PRODUCTIVITY AND QUALITY ENHANCEMENT THROUGH IMPLEMENTATION OF TOTAL PRODUCTIVE MAINTENANCE (TPM) IN A MANUFACTURING PLANT

by

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Declaration of Candidate

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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List of Acronyms

TPM	Total Productive Maintenance
PM	Preventive Maintenance
OEE	Overall Equipment Effectiveness
JIT	Just In Time
TQM	Total Quality Management
JIPM	Japan Institute of Plant Maintenance
TPS	Toyota Production System
LCC	Life cycle cost
MP	Maintenance Prevention
BM	Breakdown Maintenance
DT	Downtime
ST	Stop time
PdM	Predictive Maintenance

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Abstract

Plant and equipment maintenance is a vital issue in manufacturing. The cost of regular maintenance might be low but the major breakdown of a machine can halt the entire production line. On the other hand effective machine maintenance would enable a plant to increase productivity, efficiency, quality operations, various flexibility, and responsive to customer service. Most importantly, this may prolong the life of machines. In order to measure performance of a maintenance system, the overall equipment effectiveness (OEE) is a summarized metric of several performance measures used to determine a machine's or plant's performance and its impact on productivity. The purpose of OEE is to assist an organization with improved productivity, reliability, maintainability for both short term and long term effectiveness, and low cost yet quality product at the best value. To evaluate the OEE, research framework has been designed through interview-for initial assessment, observation of shop floor, collecting breakdown and repair data and analyzing those with statistical tools. After the documentation and analysis of data, findings are represented in graphical forms such as Pareto chart, cause effect diagram, and process flow diagram. Very little research is conducted about Total Productive Maintenance (TPM) implementation Bangladeshi manufacturing plant; so this thesis going to add value to that cause. Bangladesh spends significant portion of foreign currency to import industrial machineries. Understanding the reasons of machine breakdowns, failures, quality defects, reduced speed, setup and adjustment losses are vital for plants. Actual capacity of production line can be enhanced by understanding the big losses and evaluating OEE. Otherwise to meet the extended demand of a product, a plant has to spend more money on buying new equipment. Many Japanese and the USA manufacturing plant incorporated TPM few decades ago but this practice seems to be absent here. Practical implication of this study is that manufacturing plants needs to improve its maintenance policy.

Chapter 1
INTRODUCTION

1.1 IMPORTANCE OF THE STUDY

Machine maintenance is a vital issue especially in manufacturing plants. The cost of regular maintenance is low but major breakdown of a machine can halt the entire production line. Beverage industry is very much dynamic in nature and failure of machine in plant can incur huge loss as there is no production as well as losing market share. Effective machine maintenance would enable a plant to increase productivity, efficiency, continuous manufacturing operations, expansion of operation and responsive customer service and most importantly it may prolong the life of parts of machines. Both technical & administrative aspects are connected to machine maintenance, it is the evident of importance in this issue.

In this study, overall equipment effectiveness (OEE) metric is about to use to determine the machine maintenance performance and its impact on productivity. The purpose of OEE is to assist an organization with improve productivity, reliability, maintainability for both short term and long term, effectiveness, low cost yet quality product at the best value . When we measure OEE and its change we will monitor the key points of Total productive maintenance.

There are benefits of performing machine maintenance in an organization as follow:

1. Scheduled maintenance in organization will enable the equipment to operate at optimal efficiency & increase uptime of machines.
2. Reduce chances of complete breakdown, problems are tried to understand earlier to prevent such situation.
3. Minimize downtime to locate and replace missing parts.
4. Reduce emergency repair call, in case of breakdown it may take few days to get repair crew and spare parts.
5. Timely maintenance eliminates large scale repairs.
6. Maximizing safety & quality condition for operators as well as for maintenance crew while operation and maintenance work.
7. Many manufacturers adopt insurance policy for their machines, safer equipment will cost less on insurance.

1.2 PROBLEM STATEMENT

Most of the manufacturing plants, irrespective of their size, adopt different maintenance practices ranging from breakdown maintenance to preventive maintenance, and predictive maintenance. Although various maintenance policies are chosen, when it comes to practical implementation and commitment in maintenance activities, many plants fail to perform well. Because of perception regarding maintenance, there are a lot of people who consider maintenance activities only limited to parts repair or replacement or at best some scheduled inspection of the equipment. Ultimately, those lacking leads to reduced speed, frequent breakdown and actual production lower than designed rate. After a few inspections of shop floor, interview, and collection of some raw data and analyzing them, this study has come to identify a few problems which are causing interruption to productivity enhancement in a production plant.

1. Frequent breakdowns of Blomax, Filler/capper, Labeler, and Syrup room/CIP machines disrupt production. Analyzing breakdown time and presenting that through a Pareto chart, these machines amount to the most of the downtime in production line.
2. Line utilization and Line efficiency are found to be below 50%. These two metrics indicate low actual output of products than its designed capacity. The overall equipment effectiveness (OEE) at Blomax (bottleneck area of the production line) is also below 50%, showing a lack in maintenance activities and yield losses.
3. Machine keepers aren't aware of the importance of the machine as a profit contributor. They failed to realize that if actual output is low, it incur more cost on production. This ultimately reduces profit.
4. Records of all loss times aren't documented properly and shop floor workers, supervisors are not aware of 6 big losses.
5. Maintenance department could not able to show the results of maintenance activities in terms of cost savings and more loading time in production. Thus failed to get the level of priority maintenance activities demand from top management.
6. Machine operators' shortfall in terms of participative feeling of maintenance practice.

Most of the workers make a mistake by considering machine maintenance is the job of "maintenance" department alone, "I operate, you fix" is a misconception of this era. Because some world-class Japanese companies recognized over twenty-five years ago that the effective application of modern technology can only be achieved through people-starting with the operators and maintainers of that technology- and not through systems alone. Appropriate maintenance practice is vital for a plant, otherwise manufacturers may make wrong planning which may cost them more money and time spend in the wrong area.

1.3 OBJECTIVES/GOALS OF THE STUDY

The aim of this study is to improve current machine maintenance practices and its impact on equipment effectiveness, output product quality and quantity. The specific objectives are given below:

1. Establishing a preventive maintenance strategy for the entire life cycle of equipment.

2. Maximizing equipment effectiveness through optimization of equipment availability, performance, efficiency and product quality & improve OEE indices up to 50%.
3. Presenting maintenance results in terms of cost saving and increased loading time in production.
4. Involving all staff members from top management to shop-floor workers in maintenance activities. Promoting improved maintenance through small-group autonomous activities.

1.4 SCOPE AND LIMITATION OF THE STUDY

The following sub-sections presenting the scopes and limitation of the study.

1.4.1 Scopes of the study

1. Maintenance policy can be improved by implementing Total productive maintenance (TPM)
2. Identifying the losses that cause breakdown to machine and increasing machine availability.
3. Introduction and importance of Autonomous maintenance to plant
4. Understand the level of productivity in plant using OEE

1.4.2 Limitations of the study

1. The study is focused on making maintenance activities more efficient, it didn't considered any other function of the organization.
2. In some cases maintenance results weren't organized and not available to the researchers.

1.5 METHODOLOGY

The research was carried out in three phases which was

- First phase: Selection of machine maintenance & productivity enhancement model and introduction of model.
- Second phase: Study practical/present maintenance policy & productivity level in case study plant.
- Third phase: Study productivity performance of the plant and suggestion of improvement techniques.

During first phase, the literature review was performed to understand the various productivity measurement models. The suitable model was selected from literature review by considering the adaptability to the manufacturing plant, ease of application and ability to detect problem easily.

In the second phase, interview sessions and documentation review was carried out in the selected manufacturing plant to understand the various measurement used in the plant and to determine of the formal productivity measurement. Then, the overall equipment effectiveness was measured by its three performance matric.

In the third phase, data was collected and used to analyze the productivity performance of the manufacturing plant. The problem of low productivity was analyzed using Pareto diagram and cause and effect diagram to define the exact problem. Based on the problem defined, the improvement techniques were suggested.

1.6 CONTRIBUTION OF THE STUDY

The main contribution of this study is to inform and convince the organization about more efficient maintenance policy to resolve the challenges they face in terms of maintenance activities. Understanding productivity level of the plant by the metric of OEE is also another contribution of this study. This study also focused on making structural reform by incorporating machine operators into its maintenance activities which is known as autonomous maintenance. Also, helping the organization to realize proper maintenance at proper time can add tremendous value to productivity and cost effectiveness. Finally, the application of this approach to plant provides managerial insights on the usefulness of the model.

1.7 ORGANIZATION OF THE REPORT

This thesis is organized as follow. An overview of this study is reported in chapter 1. Goals and objectives of this thesis are listed and the methodology of how to carry this research is presented in this chapter.

Chapter 2 gives a more detail explanation about this research study. Brief introduction to Total productive maintenance. Also, TPM implementation issues, difficulties and success factors. Detail explanation of six big losses and overall equipment effectiveness (OEE) is also included in this chapter.

Research design are presented in chapter 3. The factors used in conducting this experiment are mentioned clearly.

Chapter 4 presents the analysis and discussion of the results obtained. The data was analyzed by using overall equipment effectiveness (OEE) .

Chapter 5 presents the analysis and recommendation of the study. The recommendation is made to the company and also on the scope of further work.

Chapter 2
LITERATURE REVIEW

2.1 Maintenance:

Traditionally, the word machine maintenance or simply maintenance has been considered as a support function or non-productive activities. Throughout the years, the importance of maintenance function and maintenance management experienced rapid growth. According to Wireman's research (1990) research, it was estimated that the cost for maintenance for a number of selected companies spiked from $200 billion in 1979 to $600 billion in 1989. Another research revealed that cost of corrective maintenance cost is three times than preventive maintenance (Mobley, 1990). Widespread mechanization and automation and increased capital in the production equipment & civil structures reduced the number of production personnel. As a result, the fraction of employees working in the area of maintenance as well as the fraction of maintenance spending on the total operational costs has grown over the years. In refineries, for instance, it is not uncommon that the maintenance and operations departments are the largest, and each comprises 30 percent of the total manpower. Furthermore, next to the energy costs, maintenance costs can be the largest part of any operational budget (Garg and Deshmukh, 2006). Maintenance has always been one of the most important things in manufacturing plant due to its role of maintaining the performance of all equipment, improving the efficiency, availability and safety requirements (Alsyouf and Al-Najjar, 2003). Yet, the main question faced by the maintenance management, whether its output is produced more effectively, in terms of contribution to company profits and efficiently, in terms of manpower and materials employed, is very difficult to answer (Garg and Deshmukh, 2006).

Prime objective of maintenance activities is to preserve the prime condition of a physical system to its proper function. Maintenance often divided into two parts, breakdown/reactive maintenance and preventive maintenance.

This refers to the maintenance strategy, where repair is done after the equipment failure/stoppage or upon occurrence of severe performance decline (Wireman, 1990). This maintenance strategy was primarily adopted in the manufacturing organizations, worldwide, prior to 1950. In this phase, machines are serviced only when repair is drastically required. This concept has the disadvantage of unplanned stoppages, excessive damage, spare parts problems, high repair costs, excessive waiting and maintenance time and high trouble shooting problems (Telang, 1998).

On the other hand, Preventive maintenance was introduced in 1951, which is a kind of physical checkup of the equipment to prevent equipment breakdown andprolong equipment service life. PM comprises of maintenance activities that are undertaken after a specified period of time or amount of machine use (Herbaty, 1990). During this phase, the maintenance function is established and time based maintenance (TBM) activities are generally accepted (Pai, 1997). This type of maintenance relies on the estimated probability that the equipment will breakdown or experience deterioration in performance in the specified interval. The preventive work undertaken may include equipment lubrication, cleaning, parts replacement, tightening, and adjustment. The production equipment may also be inspected for signs of deterioration during preventive maintenance work (Telang, 1998).

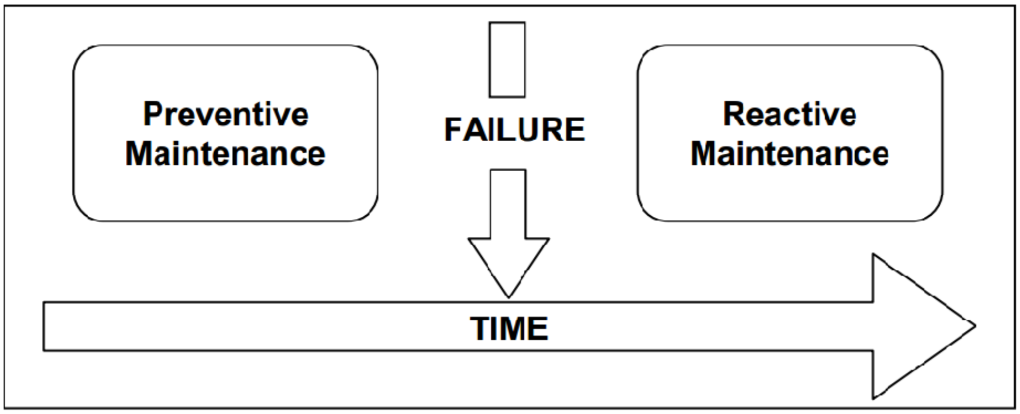


Figure 2.1 Relationship between Preventive Maintenance and reactive Maintenance according to (Sweetman, 1997)

In PM, there are four forms of maintenance practices which are time based, work based, opportunity based, and condition based maintenance. Time based maintenance is the kind of maintenance where equipment is being serviced in a certain period of time, while work based maintenance is an act of maintenance after the production has gone through a certain amount of work hours or production. Opportunity based maintenance is carried out during a break, in holiday, or when there is no production activity. Lastly, condition based maintenance is carried out according to the machine inspection by the person in charge of the designated equipment (Misti, 2016)

According to Sweetman (1997), TPM was categorized in maintenance hybrid alongside with Reliability Centered Maintenance (RCM). Reliability Centered Maintenance was also founded in the 1960s but initially oriented towards maintaining airplanes and used by aircraft manufacturers, airlines, and the government (Dekker, 1996).

RCM can be defined as a structured, logical process for developing or optimizing
the maintenance requirements of a physical resource in its operating context to realize its “inherent reliability”, where “inherent reliability” is the level of reliability which can be achieved with an effective maintenance program (Ahuja and Khamba, 2008)

TPM has close ties with lean manufacturing culture. TPM focuses on waste elimination as well as boost productivity with continuous observation on the condition of the equipment involved.

2.2 Total Preventive maintenance (TPM):

TPM methodology originated from Japan in support of its' lean manufacturing system. Dependable and effective equipment are essential pre-requisite for implementing Lean manufacturing initiatives in organizations (Sekine and Arai, 1998). There was Just-In-Time (JIT) and Total Quality Management (TQM) programs existed with good health but manufacturing organizations are putting their confidence on the latest strategic quality maintenance tool as TPM. There is intense relationship between TPM and lean manufacturing, figure depicts that TPM is the corner stone activity for most of the lean manufacturing philosophies.

