriptive analysis in section 5.7 the correlation between the pillars and the manufacturing performance is stronger on the first four pillars, Focused improvement, planned maintenance, Autonomous maintenance and Training and Education. The average correlation coefficient of Focused improvement and Autonomous maintenance is nearly equal 0.8 and for planned maintenance 0.9 and that of Training and Education with significant correlation of 0.64. Both descriptive analysis and Analytic hierarchy process output result shows the first four pillars of the Nikajimas TPM pillars are more important than the rest.

Therefore the first four TPM elements have strong association with the improvement of manufacturing performance such as lower costs, higher availability levels, faster delivery and increased flexibility as shown in Table 4.4. and figure 4.8. Safety, health and environment, shows more intangible rather than tangible benefits which is also important to the organization as a whole. Well working autonomous maintenance pillars which instigate the proper location of all tools and materials will reduce the near miss and collision risks. A proper planned maintenance execution eliminate sudden brake down and reduce the risk of injury by replacing and maintaining equipment in time before failure. Even if focused improvement pillar has indirect effect on safety its effect on the improvement of standard maintenance procedure and standard operational procedure will greatly influence the safe handling of the work. Similarly Training and education pillar grant the knowledge of the process as well as incur skill of the employee it positively affects the safe operation of the process.

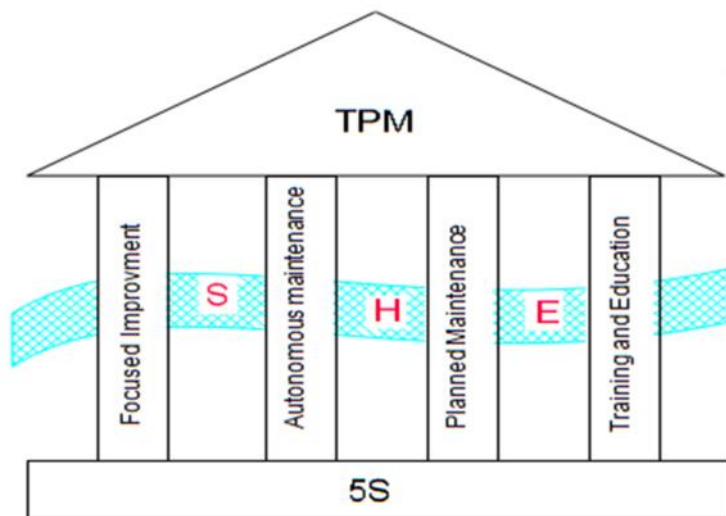


Figure 4.9 New TPM Model

Thus, all of the first four TPM pillars have significant role in boosting manufacturing performance on Nile sole factory. Since implementing all TPM pillars would be costly and not encouraging firms to use as a strategic decision to improve their performance. These four Pillars can act as a guideline for organization wanting to implement TPM in their organization. This will ensure that all important areas are covered and there is a standard structured implementation process during the TPM implementation phase. At the same time, the improvement of manufacturing performance or the benefits of TPM implementation must be recognized by the organization (Dubey, R. et al 2015). According to Robinson and Ginder (1995), for TPM to be successful, “the improvement process must be recognized as benefiting both the company and the worker” It is important to identify the critical elements of TPM and their impact on manufacturing performance because many companies fail to invest in maintenance programs because they manage maintenance by a budget and fail to see the strategic implication of a strong maintenance program (Kathleen et al., 2001). Thus, this study could act as evidence to convince management the importance of TPM implementation towards the organization.