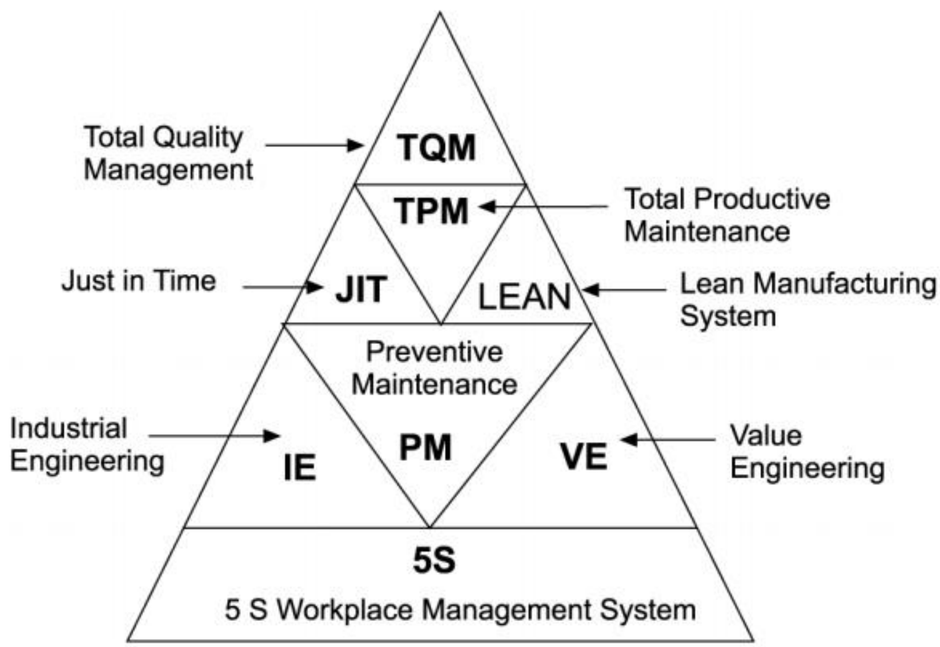


Figure 2.2 Relationship between TPM and lean manufacturing philosophies (Ahuja and Khamba, 2008:p.7).

2.2.1 History of TPM

After World War II, Japanese industries determined that to compete successfully in the world market they had to improve the quality of their products. To do so they improved management and manufacturing techniques from the United states and adopted them to their circumstances. Subsequently, Japanese were known for their quality and economical products and world focused their attention to Japanese style management techniques.

One of the ideas imported by Japan is the Preventive maintenance (PM) from the United states more than thirty years ago. They also imported other concepts with the advancement of technology and demand for economic production system such as productive maintenance (also known as PM), maintenance prevention (MP), reliability engineering, etc.

Preventive maintenance was introduced in the 1950's and productive maintenance become well established in 1960's. The development of TPM began in 1970's. The time prior to 1950's is refer to "breakdown maintenance" period.

Table 2.1 Four Stage of PM Development (Shekran,1993:p.9)

		1976	1979
Stage 1	Breakdown maintenance	12.7%	6.7%
Stage 2	Preventive maintenance	37.3%	28.8%
Stage 3	Productive maintenance	39.4%	41.7%
Stage 4	TPM	10.6%	22.8%

Japanese companies have implemented TPM in stages roughly corresponding to the development of PM development in Japan from1950 to 1980. Table shows these developments for data compiled for the years 1976 and 1979 from 124 companies belonging to JIPM (Japan Institute of Plant Maintenance). In three years, the number of plants actively participating TPM more than doubled.

Toyota is one of the companies to introduce TPM within its' production system. Toyata's officials were heard quoting that had it not been for TPM, their Toyota Production System (TPS) would not have been successful. According to its creator, Taichi ohno (Seang, 1989), the Toyota production system is based on the absolute elimination of waste. In Toyota's Just in Time (JIT) production; only the necessary items are produced when needed. The Toyota Production system strives to attain Zero defects and zero inventory level.

Nippondenso co., a well-known Toyota supplier of electrical parts, began implementing productive maintenance in 1961. In 1969, to keep up with the rapid progress in automated production, they implemented "Productive maintenance with total employee participation" TPM. Two years later, it was the first company to be awarded the distinguish Plant Prize (PM Prize) for its achievement with TPM. (Shekaran, 1993)

Table 2.2 History of PM in Japan (Shekran,1993:p.10)

	1950'S	1960'S	1970'S
ERA	PREVENTIVE MAINTENANCE ESTABLISHING MAINTENANCE FUNCTION	PRODUCTIVE MAINTENANCE RECOGNIZING IMPORTANCE OF RELIABILITY MAINTENANCE AND ECONOMIC EFFICIENCY IN PLANT DESIGN	TOTAL PRODUCTIVE MAINTENANCE ACHIVING PM EFFICIENCY THROUGH A COMPREHENSIVE SYSTEM BASED ON RESPECT FOR INDIVIDUAL AND TOTAL EMPLOYEE PARTICIPATION
APPROCH	• PM - preventive maintenance -1951 • PM –productive maintenance -1954 • MI – maintainability improvement - 1957	• Maintenance prevention – 1960 • Reliability engineering – 1962 • Maintainability engineering – 1962 • Engineering economy	• Behavioral science • MIC – management for innovation and creation PAC – performance analysis and control F plans – foreman plan • System engineering • Ecology • Terotechnology • Logistics
Major Event	1951 Toa Nenryo Kogyo is the first Japanese Company to use American style PM 1953 20 companies form PM research group (later the Japan Institute of Plant Maintenance (JIPM) 1958 George Smith (US) comes to Japan to promote PM	1960 First maintenance convention (Tokyo) 1962 Japan Management Association sends mission to US study equipment maintenance 1963 Japan attends international convention on equipment maintenance (London) 1964 First PM Prize awarded in Japan 1965 Japan attends international convention on equipment maintenance (London) 1969 Japan institute of Plant Engineering (JIPE) established	1970 International convention on equipment maintenance held in Tokyo (co-sponsored by JIPE and JMA) 1970 Japan attends international convention on equipment maintenance sponsored by UNIDO-United Nations Industrial Development Organization (West Germany) 1971 Japan attends international convention on equipment maintenance(los Angeles) 1973 UNIDO sponsors maintenance repair symposium in Japan 1973 Japan attends international terotechnology convention (Bristol, England) 1974 Japan attends EFNMS-European Federation of National Maintenance Societies maintenance congress 1976 Japan attends EFNMS maintenance congress 1978

			Japan attends EFNMS maintenance congress 1980 Japan attends EFNMS maintenance congress

2.2.2 Defining TPM

There is two different approach in terms of defining TPM. Because TPM is the modified and enhanced version of American Productive maintenance to fit the Japanese industrial environment. However, the common ground of both of the approaches are maximizing equipment effectiveness and total employee participation in maintenance works.

Nakajima (1989), a major contributor of TPM, has defined TPM as an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns, and promotes autonomous maintenance by operators through day-to-day activities involving the total workforce (Conway and Perry, 1999, Bhadury, 2000).

Willmott (1994) portraits TPM as a relatively new and practical application of TQM and suggests that TPM aims to promote a culture in which operators develop “ownership” of their machines, learn much more about them, and in the process realize skilled trades to concentrate on problem diagnostic and equipment improvement projects. TPM is not a maintenance specific policy, it is a culture, a philosophy and a new attitude towards maintenance (Chowdhury, 1995)

An effective TPM implementation program provides for a philosophy based upon the empowerment and encouragement of personnel from all areas in the organization (Davis and Willmott, 1999).

TPM is a maintenance management programme with the objective of eliminating equipment downtime. TPM is an innovative approach to plant maintenance that is complementary to Total Quality Management (TQM), Just-in-Time Manufacturing (JIT), Total Employee Involvement (TEI), Continuous Performance Improvement (CPI), and other world-class manufacturing strategies (Maggard et al., 1989; Schonberger, 1996; Ollila and Malmipuro, 1999; Cua et al., 2001).

TPM describes a synergistic relationship among all organizational functions, but particularly between production and maintenance, for the continuous improvement of product quality, operational efficiency, productivity and safety (Rhyne, 1990; Labib, 1999; Sun et al., 2003).

2.2.3 TPM Pillars:

The basic practices of TPM are often called the pillars or elements of TPM. The entire edifice of TPM is built and stands, on eight pillars (Sangameshwran and Jagannathan, 2002). TPM paves way for excellent planning, organizing, monitoring and controlling practices through its unique eight-pillar methodology. TPM initiatives, as suggested and promoted by Japan Institute of Plant Maintenance (JIPM), involve an eight pillar implementation plan that results in substantial increase in labor productivity through controlled maintenance, reduction in maintenance costs, and reduced production stoppages and downtimes.

The core TPM initiatives classified into eight TPM pillars or activities for accomplishing the manufacturing performance improvements include Autonomous Maintenance; Focused Maintenance; Planned Maintenance; Quality Maintenance; Education and Training; Office TPM; Development Management; and Safety, Health and Environment (Ireland and Dale, 2001; Shamsuddin et al., 2005; Rodrigues and Hatakeyama, 2006).

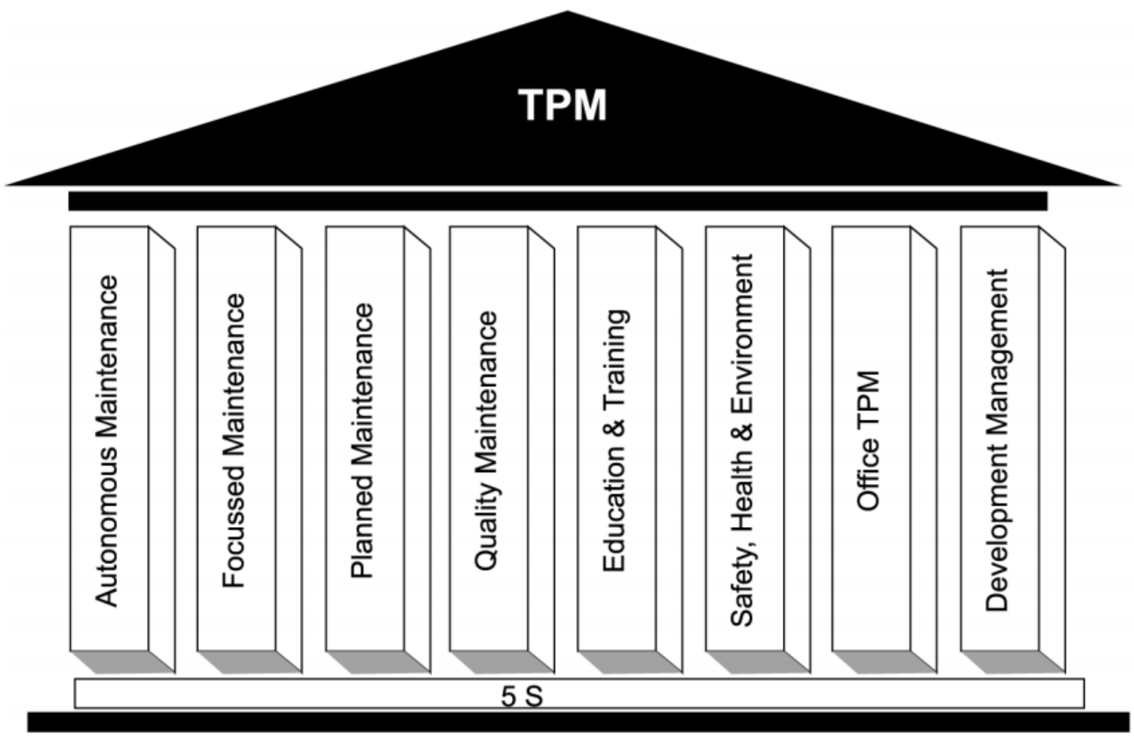


Figure 2.3 Eight pillars approach for TPM implementation (Suggested by JIPM)

2.2.3.1 Autonomous maintenance

Autonomous maintenance is the process by which equipment operators accept and share responsibility (with maintenance) for the performance and health of their equipment.” (Robinson and Ginder,1995:p. 57) The driving concept of Autonomous Maintenance (AM) is the creation of ‘expert equipment operators’ for the purpose of ‘protecting their own equipment’. (Shirose,1996) “Autonomous maintenance is the cornerstone of TPM activities.” (Komatsu,1999:p. 2).

The paradigm shift that AM addresses is a transition in the operator perception from ‘I run the equipment, Maintenance fixes it’, to ‘I own the performance of this equipment’. In this Autonomous Maintenance environment, “The greatest requirements for operators are, first, to have the ability to ‘detect abnormalities’ with regard to quality or equipment, based on a feeling that ‘there is something wrong’.” (Shirose,1996,p.208).

In autonomous activities operators are involved in daily inspection and cleaning of his or her equipment. By doing so, companies discover the most important asset in achieving continuous improvement- it’s people.

Autonomous Maintenance has two aims,
1) To foster the development and knowledge of the equipment operators
2) To establish an orderly shop floor, where the operator may detect departure from optimal conditions easily. (Tajiri and Gotoh,1992)

JIPM describes the critical operator Autonomous Maintenance skills to be (Japan Institute of Plant Maintenance,1997):

- Ability to discover abnormalities.
- Ability to correct abnormalities and restore equipment functioning.
- Ability to set optimal equipment conditions.
- Ability to maintain optimal conditions.

JIPM and Productivity, Inc. defines the operator skill levels required to support Autonomous Maintenance (Japan Institute of Plant Maintenance,1997;Productivity 2000)

Table 2.3: Operator Autonomous maintenance Skill Levels. (Pomoroski,2004:p.30)

Level 1	Recognize deterioration and improve equipment to prevent it. • Watch for and discover abnormalities in equipment operation and components. • Understand the importance of proper lubrication and lubrication methods. • Understand the importance of cleaning (inspection) and proper cleaning methods. • Understand the importance of contamination and the ability to make localized improvements.
Level 2	Understand equipment structure and functions. • Understand what to look for when checking mechanisms for normal operation. • Clean and inspect to maintain equipment performance. • Understand criteria for judging abnormalities. • Understand the relationship between specific causes and specific abnormalities. • Confidently judge when equipment needs to be shut off. • Some ability to perform breakdown diagnosis.
Level 3	Understand causes of equipment-induced quality defects. • Physically analyze problem-related phenomena. • Understand the relationship between characteristics of quality and the equipment. • Understand tolerance ranges for static and dynamic precision and how to measure such precision. • Understand causal factors behind defects
Level 4	Perform routine repair on equipment. • Be able to replace parts. • Understand life expectancy of parts. • Be able to deduce causes of breakdown

2.2.3.2 Focused Improvement Pillar (Kobetsu Kaizen)

"Focused improvement includes all activities that maximize the overall effectiveness of equipment, processes, and plants through uncompromising elimination of losses5 and improvement of performance." (Suzuki,1994:p. 1992).

The objective of Focused Improvement is for equipment to perform as well every day as it does on its best day. The driving concept behind Focused Improvement is *Zero Losses*.

Leflar noticed an important TPM paradigm change which happen to be the core belief of focused maintenance.

Old Paradigm – New equipment is the best it will ever be.
New Paradigm – New equipment is the worst it will ever be.

“The more we operate and maintain a piece of equipment, the more we learn about it. We use this knowledge to continuously improve our maintenance plan and the productivity of the machine. We would only choose to replace a machine should its technology become obsolete, not because it has deteriorated into a poorly performing machine.” (Leflar,2001:p. 18).

Equipment losses may be either chronic (the recurring gap between the equipment’s actual effectiveness and its optimal value) or sporadic (the sudden or unusual variation or increase in efficiency loss beyond the typical and expected range).

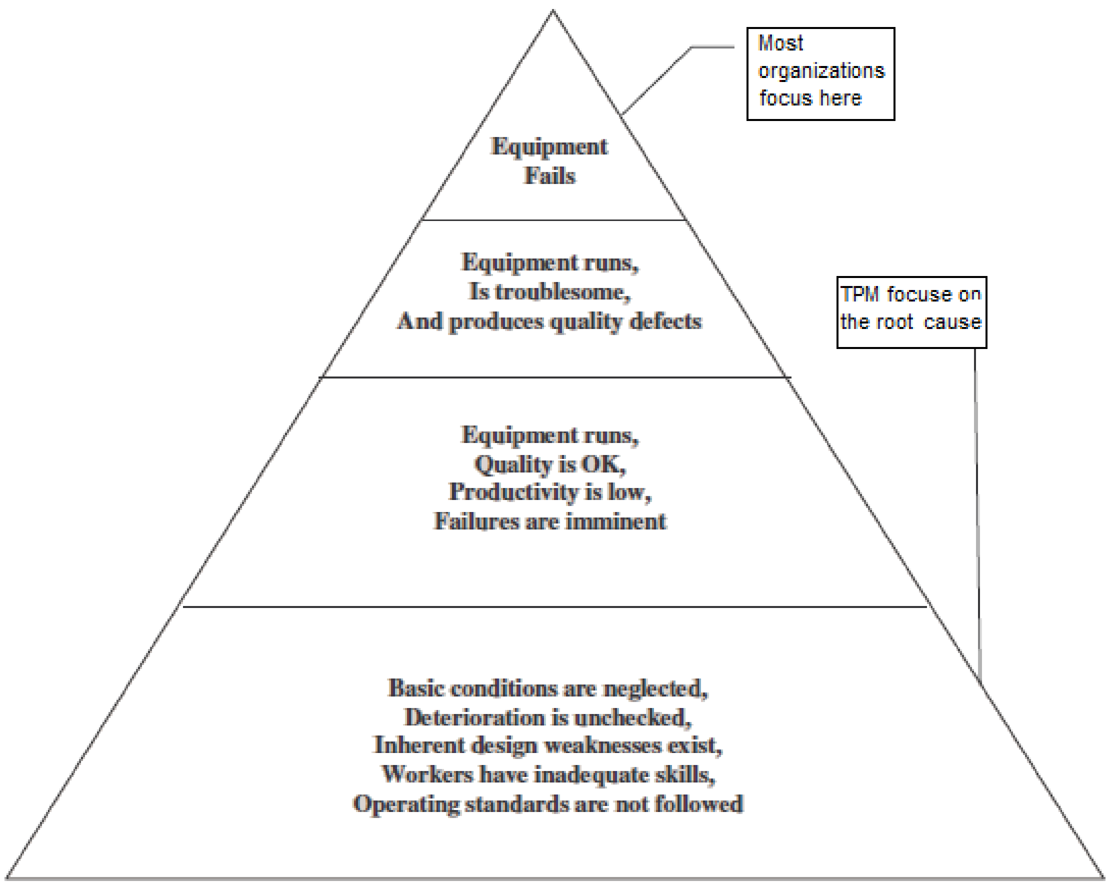


Figure 2.4 TPM pyramid of chronic conditions.(Pomoroski, 2004:p.22).

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. The learning that takes place during restoration and loss elimination then provide the TPM program a definition of optimal equipment condition that will be maintained (and improved) through the life of the equipment. (Pomorski, 2004)

2.2.3.3 Preventive maintenance

The objective of Planned Maintenance is to “establish and maintain optimal equipment and process conditions”. (Suzuki,1994:p. 145).

As defined by JIPM, “Devising a planned maintenance system means raising output (no failures, no defects) and improving the quality of maintenance technicians by increasing plant availability (machine availability). Implementing these activities efficiently can reduce input to maintenance activities and build a fluid integrated system, which includes:

- Regular preventive maintenance to stop failures (Periodic maintenance, predictive maintenance).
- Corrective maintenance and daily MP [maintenance prevention] to lower the risk of failure.
- Breakdown maintenance to restore machines to working order as soon as possible after failure.
- Guidance and assistance in ‘Jishu-Hozen’ [Autonomous Maintenance].” (Japan Institute of Plant Maintenance,1996;p. 119).

Like Focused Improvement, Planned Maintenance supports the concept of zero failures. “Planned maintenance activities put a priority on the realization of zero failures. The aim of TPM activities is to reinforce corporate structures by eliminating all losses through the attainment of zero defects, zero failures, and zero accidents. Of these, the attainment of zero failures is of the greatest significance, because failures directly lead to defective products and a lower equipment operation ratio, which in turn becomes a major factor for accidents.” (Shirose,1996:p. 309).

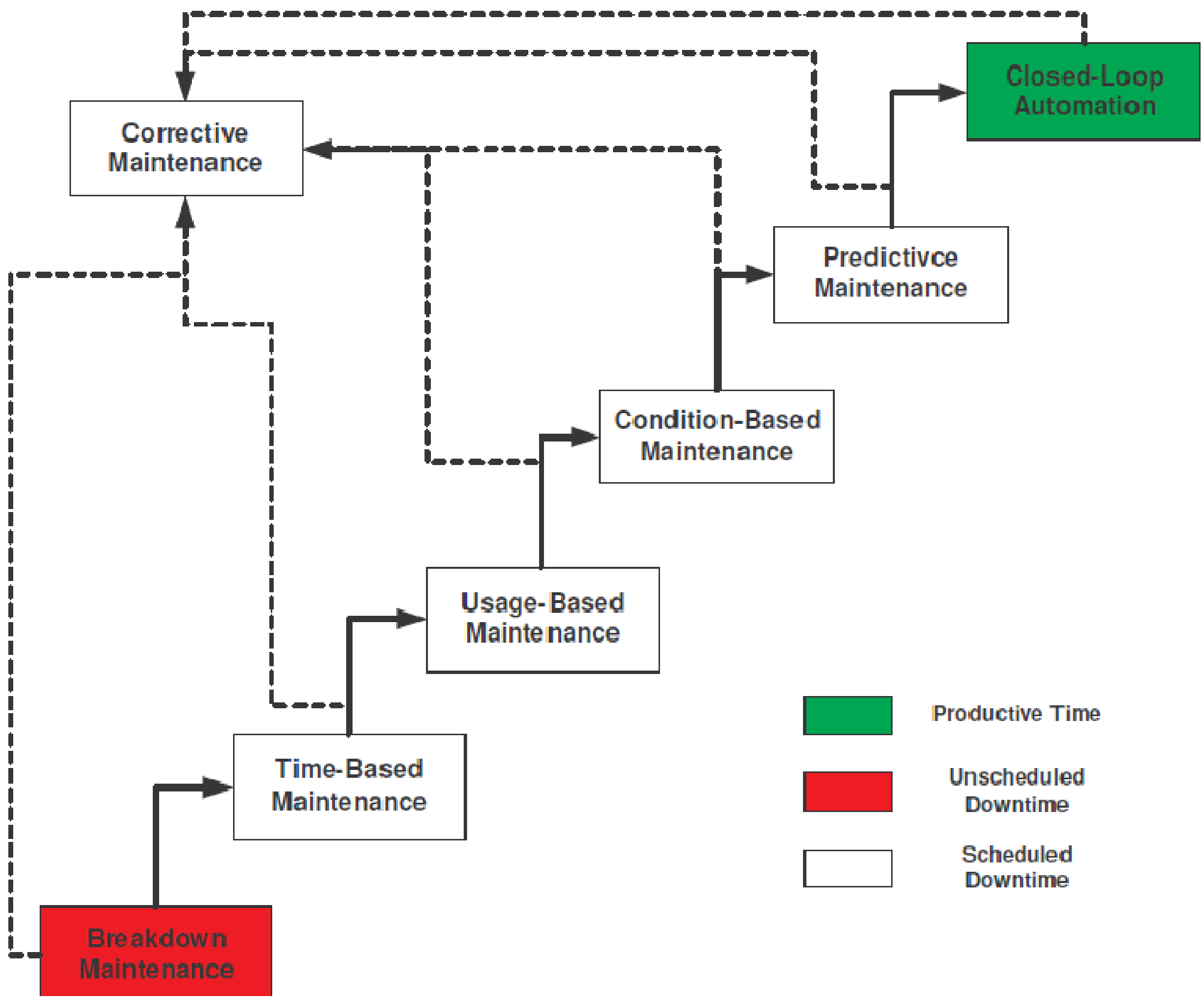


Figure 2.5 Maintenance Regimes (Pomoroski, 2004:p.47).

2.2.3.4 Maintenance Prevention (MP)

Maintenance Prevention refers to "design activities carried out during the planning and construction of new equipment, that impart to the equipment high degrees of reliability, maintainability, economy, operability, safety, and flexibility, while considering maintenance information and new technologies, and to thereby reduce maintenance expenses and deterioration losses." (Shirose,1996:p. 355).

Maintenance Prevention is also known as Early Management (Suzuki,1994), Initial Phase Management (Shirose,1996), and Initial Flow Control (Nakajima,1984). The classic objective of MP is to minimize the Life Cycle Cost (LCC) of equipment.

In large part, MP improvements are based on learning from the existing equipment and processes within the Focused Improvement, Autonomous Maintenance, and Planned Maintenance TPM pillar activities. "MP design activity minimizes future maintenance costs and deterioration losses of new equipment by taking into account (during planning and construction) maintenance data on current equipment and new technology and by designing for high reliability, maintainability, economy, operability, and safety. Ideally, MP-designed equipment must not break down or produce nonconforming products…The MP design process improves equipment [and process] reliability by investigating weaknesses in existing equipment [and processes] and feeding the information back to the designers."
(Suzuki,1994:p. 201).

2.2.3.5 Quality Maintenance

"Quality maintenance, in a nutshell, is establishment of conditions that will preclude the occurrence of defects and control of such conditions to reduce defects to zero." (Japan Institute of Plant Maintenance,1996:p. 134).

Quality Maintenance is achieved by establishing conditions for 'zero defects', maintaining conditions within specified standards, inspecting and monitoring conditions to eliminate variation, and executing preventive actions in advance of defects or equipment/process failure. The key concept of Quality Maintenance is that it focuses on preventive action 'before it happens' (cause oriented approach) rather than reactive measures 'after it happens' (results oriented approach). (Japan Institute of Plant Maintenance,1996).

The core concept of Quality Maintenance is integrating and executing the structures, practices, and methodologies established within Focused Improvement, Autonomous Maintenance, Planned Maintenance, and Maintenance Prevention. Quality Maintenance occurs during equipment/process planning and design, production technology development, and manufacturing production and maintenance activity. (Shirose,1996).

“The precondition for implementation of quality maintenance is to put the equipment, jigs, and tools for ensuring high quality in the manufacturing process, as well as processing conditions, human skills, and working methods, into their desired states.” (Shirose,1996:p.395) Pre-conditions for successful Quality Maintenance implementation include abolishment of accelerated equipment deterioration, elimination of process problems, and the development of skilled and competent users. (Shirose,1996).

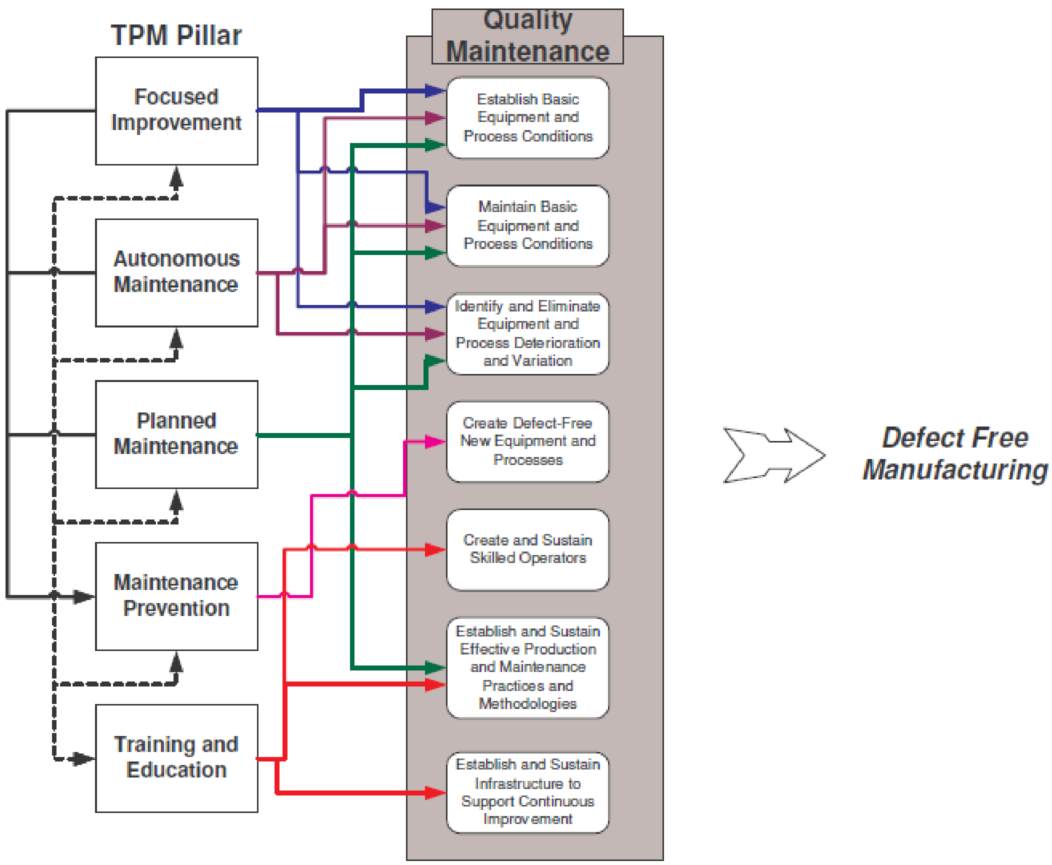


Figure 2.6 Quality Maintenance integration. (Pomoroski, 2004:p.60).

2.2.3.6 Administrative/Office TPM

Administrative TPM applies TPM activities to continuously improve the efficiency and effectiveness of logistic and administrative functions.

Manufacturing is not a stand-alone activity, but is now fully integrated with, and dependent on, its support activities. “These departments increase their productivity by documenting administrative systems and reducing waste and loss. They can help raise production-system effectiveness by improving every type of organized activity that supports production.” (Suzuki,1994:p. 284).

Like equipment effectiveness improvement, Administrative TPM focuses on identifying and eliminating effectiveness losses in administrative activities. Figure illustrates the type of effectiveness losses that are addressed in Administrative TPM. (Suzuki,1994)

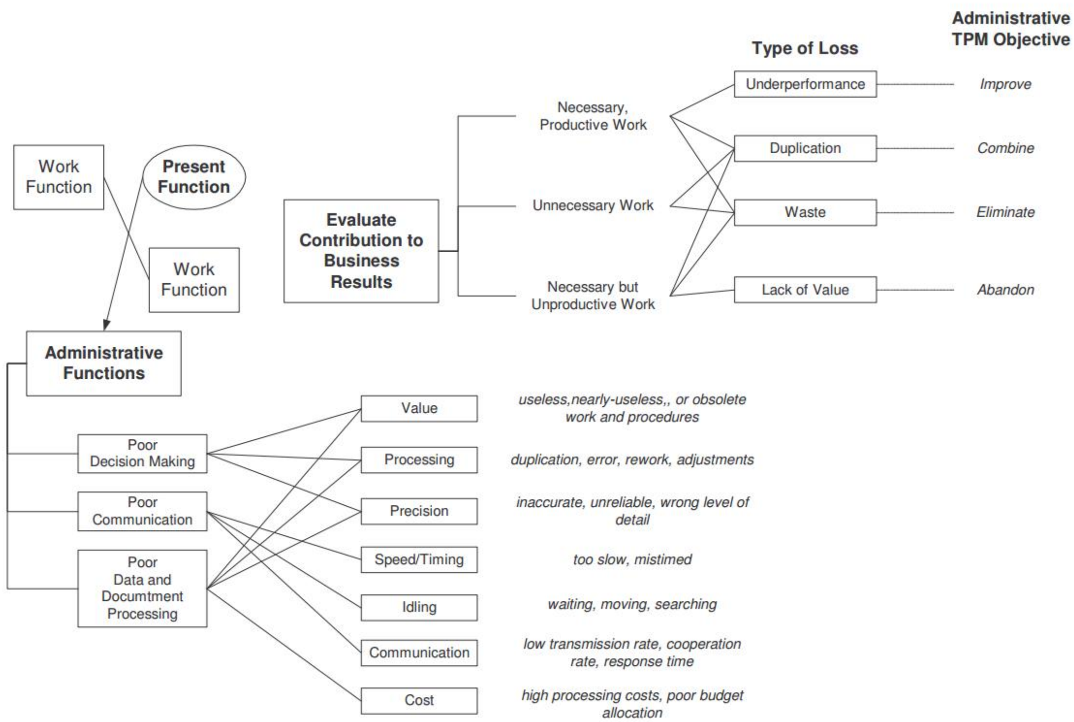


Figure 2.7 Administrative TPM effectiveness losses (Pomorski, 2004:p.62).