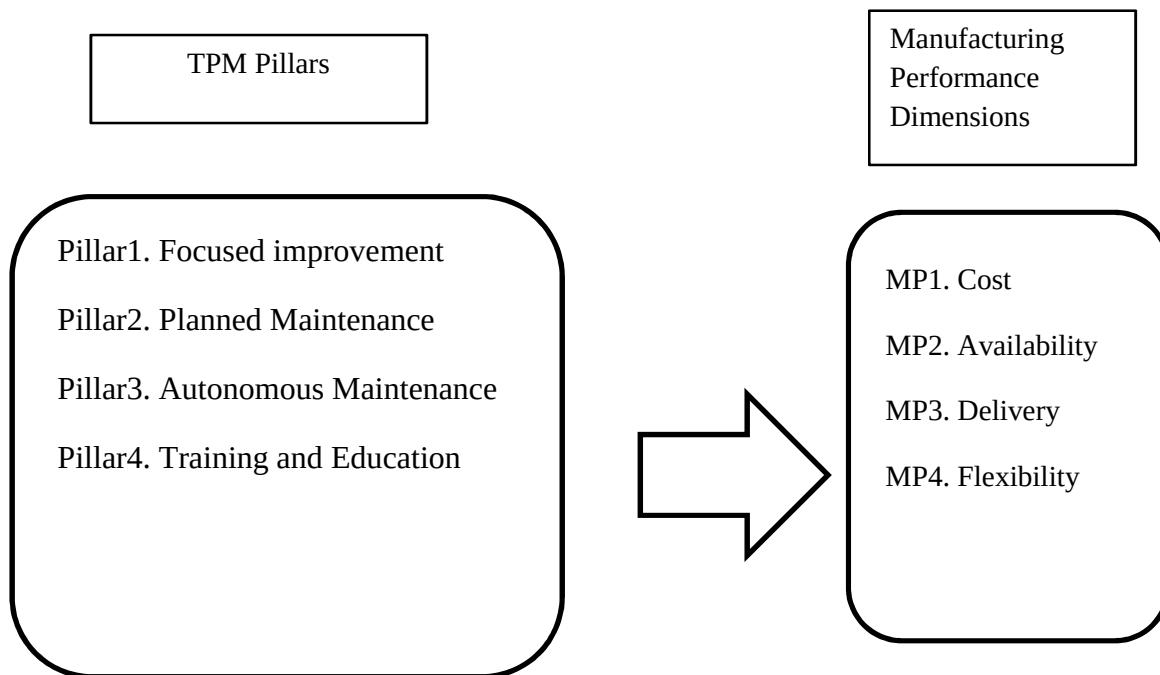


Figure 4.10: New TPM pillars relation with manufacturing performance

4.7. Summary

Production, down time, scrap level and causes of break down data are analyzed and interpreted on the first sections of this chapter and clearly indicates the current status of the case company. Downtime in March was between 17.1% and 27% across all nine machines indicates the company has a challenge to deliver its promises beside low utilization of equipment. The scrap level was observed 11.9 % on average across all machines. From Pareto chart for down time reasons the vital issues contributing for machine stoppage are those related to maintenance and process. Therefore we can justify installing Total productive maintenance pillars will improve the company's problems.

In addition, this chapter has covered the results and discussion of the survey; its objective to evaluate Improvement of Manufacturing Performance Using Selected Total Productive Maintenance Pillars in on Nile Sole Factory. The reliability and validity of the survey has been confirmed with internal consistency test using Cronbach alpha coefficient and factor analysis approach respectively. All of the survey respondents were mostly working on the shop floor.

Bivariate correlation procedure performed also showed that the selected TPM pillars have significant contribution towards the manufacturing performance of the organization. Thus, the four elements of focused improvement, planned maintenance; autonomous maintenance as well as education and training can act like a benchmark for organizations that are planning to implement TPM. By using the four pillars the company will have advantage on minimizing the cost of implementation while it solves the other vital problems of the company's manufacturing performance. The company can be competitive because it minimizes its internal cost such as maintenance cost, rework, material wastage and energy cost. The manufacturing flexibility is attained through standardizing the procedures of change overs and using the continuous improvement by the pillar focused improvement.

Similar result with that of the bivariate correlation obtained from analytic hierarchy process (AHP) in which the first four pillars are more preferred than the rest.

Chapter Five

Conclusion and Recommendation

5.1 Conclusions

This study has presented the results of the survey conducted on Nile sole factory which purpose is to selected TPM Pillars and their contribution towards manufacturing performance dimensions. From the results and discussion, the TPM Pillar that has been given the most emphasis is planned maintenance while the least emphasis on is Office TPM.

This study has investigated the contribution of TPM Pillars emphasis towards manufacturing performance dimensions in Nile sole factory. For this purpose, four manufacturing performance dimensions have been categorized after a review of the problems in the case company. Empirical evidence has been presented to support relationship between various TPM pillars and manufacturing performance. And we have selected four TPM pillars which have significant effect on preferred manufacturing performance metrics. Findings show that these TPM elements are quite important to manufacturing organization in term of lowering cost, better availability of equipment, strong delivery and increased productive levels and also increased flexibility. One of the pillar, autonomous maintenance though show more intangible benefits towards the organization such as improve working environment, skill increase of manpower and higher level of employee involvement. Thus, it can be concluded that all four TPM pillars which are focused improvement, planned maintenance, autonomous maintenance and Training and education are equally important and need to be placed equal emphasis in order to achieve the benefits in manufacturing performance. These pillars can be a sound platform or benchmark for organization that have plans to implement TPM in their plant.

Besides that, some of the respondent also placed emphasis on other TPM element not part of the four construct such as Safety, Health and Environment (SHE). This author believes that elements like SHE comes with the implementation of the four TPM elements covered in the survey. For example, during step 3 of autonomous maintenance (Pill3), safety problems are identified together with other problems. Planned maintenance aims to eliminate unexpected breakdown which indirectly improves safety because equipment problems often lead to accidents, which are

often due to operator's lack of experience in dealing with abnormalities or carrying non-routine tasks.