2.2.3.7 Safety & environment TPM

TPM Safety and Environmental pillar is equally, if not more, important than the seven others. Shirose describes safety as “the maintenance of peace of mind”. (Shirose,1996:p. 500).

Suzuki provides examples of how TPM improves safety and environmental protection. Faulty or unreliable equipment is a source of danger to the operator and
the environment. The TPM objective of Zero-failure and Zero-defects directly supports Zero-accidents.

- Autonomous Maintenance teaches equipment operators how to properly operate equipment and maintain a clean and organized workstation. 5-S activity eliminates unsafe conditions in the work area.
- TPM-trained operators have a better understanding of their equipment and processes and are able to quickly detect and resolve abnormalities that might result in unsafe conditions.
- Operation of equipment by unqualified operators is eliminated through effective deployment of TPM.
- Operators accept responsibility for safety and environmental protection at their workstations.
- Safety and environmental protection standards are proliferated and enforces as part of the TPM Quality Maintenance pillar.

According to the Heinrich Principle, (Heinrich,1980), for every 500,000 safety incidents there are 300 ‘near misses’, 29 injuries, and 1 death, see the figure Investigating industrial accidents, Heinrich found that 88% of accidents where caused by unsafe acts of people, 10% where the result of unsafe physical conditions, and 2% he considered ‘acts of God’.

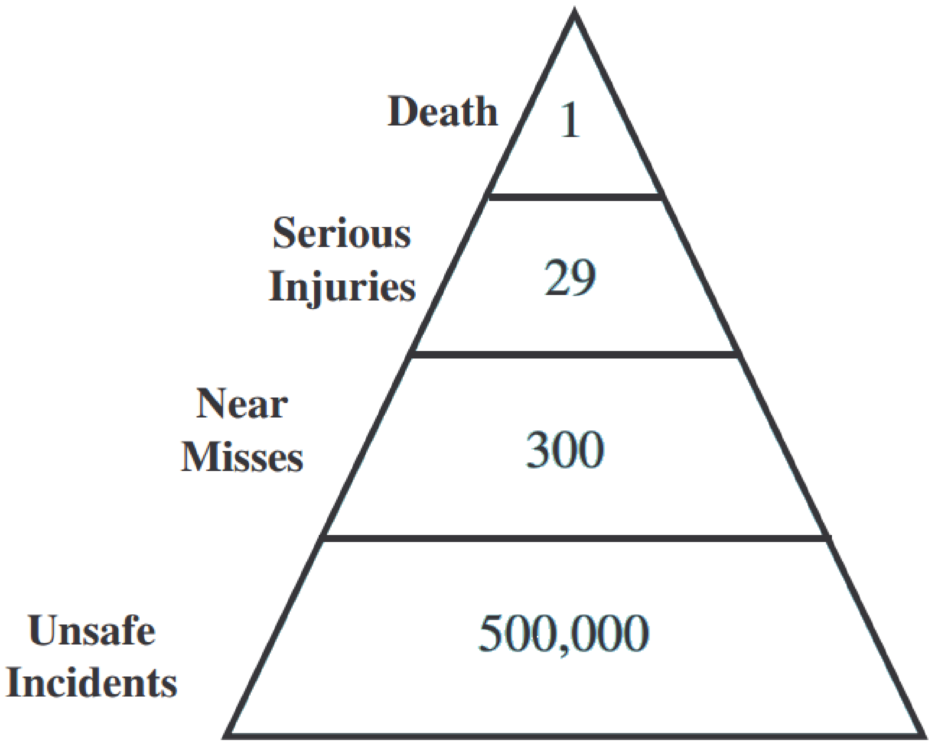


Figure 2.8 The Heinrich Principle (Pomorski, 2004:p.64).

Suzuki describes six phases that an operation passes through during an industrial accident. (Suzuki,1994).

- Phase 1 – Normal operation, stable state.
- Phase 2 – Signs of abnormality, the system becomes more and more disordered.
- Phase 3 – Unsteady state, difficult to restore to normal.
- Phase 4 – Obvious danger as a result of failure or abnormality. Damage and injury can still be contained and minimized.
- Phase 5 – Injury and severe damage occur.
- Phase 6 – Recovery after the situation is under control.

TPM practices, such as those listed below, allow quick operator intervention and prevent incidents from approaching Phase 3.

1. Monitor equipment and processes and quickly correct abnormalities.
2. Install and check safety equipment.
3. Identify and eliminate hidden equipment abnormalities and defects.

“Manufacturing management in the 21st century will not be effective if the environmental issues are ignored. Manufacturing management that does not take environmental issues into consideration will be removed from society. One of the causes of environmental issues is that industries, academic institutions, and government agencies have been specialized in research, development, promotion, and diffusion of design technologies to produce more artificial products. There is very little concern about setting conditions for equipment to the most favorable ones after it is put into operation or diagnostic techniques to maintain those conditions.” (Ichikawa,1999:p. 9).

Ichikawa proposes that TPM address the following key environmental objectives within the Safety and Environmental pillar. (Ichikawa,1999)

1. Construct an Environmental Management System (EMS) that integrates environmental issues as a system. This objective is consistent with ISO14001/14004.
2. Implement activities, through the TPM program, to reduce the environmental impact of manufacturing operations.
3. Create systems to reduce the environmental impact of manufacturing product and process development.
4. Enhance the environmental awareness and education of all employees.

2.2.3.8 5S

5S is “a systematic method to organize, order, clean, and standardize a workplace and keep it that way.” (Productivity,1999:p. 1-10).

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

Figure 2.9 key activities for effective 5S implementation at the workplace. (Ahuja and Khamba, 2008:p.14).

A common methodology used during the initial Sort phase of 5S is the Redtag Inspection. The Redtag process allows operators to identify the items that are required for production use at the workstation and provides an action path for appropriate storage or disposal of items not required at the workstation. Items that are not required immediately15 for production at the workstation are red tagged for disposition. The red tagged items are then sent to the red tag holding area for further evaluation. In order to implement the red-tag strategy effectively, a red-tag holding area must be created.

A common rule of thumb is the “24 Hour Rule”. Items that are used daily to support production remain at the workstation. Any item that is used less frequently than every day is removed for disposition.

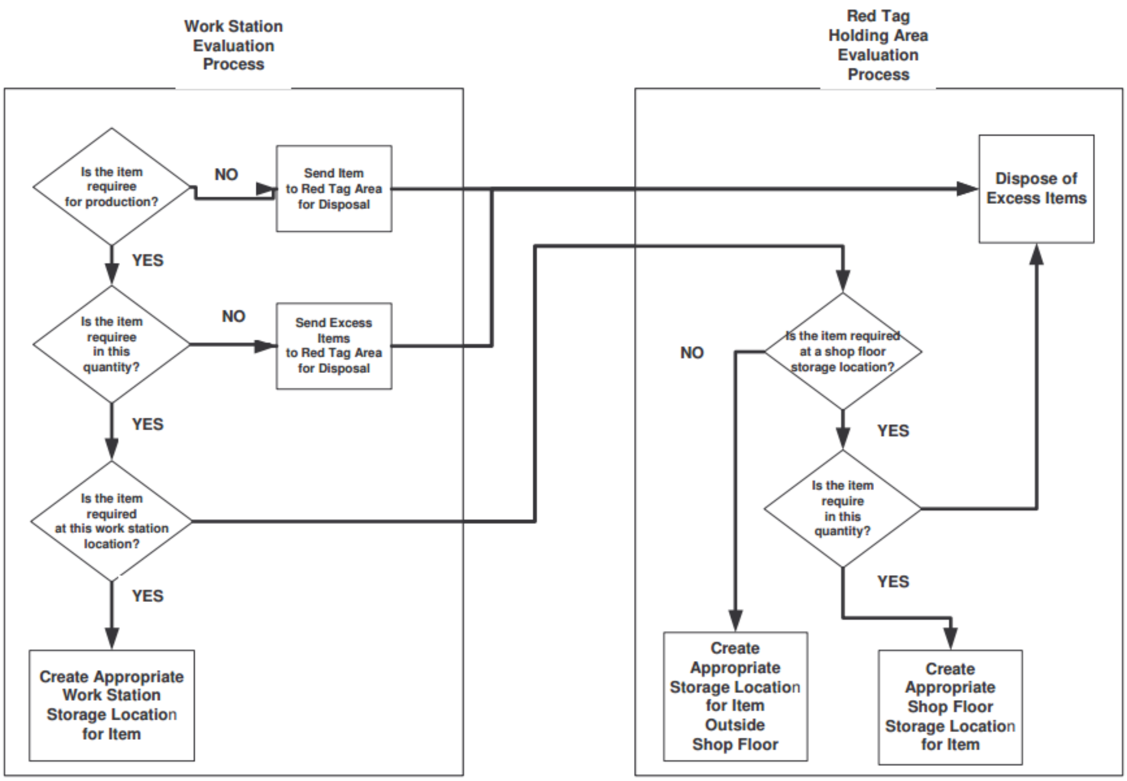


Figure 2.10 Red tag decision process (Pomoroski, 2004:p.37).

2.3 Difference between PM and TPM:

There are some big differences between traditional PM in the United States with TPM. "In TPM, maximum production efficiency improvement is the aim. To achieve this, TPM was designed to avoid the downtime caused by the six big losses. However in traditional US-style PM, they focused on equipment specialist. With this approach, the maximum production efficiency improvement cannot be achieved as in TPM."(Misti, 2016:p.13).

The other thing in TPM is the autonomous maintenance which indicates that operators should know about their own equipment and know how to preserve them. This will ensure that the equipment should be in the mint condition and will operate at its maximum potential while running it in production. On the other hand, in PM, maintenance is carried out by the maintenance workers and it is not the work of the operator to know and preserve their own equipment (Chan et. al, 2005).

2.4 OTHER MAINTENANCE OPTIONS

2.4.1 Breakdown Maintenance (BM):

Breakdown Maintenance refers to maintenance activity where repair is performed following equipment failure/stoppage or upon a hazardous decline in equipment performance. (Japan Institute of Plant Maintenance,1996)

2.4.2 Time-Based Maintenance:

Time-Based Maintenance refers to preventive maintenance activity that is scheduled based on an interval of time (for instance daily, weekly, monthly, etc.) “Preventive maintenance … keeps equipment functioning by controlling equipment components, assemblies, subassemblies, accessories, attachments, and so on. It also maintains the performance of structural materials and prevents corrosion, fatigue, and other forms of deterioration from weakening them.”(Suzuki,1994:p. 149).

2.4.3 Usage-Based Maintenance:

Usage-Based Maintenance refers to preventive maintenance activity that is scheduled based on some measure of equipment usage (for example number of units processed, number of production cycles, operating hours, etc.) Usage-Based Maintenance is significantly different from Time-Based Maintenance in that it is scheduled based on the stress and deterioration that production activity places on equipment rather than just a period of time. Since equipment may run different levels of production from one time period to another, Usage-Based Maintenance allows preventive maintenance to be aligned with the actual workload placed on the equipment. (Pomorski, 2004)

2.4.4 Condition-Based Maintenance

Condition-Based Maintenance expands on the concept of Usage-Based Maintenance by scheduling maintenance based on observed (or measured) wear, variation, or degradation caused by the stress of production on equipment. Examples of monitored equipment parameters include vibration analysis, ultrasonic inspection, wear particle analysis, infrared thermography, video imaging, water quality analysis, motor-condition analysis, jigs/fixtures/test gauges, and continuous condition monitoring. (Leflar,2001).

Leflar identifies two types of equipment degradation that should be considered when developing the site Planned Maintenance TPM pillar. (Leflar,2001).

Graceful Deterioration: Degradation is gradual and the thresholds of acceptable performance can be learned and failures projected within scheduled inspection cycles. Since the deterioration progresses slowly, the pre-failure degradation is identifiable within the scheduled Condition-Based Maintenance inspection cycles.

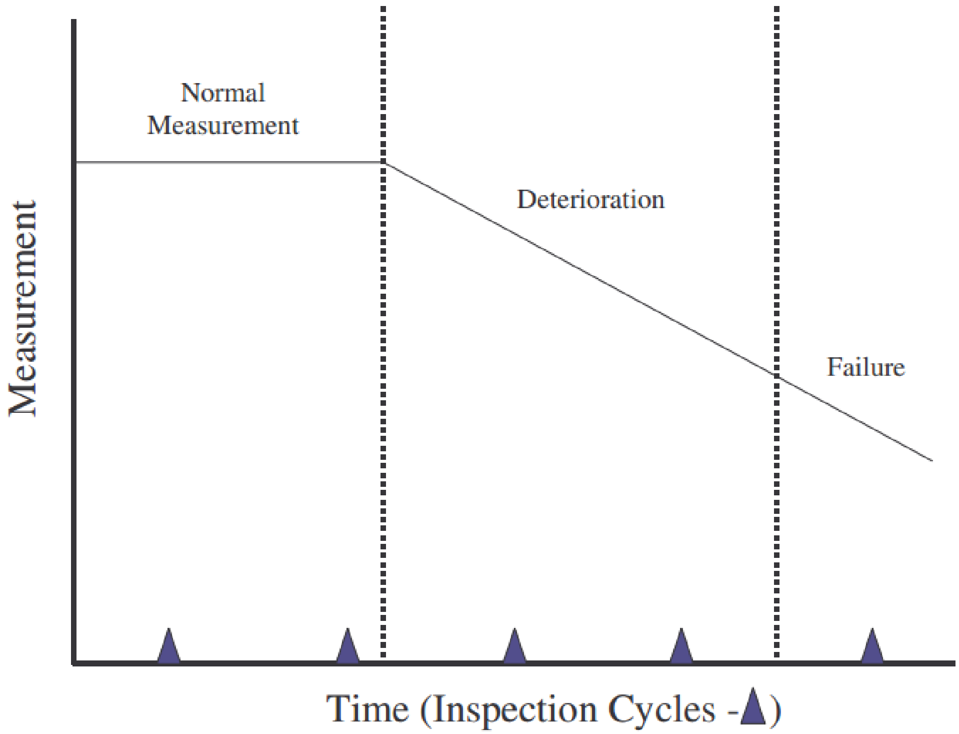


Figure 2.11 Graceful Deterioration (Pomoroski, 2004:p.50).

Non-graceful Deterioration: Deterioration progresses rapidly (from normal measurement to failure in less than the inspection cycle) and may not be detected within the inspection cycle of Condition-Based Maintenance. Non-graceful deterioration may be learned, which allows the life expectancy of the component or function to be projected. In this case, Calendar-Maintenance Maintenance or Usage Based Maintenance preventive maintenance scheduling will be effective.