5.2 Recommendations

- In order to improve the down time and increase the availability of machines Autonomous maintenance and planned maintenance pillars play vital roll if properly installed and sustained. The company should consider using these selected pillars to revert the current vital performance problems of the company.
- As indicated in the analysis the scrap level and rework amount is high enough that costs the company time and material if it goes like this the company will lose its competitiveness because of high production cost related to scrap and reworks. Therefore TPM pillars of Focused improvement and Training and Education will help to improve the process and reduce scraps and reworks by giving the employee skill and concern to follow the process for continuous improvement.
- SHE is one of the most important pillars and could be well defused in all the other pillars as shown in the model. As discussed in previous section almost all selected four pillars have activities that help safety of the shop floor when fully implemented. We need to strengthen and add safety audit programs during the implementation and sustaining will play significant role in making the working environment safe working place.

5.3 Future Works

Since this paper has already demonstrate the significant relationship of selected TPM Pillars and their contribution towards manufacturing performance, future works could focus on the effect of selected TPM Pillars on other continuous improvement programs like lean manufacturing, Total Quality Management (TQM) and Reliability Centered Maintenance (RCM) in manufacturing of Ethiopian industries.

Besides that, the adoptability of the four TPM pillars derive from this study in an actual case study scenario could be conducted in order to view the results first hand and also to improve further the implementation plan.

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Appendix 1

Addis Ababa University

Addis Ababa Institute of Technology

School of Mechanical and industrial Engineering

Industrial Engineering Stream

Questionnaire

Questionnaire on Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars

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Dear Respondents,

This questionnaire is designed based on the Topic: Enhancing Manufacturing Process through Prioritizing Total Productive Maintenance Pillars in Nile Sole Factory. The main purpose of this questionnaire is to obtain information about your company's overall experience with Total productive maintenance pillars.

Any information you give would be kept confidential as the data are needed for academic purpose only.

Your kind cooperation is very much appreciated.

Part I: General Information

1. Gender: A. Male 26 B. Female 8

2. Age: A. 17-30 17 B. 31-40 10 C. 41-50 6 D. 50+

3. Current position: A. Managerial 9 B. Non-managerial 25

4. Educational Background (tick only the highest level you have):

A. Masters B. Bachelors 7 C. Diploma/TVET 24 D. Completed High school 3

E. Completed Elementary School Other

5. Years of experienceA. 1-2 11 B. 3-5 12 C. 6-10. 5 D. 11-15 4 E. Above 16 2**Part II TPM Pillar dimensions.****1. Focused improvement**

Pill1	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill1.1 You have training courses in the past about the work you carried on.		2		20	12
Pill1.2 Maintaining basic equipment condition and return back to optimum condition		8	4	14	8
Pill1.3 Maintenance aims to eliminate even minor defects of equipment		3	8	19	7
Pill1.4 Information on productivity is readily available to employees		3	3	25	4
Pill1.5 Use of Pareto charts, 5 why analysis, fishbone diagram, RCFA, etc. to analyze and eliminate productivity losses		1	3	23	7
Pill1.6 Your company use TPM as a tool to boost Manufacturing performance				19	15

2. Planned maintenance

Pill2	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill2.1 There is a process in place to inspect equipment and machinery regularly based on the inspection program.		8	2	20	4
Pill2.2 Equipment and machinery are cleaned regularly.	2	6		26	
Pill2.3 PM Check sheets specifying PM work for each equipment are used			3	27	4
Pill2.4 There is Monitoring and analyses of machine failure and taking action to prevent reoccurrence.			5	20	9
Pill2.5. There is a program for the inspection of machinery and equipment.			3	23	8
Pill2.6 Cleaning materials and tools are available when ever required.	3	18		13	
Pill2.7 Control devices and equipment inspected regularly and to schedule.			6	16	12

3. Autonomous Maintenance

Pill3	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill3.1 5S initiatives in the organization are Implemented		6	2	16	10
Pill3.2 The plant emphasizes putting all tools and fixtures in their place		16	4	11	3
Pill3.3 Deployment of cleaning, lubrication, tightening standard are well underway.			5	25	4
Pill3.4 Operators participate in small group activity or problem solving teams to help improve manufacturing processes.			1	18	15
Pill3.5 Clear Demonstration of ownership of machines by production operators			1	28	5
Pill3.6 Visual control like , TPM activity board, labels, etc are Deployed		1	1	21	11