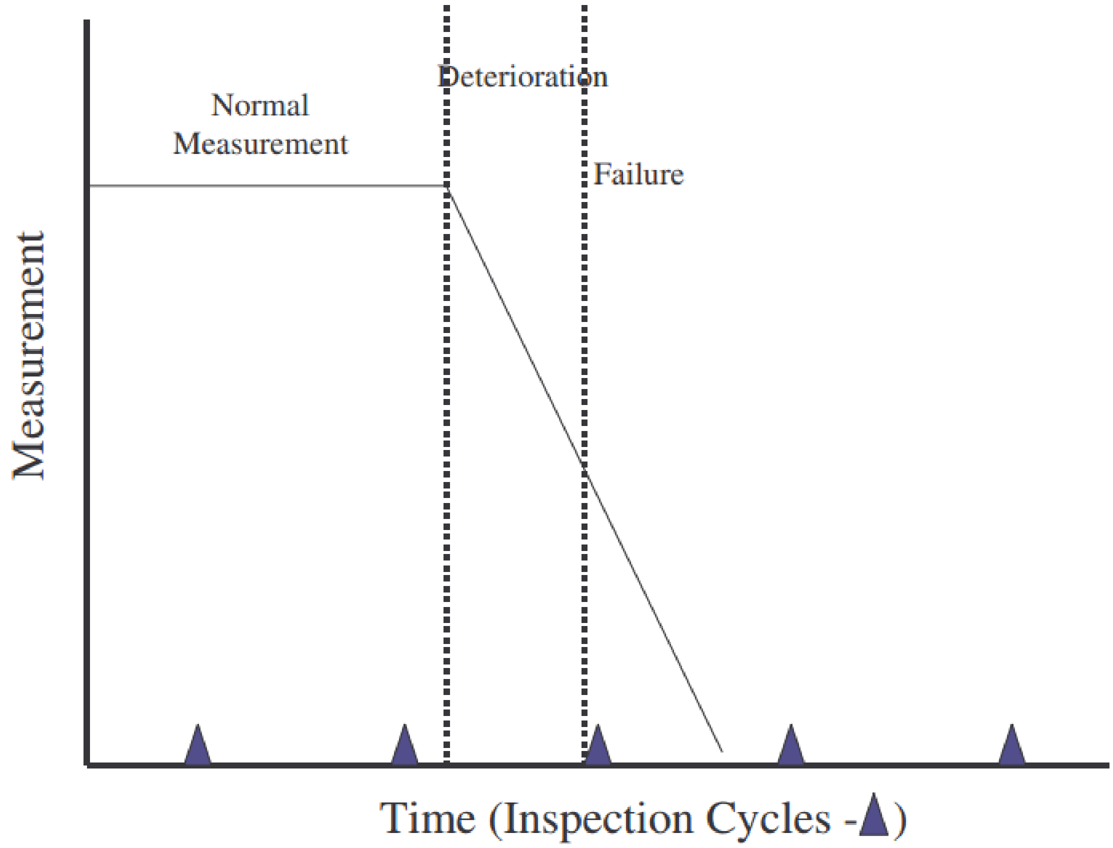


Figure 2.12 Non-graceful deterioration ((Pomoroski, 2004:p.51).

2.4.5 Predictive maintenance

Predictive Maintenance "measures physical parameters against a known engineering limit in order to detect, analyze, and correct equipment problems before capacity reductions or losses occur…The key to the predictive method is finding the physical parameter that will trend the failure of the equipment." (Wireman,1991:p.87).

Nhsinaga, notes that the flow of predictive maintenance is divided into three broad elements,

1) Establishment of diagnostic technologies (monitoring techniques),
2) Diagnosis (comparing actual to target readings), and
3) Maintenance action (responding to variation). (Nishinaga, 1999)

2.4.6 Corrective maintenance

This is a system, introduced in 1957, in which then concept to prevent equipment failures is further expanded to be applied to the improvement of equipment so that the equipment failure can be eliminated (improving the reliability) and the equipment can be easily maintained (improving equipment maintainability) (Steinbacher and Steinbacher, 1993). "The primary difference between corrective and preventive maintenance is that a problem must exist before corrective actions are taken (Higgins et al., 1995). The purpose of corrective maintenance is improving equipment reliability, maintainability, and safety; design weaknesses (material, shapes); existing equipment undergoes structural reform; to reduce deterioration and failures, and to aim at maintenance-free equipment." (Ahuja and Khamba,2008)

2.5 Six big losses

Nakajima (1988) defines these 'six big losses' as follows:

- Failures and break-downs
- Set-up and adjustments
- Idling and minor stoppages
- Reduced speed
- Defects and rework
- Start-up losses

2.5.1 Breakdown losses

Two types of losses are caused by breakdown: time losses- reduced productivity; quality losses- defective products.

Breakdown losses can be classified into two types; sporadic losses and chronic losses. Sporadic Breakdown- is the sudden, dramatic unexpected equipment failure. This failure are very obvious and are easily corrected. Chronic breakdown or frequent breakdowns are minor breakdowns which are often ignored or neglected after repeated unsuccessful attempts to cure them. (Sherkan,1993)

2.5.2 Set up and adjustment losses

Losses during set up and adjustments results in downtime and defective products. They occur, when the production of one item end and the equipment is adjusted to meet the requirement of another item. Many companies are now working to achieve single minute set ups. (Set up's less than 10 minutes)

2.5.3 Idling and minor stoppage losses

A minor stoppage occurs when production is interrupted by a temporary malfunction or when a machine is idle. For example, some work piece may get entangled and block the top of chute, causing the equipment to idle; at other time sensors alerted by the production of defective products may shut down the machine. These types of losses is clearly different from breakdown losses. In such circumstances, the production is restored to its initial condition by simply removing the obstructing work piece and resetting the equipment. (Sherkan,1993)

Small problems like this often have a dramatic effect on equipment effectiveness. This type of losses can have severe effect on equipment such as robots, automated assemblers, conveyers and so on.

2.5.4 Reduced speed losses

Reduced speed losses refers to the difference between equipment designed speed and the actual operating speed. Speed losses are typically overlooked in equipment operation, although they constitute a large obstacle to equipment effectiveness. The goal should be to eliminate the gap between designed seed and actual speed. (Sherkan,1993)

2.5.5 Quality Defects

Quality defects from process and rework are losses in quality caused by malfunction of production equipment. Sporadic defects are easily and promptly corrected by returning equipment conditions to normal. These defects include sudden increases in defective quantity. The causes of chronic defects on the other hand, are difficult to identify. (Sherkan,1993)

2.5.6 Start Up losses

Set up losses are yield losses that occur during the early stages of production, from machine start up to stabilization. The volume loss varies with degree of stability of processing condition; maintenance level of equipment, jigs, and dies; operators' technical skill; etc. (Sherkan,1993)

2.6 Overall equipment effectiveness

Overall Equipment Effectiveness (OEE) is the TPM metric for measuring equipment effectiveness or productivity. “A company cannot make business gains solely by using cost cutting measures because it cannot cut costs enough to become a world-class competitor. Instead it must invest resources in productivity improvement. This generally increases factory throughput and cuts cost at the same time.” (Leflar,2001: p. 9).

OEE is the product of three performance metric namely Availability, Performance and quality.

$$Availability = \frac{Loading\ time - downtime}{Loading\ time}\ X\ 100$$

“Loading time: Also called Scheduled time or Planned Production Time. The time that normal operations intend to make production. It includes all events that are common to meeting delivery schedules, such as product changeovers or transitions, set ups, information downloads, all production run time, and unplanned stoppages for equipment, people, quality, and testing.

Downtime: Downtime (DT). All Unplanned Machine downtime events should be categorized into the following categories:

- DT Technical: Downtime due to any equipment failures affecting the machine or process, including periphery equipment, (utilities, sprinklers, doors, humidifiers etc.), equipment failure due to maintenance errors, and equipment-caused dirt or scratches.

- DT Operational: Downtime caused by not following procedures, operating outside of specifications, operator error, etc.

- DT Quality: Downtime caused by nonconforming supplies and raw materials, process control problems, unplanned testing, non-manufacturable product, and dirt from the product or process. ” (Hansen, 2001, p. 27).

$$Performance\ rate = \frac{Theoretical\ cycle\ time}{Actual\ cycle\ time}$$

Theoretical cycle time= Ideal Speed (Equipment Capacity as Designed)

The best rate of speed or cycle time for key equipment or the flow line bottleneck, given a size and format of product. For example, key equipment or a flow line bottleneck is designed and accredited for 17 sec cycle time, or 3.53 units/min for a certain size.

$$Actual\ cycle\ time = \frac{Runtime}{Actual\ amount\ produced}$$

Runtime= Loading time – Non-operating time = Loading time – (All downtime + All stop time)

“Stop Time: Stop Time (ST) can be Planned or Unplanned.

- ST Operational: Planned stop time. It includes operational actions such as product changeovers and size changes, as well as standard testing, planned material loading, and required documentation.

- ST Induced. Unplanned stop time when the line is down due to external (non-machine) reasons such as lack of materials and supplies, lack of people, lack of information, and unplanned meetings. ” (Hansen, 2001, p. 28)

$$Quality\ rate = \frac{number\ of\ good\ units}{total\ units\ produced}$$

$$OEE = Availability\ X\ Performance\ rate\ X\ Quality\ rate$$

2.7 TPM implementation process

A core concept of TPM is that its implementation is based on a defined, structured, and repeatable implementation process. Elliott, discussing the development of world-class organizational performance, notes, “Winning requires an institutionalized management-proof process that is sustainable despite changes in leadership, strategy, and business conditions…” (Elliott 2001 p.7) He continues to say that “Manufacturing perfection is like any other form of excellence: It is a very defined combination of doing the right thing and doing it in an extraordinary manner.” (Elliott 2001 p. 9) Nakajima developed the classic twelve-step TPM implementation process (Nakajima 1984; Nakajima 1988; Nakajima 1989) that has been the foundation for TPM implementation since 1984 (see Figure). Numerous TPM practitioners have suggested their own version of a TPM implementation process, however, most are a variation or simplification of the Nakajima Model.

Table 2.4 12 steps of TPM implementation

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
Preparation	1. Formally announce the decision to introduce TPM.	• Top management announcement of TPM introduction at formal meeting and through newsletter	•Top management TPM overview training. •TPM case studies or pilot team results. •TPM readiness assessment. •Top management buy-in. •Top management commitment to TPM Implementation.
Preparation	2. Conduct TPM introductory education	• Senior management group training. • Slide-show overview presentation for	•Management training. •TPM philosophy promotion to employees
	Publicity campaign	Presentation for remaining employees	•TPM Overview and Management responsibility presentation to all management levels. •Presentation of TPM overview to all employees
Preparation	3. Create a TPM promotion organization.	• TPM Steering Committee and specialist subcommittees. • TPM Promotions Office.	•Create a TPM Steering Committee composed of top management representing all functions. •Identify and staff a TPM Promotion Office reporting to top management. Promotion Office to include a TPM Coordinator, TPM Facilitator(s) (1 per 12 teams), and a TPM content expert. •Identify TPM champion(s) and their responsibilities. •Determine mission and strategy. •Include TPM in the business plan. •Develop TPM step-by step plan. •Determine TPM education sourcing. •Establish the TPM budget. •Create TPM pillar subcommittees (chairman). •Train the TPM trainer. •Pilot project training for supervisors and managers. •TPM facilitator training (include supervisors

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
Preparation	4. Establish basic TPM policies and goals.	• Set baselines and targets.	1. Determine TPM initiative objectives. 2. Define TPM policies. 3. Define OEE methodology and loss category definitions. 4. Implement data collection system. 5. Create OEE data reporting mechanism. 6. Acquire data from the current source of data. 7. Determine bottleneck (constraint) operations and equipment. 8. Determine pilot project tool(s). 9. Select sponsor(s) for pilot project(s). 10. Determine the TPM compensation, reward, and recognition system.
Preparation	5. Draft a master plan for implementing TPM	• Master plan from preparation stage to application for TPM prize.	1. Create the TPM sustaining plan. 2. Define basic skills required. Training course development. 3. Created a timeline (3 to 5 years) for each planned TPM activity in Steps 7 to 12.
Introduction	6. Kick off the TPM initiative.	• Master plan from preparation stage to application for TPM prize.	1. Top management presents the TPM policies, goals, and master plan to all employees. 2. Ensure long-term commitment of the management team.

TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
Implementation	7. Establish a system for improving production efficiency. **Focused Improvement Pillar** **Autonomous Maintenance Pillar** **Planned Maintenance Pillar** **Education and Training Pillar**	1. Conduct Focused Improvement activities. 2. Establish and deploy the Autonomous Maintenance program. 3. Implement the Planned Maintenance program. 4. Conduct operation and maintenance skill training.	1. Team skills training. 2. Problem solving skills training. 3. Communication skills training. 4. Business meeting skills training. 5. Project management skills training. 6. TPM process training. 7. TPM activity board training. 8. Establish cross-team communications. 9. Structure team communication to management. 10. OEE training. 11. Launch team projects. 12. Establish TPM process audits. 13. Execute mid-project project progress reviews (progress, problems, plans, learning). 14. Establish and execute periodic team reports to management. 15. Establish cost savings analysis (ROI) for team projects. 16. Identify, demonstrate, and communicate contribution to customer success. 17. Share success stories with other teams and management. 18. Establish end-of-project reviews. 19. Implement standard procedures and methodologies for Visual Controls and One Point Lessons. 20, Renew and repeat cycle.

Implementation	8. Establish and deploy the	Develop optimal vertical startup for products, processes, and equipment.	TPM team training.
TPM Implementation Phase	TPM Implementation Step	Key Points	Actions
	Maintenance Prevention activities. **Maintenance Prevention Pillar**		
Implementation	9. Establish Quality Maintenance systems. **Quality Maintenance Pillar**	Establish, maintain, and control conditions for zero failures, zero defects, zero accidents.	TPM team training
Implementation	10. Create systems for eliminating efficiency losses in administrative and logistic functions. **Administrative Maintenance Pillar**	• Increase production support efficiency. • Improve and streamline administrative and office functions.	• TPM team training. • Proliferate throughout the company.
Implementation	11. Create the systems for managing health, safety, and the environment. **Safety and Environmental Pillar**	Create systems to ensure zero safety and environmental accidents.	TPM team training.
Consolidation and Sustaining	12. Sustain full TPM implementation and continually improve the TPM process.	• Raise TPM team goals. • Establish ongoing audits. • Apply for JIPM TPM Prize (optional)	• Review and raise the TPM team goals. • Understand and attain JIPM TPM Prize criteria. • Audit the TPM process.

2.8 TPM implementation issues and difficulties

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

"The failure of the organizations to successfully harness the true potential of TPM can also be attributed to confusion over what exactly constitutes TPM, lack of management consensus, underestimating the importance of knowledge, inconsistent and unclear expectations, neglecting the basics, and TPM implementation within an existing organization structure that does not provide the necessary support. These problems reflect the lack of a clear understanding of what are the fundamental and complementary manufacturing practices. It has been observed that companies that have experienced failure in the TPM implementation programs have often neglected the development of basic practices continuous improvement, total employee involvement, cross functional teams, that support the implementation of TPM techniques." (Ahuja and Khamba, 2008:p.24).

Another significant contributor for failure of TPM implementation program is the organization's inability to obviate resistance to change. The resistance to change takes a number of forms, that is, reluctance of individuals to change roles (Riis et al., 1997; Cooke, 2000)

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

2.9 Success factors for TPM implementation

In order to realize the true potential of TPM and ensure successful TPM implementation, TPM goals and objectives need to be fully integrated into the strategic and business plans of the organizations, because TPM affects the entire organization, and is not limited to production.

"Swanson (1997) recommends four key components for successful implementation of TPM in an organization as: worker training, operator involvement, teams and preventive maintenance." (Ahuja and Khamba, 2008:p.27).

"As can be expected, several of the factors that have led to the successful TPM programs are simply doing the opposite of the barriers. One key strategy, in effective implementation of TPM workgroups is, management's support the efforts to drive continuous improvement in the team environment. Building on trust through effective communication, worker participation in decisions, acceptance of ideas, and frequent feedback are catalysts that drive improvement through strategic TPM implementing programs. Team Leadership must provide consistent messages, and should include encouragement, facilitating and maintaining order, and help with decision-making. The role of the worker needs to change from one that supports the traditional craft mentality of maintaining specialized jobs, to one that allows greater flexibility. In addition, this new role necessitates removing age-old barriers in place since the inception of automated production"(McAdam and Duffner, 1996; Ahuja and Khamba, 2008)

"Davis (1997) has suggested that the experience of TPM implementation in the UK has shown that the key factors for successful implementations are to approach TPM realistically; developing a practical plan and employing program and project management principles; accept that TPM will take a long time to spread across the organization and change existing maintenance culture; be determined to keep going, put in place, train and develop a network of TPM co-coordinators that will promote and support TPM activities every day; support TPM co-coordinators with time and resources, plus senior level back up; put in place relevant measures of performance and continually monitor and publicize benefits achieved in financial terms." (Ahuja and khamba, 2008)

Chapter 3
Research Design

3.1 INTRODUCTION

The study includes productivity & quality enhancement through implementation of TPM in a manufacturing plant. In order to achieve the objective of the study, the research was performed using a real case study at a Bangladeshi manufacturing plant, known as ABC plant. In this chapter, the research design is described in detail and acts as a framework on how the research will be conducted.

3.2 RESEARCH APPROACH

The main purpose of the research is to study the machine maintenance policy in a Bangladeshi Manufacturing plant. We need to know what type of maintenance techniques they applied and how significant the measure were. Besides, we also wanted to know the actual level of productivity performance in the plant in order to improve productivity. Hence the single case study is conducted on a selected manufacturing plant in which the plant permits the research activities.

Case study research method is an empirical inquiry that investigates a contemporary phenomenon within its real life context, when the boundaries between phenomenon and context are not clearly evident, and in which multiple source of evidence are used. Case study with its use of multiple data collection methods and analysis techniques provides the opportunities to triangulate data in order to strengthen the research finding and conclusion. The case study provides mean for working with information obtained through interviews with the staffs who holds key position in production and quality assurance. From the interviews, we could gauge how much they understood about productivity, the occurrence during operation every month and etc. Furthermore with the case study the documentation and records in the plant can be study thoroughly to understand what measurements they used for monitoring the productivity performance.

3.3 FOCUS AREA

Total productive maintenance or TPM is the prime focus of this research study. World Class Corporation successfully implemented this policy in their plants to emerge as global organization. TPM focuses on maximizing equipment effectiveness. Due to frequent breakdown production availability is severely hampered. We can classify these losses into 6 categories named as 6 big losses. This classification losses help to understand which one causes most damage and where to focus on.

Besides, equipment couldn’t operate up to its design capacity or design speed. This reduced speed and breakdown affect the quality of product also. So, TPM work on to eradicate or at least minimizing the impacts to a tolerant level so that world class production environment can be achieved.

Autonomous maintenance revolutionized the maintenance practice in world class organization like Toyota which incorporates its workers into maintenance activities. Traditional maintenance team is there to fix the machine but involving machine operator gives an edge as they are the first responder to any kind of machine breakdown or failure. Cleaning, lubricating, bolting, inspection these basic tasks are done by machine operator so that maintenance team can focus on more specialized problems.

However, implementing these measures aren't all. It requires measurement of these activities to identify any underlying issue. Overall equipment effectiveness (OEE) is such matric to understand the condition of TPM implementation in a manufacturing plant. OEE measures machine availability, performance of the machine and quality rate.

3.4 RESEARCH DESIGN FRAMEWORK

3.4.1 Factors Considered

During design research framework, the following factors had considered

- Overall equipment effectiveness (OEE)

  Overall equipment effectiveness is metric to understand the productivity of plant. It is an effective tool to learn the TPM level in a plant. The first & foremost goal of TPM is to maximizing equipment effectiveness. This measure combine availability, performance rate of equipment as well as quality rate.

- Time Period selection

  In terms of implementing TPM, there need to understand the current productivity of plant. OEE is simple matric to have an understanding on productivity. For OEE calculation wide time horizon is useful as plant goes through many different activities all around the world. If time period is short, it will lead to mistake in accessing the productivity performance of the plant. To precise data analysis wide time period, more data is required. A 8-month period out of a typical 12-month production calendar was selected to ensure that more than sixty percent of the time period was taken into consideration. Hence, we used 8 months of data.

3.4.2 Data Analysis Method

Qualitative and quantitative data are collected through interview, observation, and documentation review, and through collection of physical samples. From the data collected, the data is analyzed by tabulation of data, graphical analysis and pattern-matching.

Qualitative data collected from interviews and documentation review on different measurement used in ABC Plant is analyzed using pattern-matching. Each measurement is compared with the basic definition of it meaning to define the productivity to define the productivity measures used in the plant. The denominator of each measurement is match with the input in productivity definition whether it is an input sent into a process or system. Similar with the output, the nominator of each measurement is matched with the definition of productivity to determine if it is an output produced from the system or process.

Quantitative data collected from physical samples for inputs and outputs are analyzed using tabulation of production output quantity and input quantity to define the base period. Data that are generated from the breakdown table, production capacity, actual yield, quality is analyzed by using bar graph.

3.4.3 TOOL AND TECHNIQUES USED

A number of statistical and graphical tools are available in literatures. All of them are applicable depending on the circumstances and each of them has its advantages and disadvantages. Some of the appropriate tools are described below

3.4.3.1 Pareto Diagram

A Pareto diagram is a graph that ranks data classification is descending order from left to right. In this case, the data classification is types of field with low productivity. The vital few are on the left and the useful many are on the right. The vertical scale is dollars or frequency and the percent of each category can be placed above the column. Pareto is used to identify the most important problems. Usually, 80% of the total results come from 20% of the items. Actually the most important items could be identified by listing them in descending order. However, the graph has the advantage of providing a visual impact, showing those vital few characteristics that need attention. Resources are then directed to the vital few to take the necessary corrective action.

3.4.3.2 Cause-And-Effect Diagram

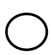
A cause-and-effect diagram is a picture composed of lines and symbols designed to represent a meaningful relationship between an effect and its causes C&E diagrams are used to investigate either a bad effect and to take action to correct the cause or a good effect and to learn those causes that are responsible. Each major cause is further subdivided into numerous minor causes. Once the C&E diagrams are complete, it must be evaluate to determine the most likely causes.

3.4.3.3 Flow Process Chart

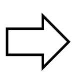
The flow process chart is a tool for recording a process in a compact and sequential manner, as a means of better understanding it and improving it. The chart represents graphically the each steps or events that occur during the performance of a tsk or during a series of action. The chart usually beings with the raw material entering the factory and follows it through every steps, such as transportation to storage, inspection, machine operations, and assembly.

A carefully study of a chart, given a graphic picture of every step in the process through the factory, is almost certain to suggest improvements. It is frequently found that certain operations can be eliminated entirely or that a part of an operation can be eliminated, that one operation can be combined with another, that better routes for the parts can be found, more economical machines used, delays between operations eliminated, and other improvements made, all of which serve to produce a better product at a lower cost. The process chart assists in showing the how the effects of changes in one part of the process will have on other parts or elements. Moreover, the chart may aid in discovering particular operations in the process which should be subjected to more careful analysis.

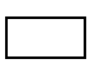
The process chart symbols used in the illustration are described below:

 Operation

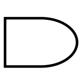
An operation occurs when an object is intentionally changed in one or more of its characteristics. An operation represents a major step in the process and usually occur at a machine or work station.

 Transportation

Transportation occurs where an object is moved from one place to another, except when the movement is an integral part of an operation or an inspection.

 Inspection

An inspection occurs when an objects is moved from one place to another, except when the movement is an integral part of an operation or an inspection.

 Delay

A delay occurs when the immediate performance of the next planned action neither does nor takes place.

 Storage

Storage occurs when an object is kept under control such that it withdrawal requires authorization.

3.4.4 FRAMEWORK OF RESEARCH

Figure 3.1 shows the framework of the research. The research was carried out in three phases which was

- First phase: Selection of machine maintenance & productivity enhancement model and introduction of model.
- Second phase: Study practical/present maintenance policy & productivity level in case study plant.
- Third phase: Study productivity performance of the plant and suggestion of improvement techniques.

During first phase, the literature review was performed to understand the various productivity measurement models. The suitable model was selected from literature review by considering the adaptability to the manufacturing plant, ease of application and ability to detect problem easily.
In the second phase, interview sessions and documentation review was carried out in the selected manufacturing plant to understand the various measurement used in the plant and to determine of the formal productivity measurement. Then, the overall equipment effectiveness was measured by its three performance matric.

In the third phase, data was collected and used to analyze the productivity performance of the manufacturing plant. The problem of low productivity was analyzed using Pareto diagram and cause and effect diagram to define the exact problem. Based on the problem defined, the improvement techniques were suggested.

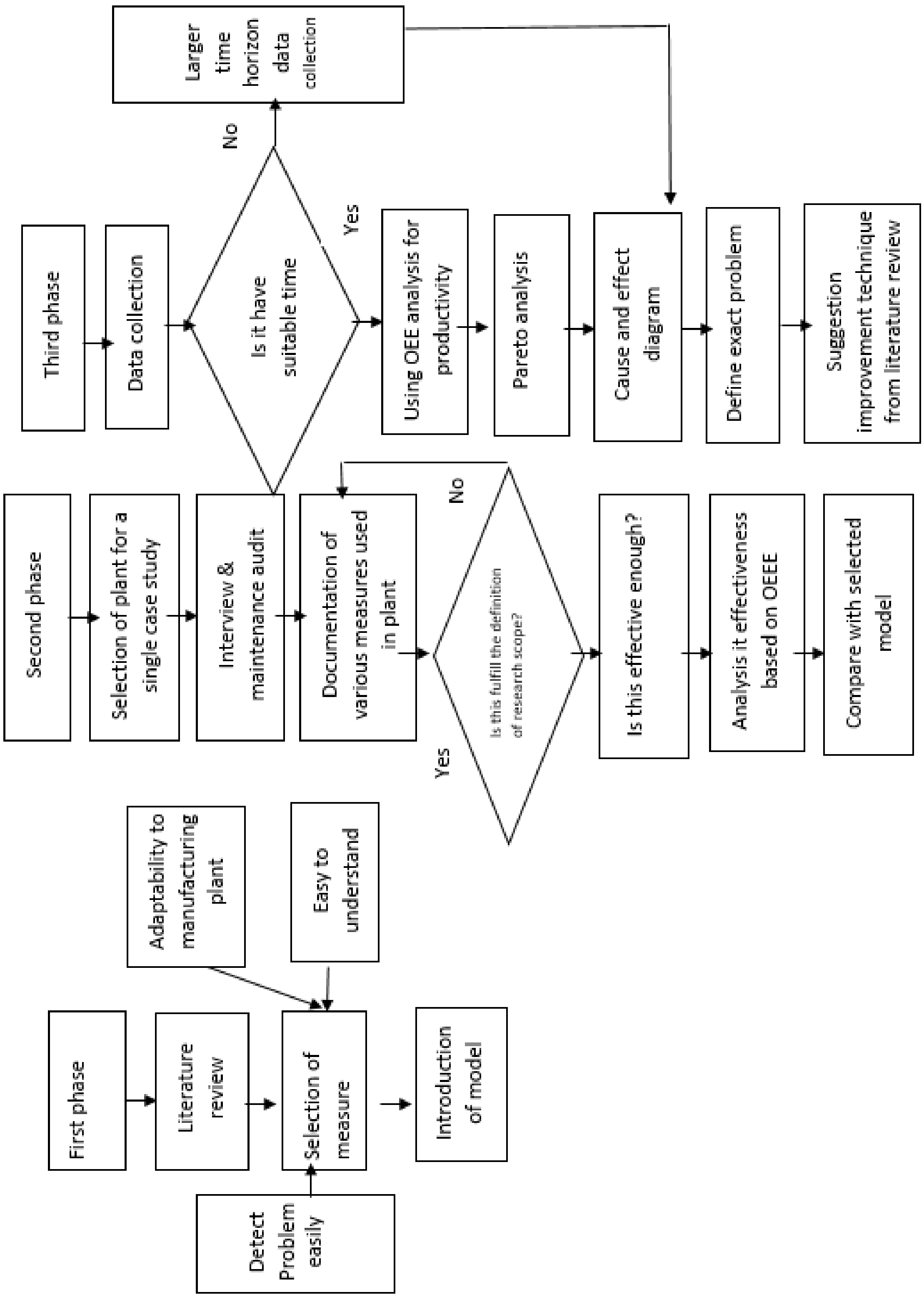


Figure 3.1 Research framework model

Chapter 4
DATA ANALYSIS AND DISCUSSION

4.1 COMPANY INTRODUCTION

ABC group is one of the leading company of fast moving consumer products (FMCG) industry with products ranging from Beverages, Biscuit & dairy products, Pharmaceuticals. Its' product has significant presence in domestic market as well as from year 2007 it had started to export products to India, UAE, Kuwait, Qatar, Oman, Nepal, Bhutan, South Africa and more than 23 countries. For the innovation & product development it has its' own R&D centers in the manufacturing plants.

XYZ is a subsidiary company of ABC group, which is our research subject of this paper. XYZ started it's production from 2006 and it has more than 900 employees working in two shifts per day.

At the inception it produced products of a single brand. Now it has expanded into multiple brand and variety of products under its umbrella. For the nature of this industry company adopted automation process from the beginning. Almost 90 % activities regarding production is automated. Production strategy is mass production & align with MTS (Make to Stock) strategy.

4.2 CURRENT PRODUCTION SYSTEM DIFFICULTIES:

ABC organization adopted almost full automation process in its XYZ plant. In Production line Company encounter some typical as well as unique problem.

1. In the traditional maintenance system, only technical support department takes in charge of the regular maintenance and repair. The operators simply need to handle equipments without any knowledge and education of regular maintenance and equipment efficiency operations. That is a fact they cannot forecast when the machines breakdown and cannot find out the causes and roots of the problems. Once breakdown takes place, they have to stop the production line and look for technicians' support, which as a result increases the downtime and repair time, and also reduce the OEE of the equipment.

2. Production is generally demand and forecast driven. For production scheduling they heavily relay on historical data and current market demand. Due to production mix, it is unavoidable that the frequent adjustments and changeover with the equipment and tools occur. It's always a problem that defects continuously were yielded after the operators changed and adjusted the parts on the machines when the machines worked at optimal state.

4.3 FEASIBILITY ANALYSIS OF INTRODUCING TPM TO ABC

Requirement: all of employees are aware of the truth that ABC lags behind those enterprises that adopt advanced equipment management methods. To stay competitive in beverage industry, TPM is a prerequisite for ABC to improve current deficiency in equipment management.

Possibility: ABC has obtained the licenses of ISO9001 and ISO14000 for years. All employees from top down discipline themselves with quality management philosophy and are willing to attempt all advanced management concepts and methods to improve firm's benefits.