4. Training and education

Pill4	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill4.1 TPM training conducted for all employees covering the overview of TPM concept.		9	6	15	4
Pill4.2 Production operators are trained to perform routine PM task, setting of machine, etc	6	13	5	9	1
Pill4.3 Employees receive training to perform multiple task				19	15
Pill4.4 At this factory, employees only learn how to do one job/task		4	1	25	4
Pill4.5 There exists staff development program that focus on upgrading employees technical, problem solving, team working skills, etc			1	24	9

5. Quality Maintenance

Pill5	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill5.1 The maintenance team is good in handling maintenances in professional way.	1	17	6	10	
Pill5.2 Working on minimizing and eliminating defect is our concern in our day today activity.		5	6	23	
Pill5.3 Cause oriented rather than reactive approach is the way we are working here.	11	19	4		
Pill5.4 No customer compliant on quality as a result of poor maintenance approach.	20	14			
Pill5.5 There are scraps and quality defects as a result of poor maintenance handling.	30	4			

6. Early Equipment Management

Pill6	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill6.1 A new product easily gets to the standard quality and has less development lead time.	3	23	8		
Pill6.2 During inclusion of new machine the level of scrap is low.		15	19		
Pill6.3 During introduction of new machine no breakdown or down time is registered	7	26	1		
Pill6.4 During startup of new machine the ability of the firm to deliver in volume at the right quality is good enough.	13	19	1		
Pill6.5 You believe new installations and new product development are not main issues in the production performance	22	12			

7. Office TPM

Pill7	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill7.1 We know that Usually office work will not affect the production effectiveness.	11	19	4		
Pill7.2 The interaction with the administrative peoples does not determines how effective of the shop floor.	22	12			
Pill7.3 We have noticed that effectiveness of logistic affects the performance of shop floor activity.	30	4			
Pill7.4 The decision making from the office is good to facilitate productivity	1	16	7	10	
Pill7.5 The organization in the office is clearly making it effective in helping the shop floor.		4	7	23	

8. Safety ,Health and Environment

Pill8	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
Pill8.1 We feel safe in our day to day activity and it affects our performance	11	23			
Pill8.2 There are serious accidents frequently happened on the shop floor	13	18	3		
Pill8.3 Basic safety precautions and training are given for unsafe conditions on the process.	3	9	18	6	
Pill8.4 There are caution signs and procedures to be followed everywhere on unsafe conditions in working areas.	13	21			
Pill8.5 There is a counter measure to be installed to eliminate re-occurrence of accidents		11	17	6	

Part III Manufacturing performance dimensions

1. Cost

MP1	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
MP1.1 Reduction of operating cost through TPM strategies are implemented		9	2	12	11
MP1.2 There is an effort to reduce energy consumption (e.g. electricity bill) and overhead expenditure			1	25	8
MP1.3 There is effort to reduce of percentage of internal scrap and rework in operations.			1	25	8
MP1.4 There is an effort to reduce customer's returns due to defects.		1	3	20	10
MP1.5 Cost Analysis are being in use for Determining the level of maintenance expense	2	8	2	10	12

2. Availability

MP2	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
MP2.1 Equipment Break downs get in time solution to resume operation.		8	2	20	4
MP2.2 Preventive actions have been taken to reduce breakdowns.	2	6		26	
MP2.3 Machine operators keep their machine clean and do inspection to prevent breakdowns..			3	27	4
MP2.4 Causes of breakdowns(failure) are analyzed and counter measure implemented			5	20	9
MP2.5 Technicians have enough resource to handle Equipment breakdowns to resume in time operation.(Knowledge and tools).			3	23	8
MP2.6 There is enough number of skilled staff to conduct the maintenance sufficient in every shift	3	18		13	
MP2.7 There is significant Equipment's unavailability time due to technical malfunctions.			6	16	12

3. Delivery

MP3	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
MP3.1 The company achieving dependable deliveries by having high percentage of products delivered on time.		2	1	21	10
MP3.2 The company achieving faster deliveries by averaging low lead times between receipt of order till delivery	1	2	2	28	6
MP3.3 There is preparedness to reduce cycle time to develop new product.	1	4	6	21	2
MP3.4 There is readiness to handle demand changes, like raw material preparation, before production begins.	9	15	3	5	3

4. Flexibility

MP4	1- Strongly Agree	2- Agree	3- Neither	4- disagree	5- Strongly disagree
MP4.1 Change over time is took fairly acceptable duration				25	9
MP4.2 There is well written procedures during product changeovers				15	19
MP4.3 Operators and technicians are working to reduce change over time.		1	1	21	11
MP4.4 Errors or malfunctions of the machine relived gratefully not to disrupt the production.	1	16	8	7	2
MP4.5 It is easy to test and introduce new products in the existing mix.	9	6	9	8	2