Forecast: after implementing of TPM in ABC, tangible and intangible benefits can be achieved. The obvious benefits through TPM represent minimized breakdown, less downtime, less repair cost, less labor time and intensity, higher efficiency of production lines. While, intangible benefits bring about improving morale in the company, decreasing pollutions due to less repair and maintenance, and enhancing company's reputation in the market due to high availability of orders and quality of products.

4.4 PROCESS FLOW DIAGRAM

Following figure is the typical process flow diagram of production line 4, the subject of our study. Raw materials of the product are Finished syrup, treated water & CO_2. Plant has sate of the art water treatment equipment and process as well as it has its own CO_2 storage inside the plant. CO_2 is a basic component of soft drinks to preserve the product for a long period of time.

Mixture of finished syrup, treated water and CO_2 is stored in a storage tank which can hold up to 24,000 litre of liquid at a time. In case of changeover, this storage tank undergoes Clean-in-process (CIP) to make ready for product mix in the production line.

Blomax, is the bottleneck section of the production line, stretch blow molding transforms preform PET into full blown PET. Machine can do this 20 pcs at a time. After blowing highly compressed air into the cavity of PET bottles are rinsed to clean. Then at filler section substances are filled into the bottle, filler is connected to the storage tank. Filler fills 80 bottle at a time. Each bottle is capped with proper torque and warmed for a while on the conveyed belt.

Above equipment are imperative for the product manufacture, rest of the equipment support the production system to fullfil some required standards. Labels are glued on the bottle outer periphery & Batch no, Manufacture date and expirary date are printed on the bottle by automated date coder machine. Bottles are wrapped at the palletizer section and ready to be shipped to warehouse.

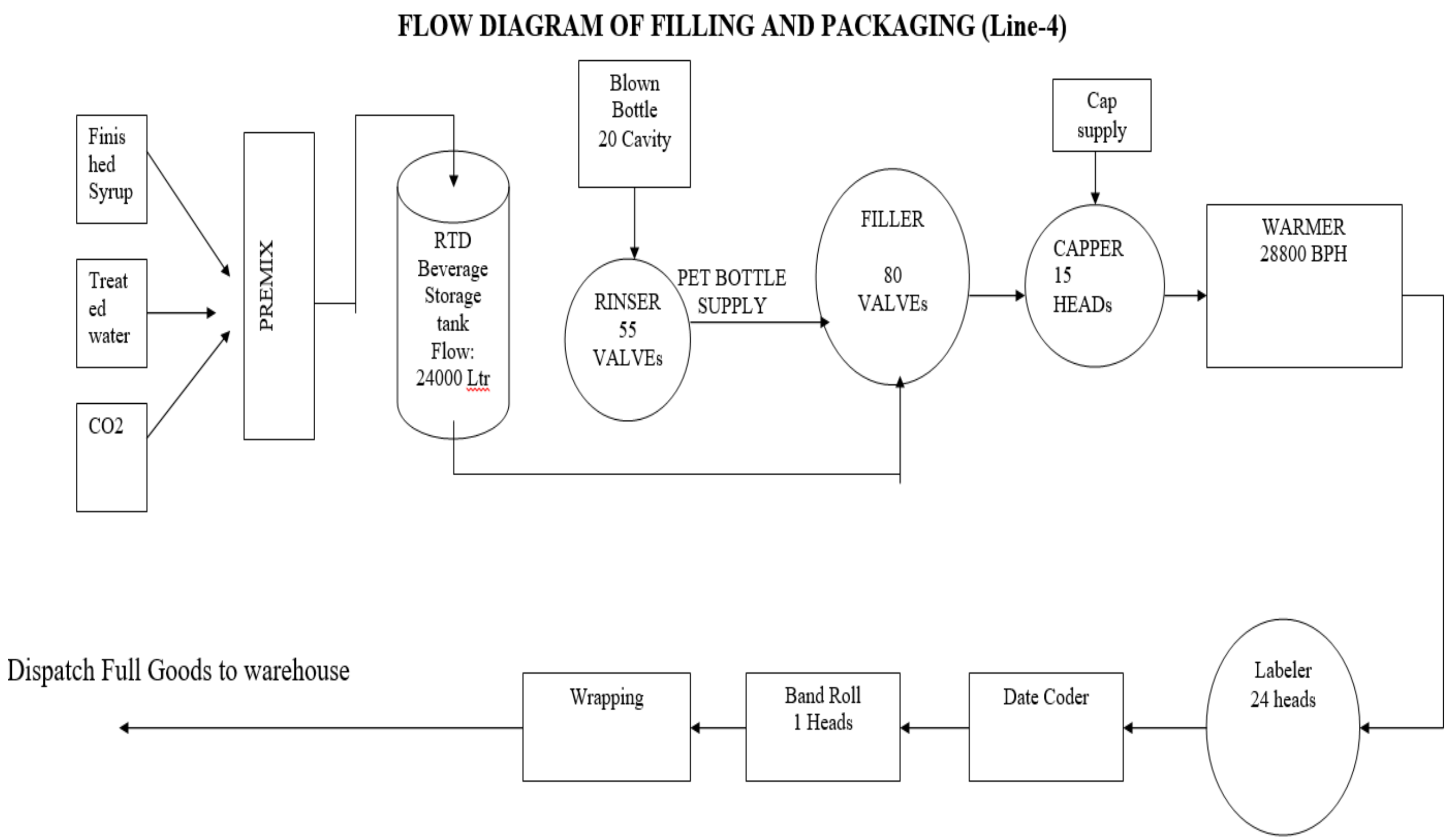


Figure 4.1 Process flow diagram of production line

4.5 DATA COLLECTION

Research study timeline comprises from 1st February to 30th September 2016. Each month has on an average 25 calendar working days, two shifts per day and 12 working hours per shifts.
The analysis of losses primarily encircles following aspects:

a. Maintenance and breakdown time
b. Actual production vs. designed capacity
c. Quality Defects

4.5.1 Analysis of Breakdown time loss

Table shows the data of Breakdown loss in each month of the study and criteria of those losses. There are 5 different product and more than 7 SKU of these products are produced in a single production line over this time span. Furthermore, the inputs for each product are not recorded individually. Therefore, total sum of overall inputs are used in this study.

Table 4.1 Breakdown time in different equipment over time period

Time period	**Breakdown criteria**							
	Blomax	Wrapping m/c	Labeler	Syrup room	Filler	Power	Others	Total
February	4702	468	2277	2656	1279	816	2963	15161
March	7259	787	880	2302	705	662	4134	16729
April	5525	1061	1346	1832	410	657	6314	17145
May	3740	377	1210	1050	445	430	1377	8669
June	5285	2492	2128	3377	1189	71	3221	17763
July	3121	1346	2350	3039	597	281	2034	12768
August	5380	1353	1290	1383	1114	150	1167	11837
September	3558	717	1506	1926	1280	586	1161	10734

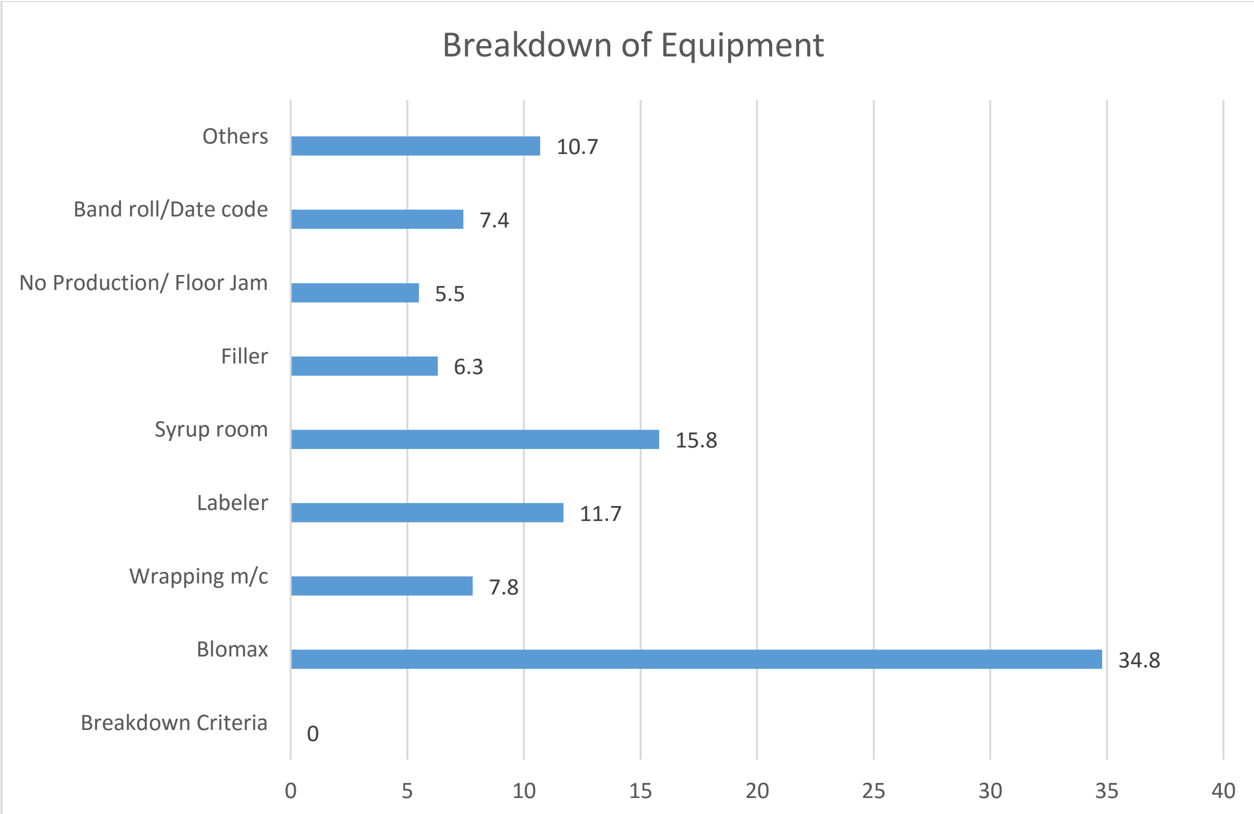


Figure 4.2 Breakdown time at different equipment consuming in percentage

Breakdown time of February, 2016 represented by Pareto chart in the following figure. Four equipment that contribute more than 80% breakdown time namely InnoPET Blomax, Syrup room (CIP at storage tank due to product changeover), Labeler and wrapping machine. One thing to mention breakdown on labeler was high at first quarter but government relaxed condition of using band roll machine in the production line. So, the plant reduced band roll from its production line at the later part of study period.

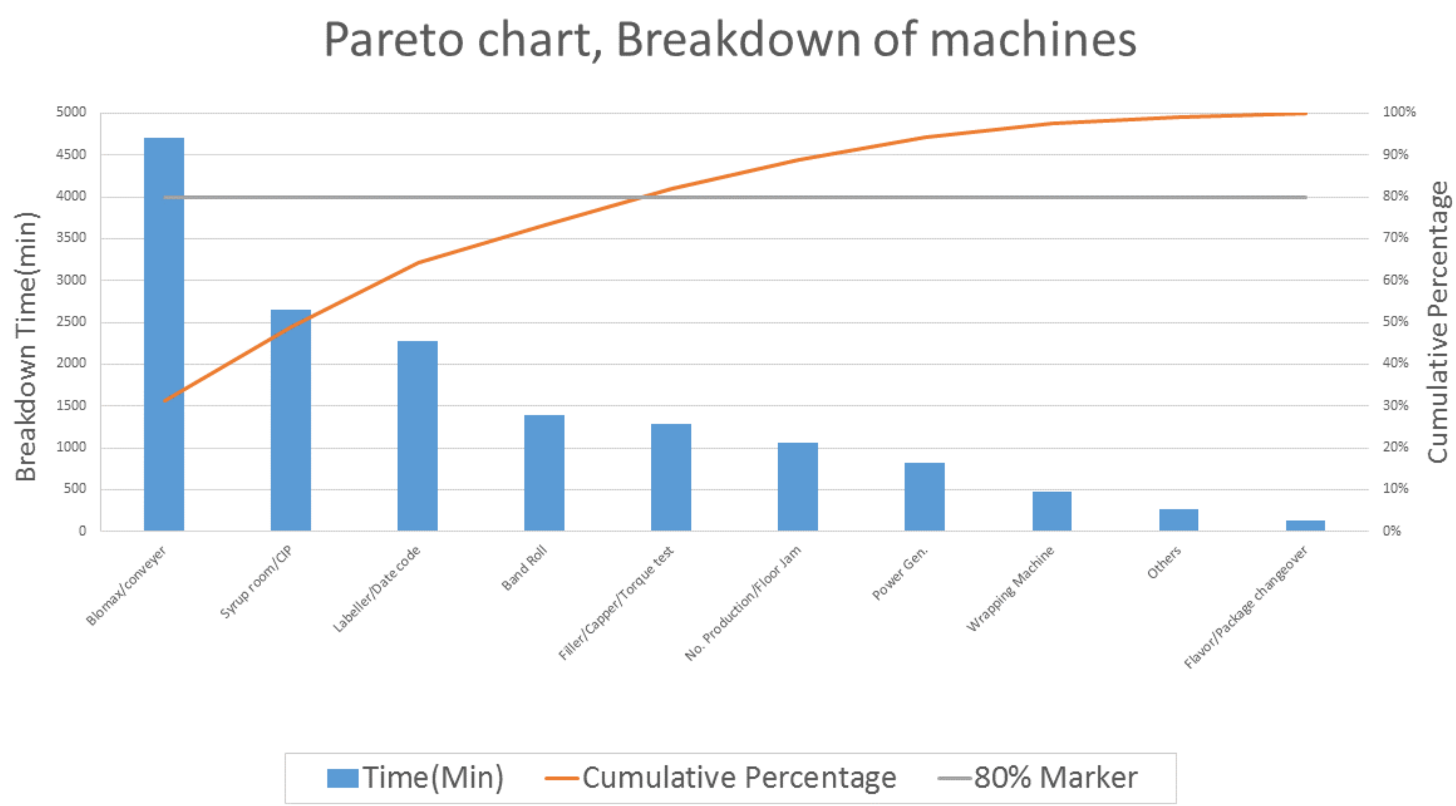


Figure 4.3 Pareto Chart of Breakdown time for the month of February, 2016

4.5.2 Analysis of production capacity and actual production

Table shows production capacity and actual production of each month. Here, the unit is ‘case’. For information each case contain 24 pcs. To keep uniformity, 1litre SKU is skipped from data analysis which has different production capacity and other corresponding values. Line utilization is the ratio of actual production to production capacity.

Table 4.2 Production capacity, Actual Production and quality defects table

Time Period	No. of production day	Production Capacity, Cases	Actual Production, Cases	Quality defects, Cases	Line utilization, %
February	28	806400	342452	708	42.5
March	31	892800	389086	1140	43.6
April	26	662400	215918	989	32.6
May	17	460800	158427	743	34.4
June	28	691200	287530	842	41.6
July	21	547200	236943	548	43.3
August	27	768800	381166	740	49.6
September	25	720000	393459	845	54.7

No of total production day varied during the study period. March, 2016 plant operated for the every calendar day of the month. However, In May plant operated for only 16 days. During that period InnoPET Blomax equipment underwent maintenance. Maintenance of that equipment was overdue since November, 2015. Again in July, 2016 production line 4 only operated for 21 days. Plant was able to fulfill the demand by other production line during that period of time. After that in the month of August and September there was steady growth of production day.

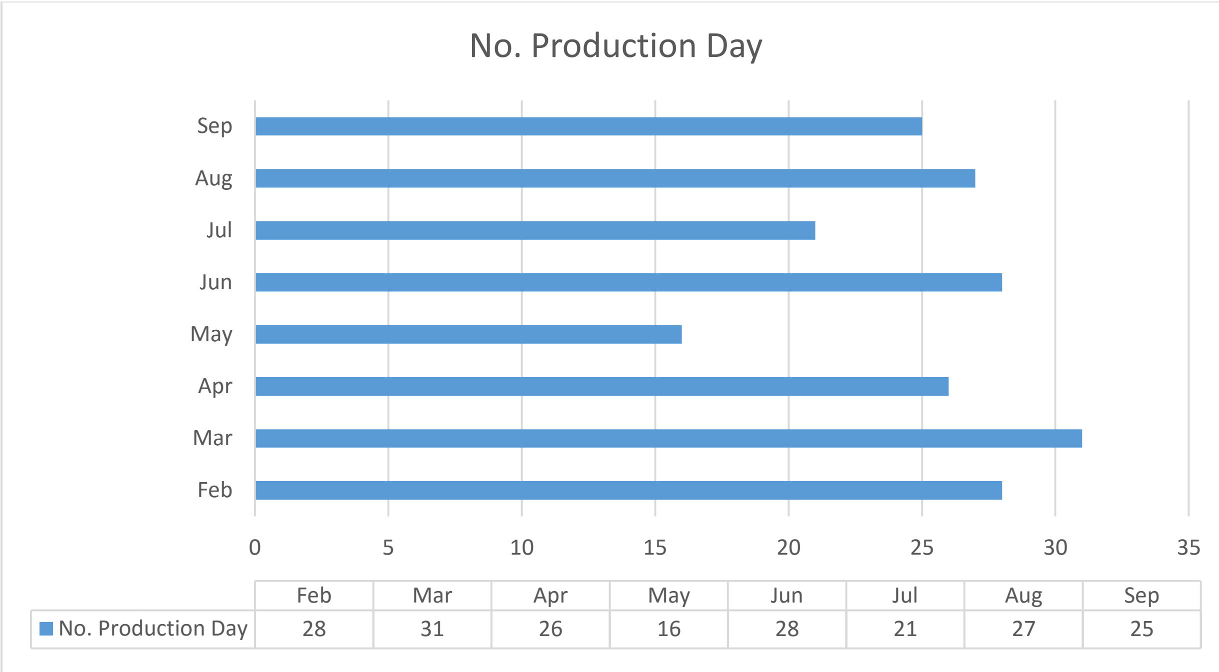


Figure 4.3 Number of production day in each month over the time period

Production capacity of the plant is 28800 cases per day for a single production line. This capacity is provided by the machine manufacturer. They consider only the load of motor, air compressor, valve etc in their calculation, this capacity doesn't consider the material load on the equipment. However, in this study we considered the designed capacity of the equipment. Although design capacity was fixed for single day, it varied from nine 900 thousand cases to 460 thousand cases due to varied no of production days in months. At best, Plant produced nearly 400 thousand cases in the month of September. Basically for three reasons plant barely meet half of its capacity:

1. Frequent machine Breakdown
2. Overdue of machine overhauling
3. Relaxed preventive maintenance

May,2016 experienced lowest number of production due to rampant machine breakdown. Actual production gained momentum during the later part of the study period.

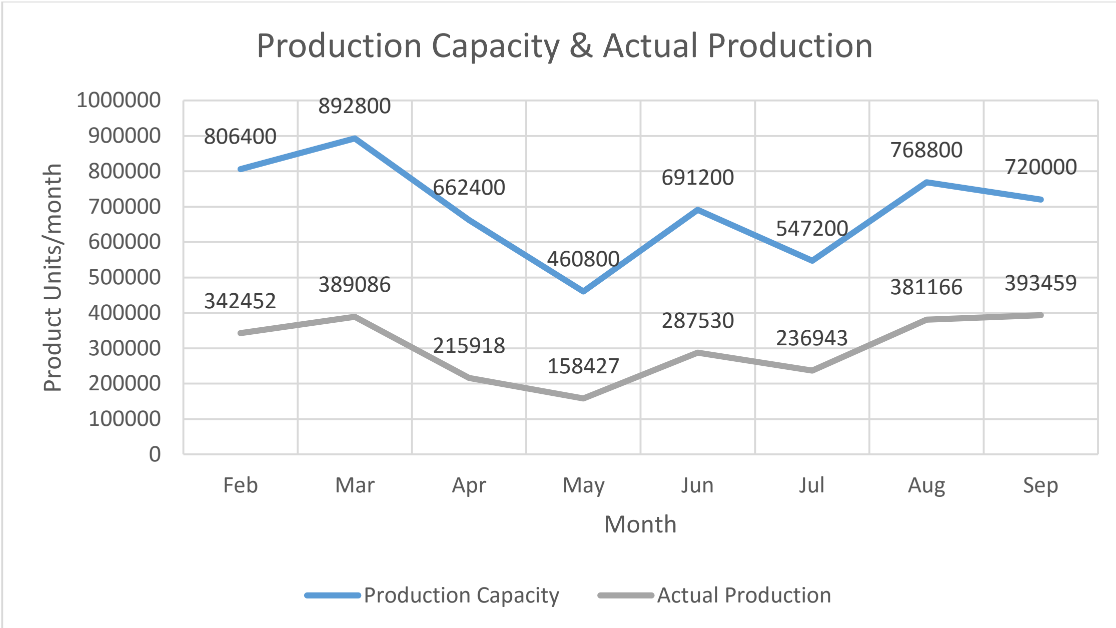


Figure 4.4 Comparison between Production capacity and actual Production

Time Period	Loading time, mins	Operating Time, mins	Availability	Theoretical cycle time	Actual cycle time	Performance rate	Quality defects	Good Units, Cases	Quality rate	OEE, %
February	39260	24099	0.614	0.125	0.176	0.71	708	342452	0.996	43.42
March	44340	27611	0.623	0.125	0.177	0.706	1140	389086	0.994	43.72
April	31245	14100	0.451	0.125	0.163	0.767	989	215918	0.991	34.28
May	22865	14196	0.621	0.125	0.224	0.558	743	158427	0.991	34.34
June	33665	15902	0.47	0.125	0.138	0.906	842	287530	0.994	42.33
July	27180	14412	0.53	0.125	0.152	0.822	548	236943	0.995	43.35
August	38550	26713	0.693	0.125	0.175	0.714	740	381166	0.996	49.28
September	35620	24886	0.699	0.125	0.158	0.791	845	393459	0.996	55.07

4.6 PERFORMANCE COMPARISON BETWEEN FEBRUARY-MAY AND JUNE-SEPTEMBER

In our study we bisected the timeline into two quarters. 1st Quarter comprises from February to May, 2016 and the quarter contain time period of June to September, 2016.

Column 2 represents loading time (Scheduled production time) for the corresponding time period. Column 3 indicates operating time for production. We obtain this value by subtracting total breakdown time from loading time. Total breakdown time is clearly mentioned in breakdown table.

Column 3:
Next, we calculated availability metric. This is ratio of operating time to Schedule/loading time.

$$Availability = \frac{Operating\ time}{loading\ time} = \frac{24099}{39260} = 0.614$$

Column 4:
Theoretical cycle time is designated by machine/ equipment manufacturer. Simply, it shows how much time is required for a single product. In this case, theoretical cycle time is 0.125 s/pcs .

Theoretical cycle time=$\frac{1440\ X\ 60}{28800\ X\ 24} = 0.125$; Designed capacity for single production line is 28800 cases in 24 hour. 1440 mins or 24 hour is ideal scheduled production time.

Column 5:
Similar way, actual cycle time is also evaluated. Numerator is loading time of corresponding month and denominator is the actual production of that month.

Column 6 :
Operating rate / performance rate is theoretical cycle time to actual production time.

$$Performance\ rate = \frac{Theoretical\ cycle\ time}{actual\ cycle\ time} = \frac{0.125}{0.176} = 0.710$$

Column 7,8, 9:
These three column represent quality matric of OEE. Defects quantity is mentioned in earlier table. Technically, Actual production is net actual production or good units. So, the total units is the sum of defects and actual production.

$$Quality\ rate = \frac{Good\ units}{Total\ Units} = \frac{342452}{343160} = 0.996$$

Column 10:
Overall equipment effectiveness (OEE) is the product of column 3, 6 and 9 .

$$OEE = Availability\ X\ Performance\ rate\ X\ Quality\ rate = 0.614\ X\ 0.710\ X\ 0.996$$
$$= 43.42$$

4.7 CAUSE AND EFFECT DIAGRAM (FISHBONE DIAGRAM):

The causes of low productivity can be classified in to 4 main reasons. Machine maintenance overdue overhauling, this reduce the operating speed of the machine. Thus there is long cycle time for production. Overhauling of equipment also contribute to recurrent long breakdown of particular equipment.

For this repetitive failure this the failure of maintenance as well as production team to inspect, prevent deterioration and in case of deterioration restore the equipment to its original state. Preventive maintenance strategy is relaxed instead of rigid procedures. Whenever repeated issue pop up again and again they don't invest themselves to research on this issue to figure out solution.

Machine operator have very limited skill to operate the machine. Machine are sophisticated, authority for obvious reason discourage operators not to do unconventional things with machine. Operators are not well versed to their machine. They have little participation and knowledge about cleaning, bolting, lubrication of machine parts.

Administration wants instant gratification form maintenance activities. There is a perception of maintenance as expenditure rather than an investment on machines. There is a requirement of maintenance budget for each year and maintenance cost log to track and evaluate maintenance activities.

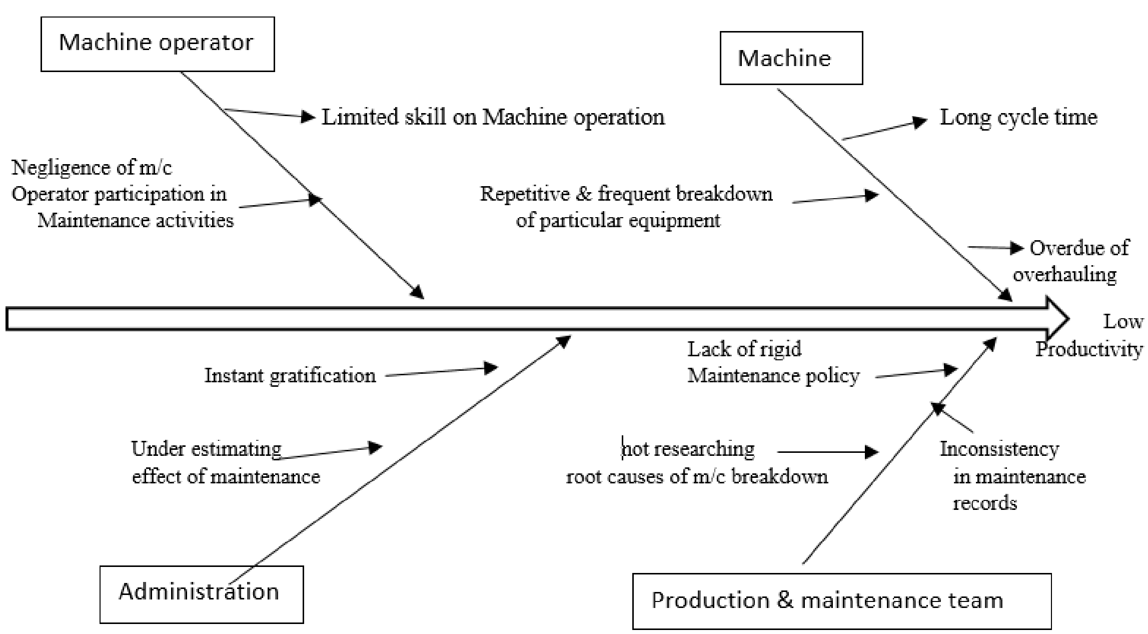


Figure 4.5 Cause and effect diagram investigating low productivity

DISCUSSION

From, data analysis it is quite evident that production line underwent recurring breakdown on few specific equipment. This chronic losses are main sources of availability loss. Apart from chronic losses there are some other minor losses which also draw attention. In literature review, six big losses are described in detail. Identifying these six big losses and elimination or minimization is very important for successful implementation of TPM in ABC plant.

4.8 REDUCING AND ELIMINATING CHRONIC LOSSES

Chronic losses can be reduced by increasing equipment reliability, restoring equipment to its original operating conditions, identifying and establishing optimal operating conditions and eliminating small defects that are overlooked.

4.8.1 Cleaning

Cleaning is an effective way to check and control equipment deterioration. JIPM encourages the use of cleaning as a primary form of inspection for several reasons:

a) During cleaning, each part of the equipment is touched or handled.
b) In the course of touching each part, the worker can discover problem such as overheating, vibration, abnormal noises, loose bolts etc.
c) Removing dust, dirt and grease (and applying proper lubrication slows deterioration)

4.8.2 Predictive Maintenance

Deterioration can be detected through predictive maintenance. Diagnostic techniques can be used to measure chemical and physical indication of the extent of deterioration of the equipment.
To conduct predictive maintenance, the following information should be valuable:

a) How to measure deterioration
b) How to detect signs of abnormality
c) What ‘normal’ condition are
d) Where the line between abnormality and normal lies

4.8.3 P-M Analysis

PM analysis is a technique developed to promote the systematic elimination of defects that contribute to chronic losses.

PM is an acronym for P (Phenomena, Physical, Problem) and M (Mechanism, Manpower, Machine, Material).

Step 1: Clarify the problem

Step 2: Conduct a physical analysis of the problem

Step 3: List every condition potentially related to the problem

Step 4: Evaluate equipment, material and method

Step 5: Plan the investigation

Step 6: Investigate the malfunction

Step 7: Formulate the improvement plan

4.9 PROGRAM TO ACHIEVE ZERO BREAKDOWN

Defects in machine can be physically and psychologically hidden. Physically hidden defects:

a) Poor inspection and analysis of deterioration
b) Poor layout and assemblies that are difficult to inspect
c) Dirt, dust and contamination

Defects can be physically hidden because

a) Defects are consciously ignored, even when visible
b) The problem is underestimated
c) The problem is overlooked, even though constant symptoms are visible

Table 4.3 Activities for Zero Breakdown (Source: Shekran, 1993)

1	2	3	4	5
Maintenance basic equip. conditions	Maintain operating standards	Restore deterioration	Improve design weakness	Prevent human error
1. Equipment cleaning- eliminate source of contamination 2. Tightening- prevent looseness 3. Lubrication- highlight lubrication points 4. Prepare cleaning and lubricating standards	1. Set design capacity and load limiting value 2. Standardize operating methods 3. Set and improve operating conditions for units and parts 4. Set and improve construction standards 5. Installation, piping, wiring 6. Prevent dust and moisture in revolving and sliding parts 7. Set environmental conditions dust, temperature, humidity, vibration, shock.	Detect and predict deterioration 1. Visually inspect items common to all units(five senses); expose deterioration. 2. Prepare daily inspection standards 3. Part by part MTBF analysis: estimate lifetimes 4. Set limiting values for parts replacement 5. Prepare inspection, testing, parts replacement standards 6. Learn to interpret abnormal signals 7. Study deterioration prediction parameters and measurement methods Establish repair methods 1. Standardize disassembly, reassembly measurement and replacement method. 2. Standardize parts 3. Improve tools and apparatus	1. Strengthen parts to extend lifetimes: mechanisms and structures, materials and shapes, dimensional accuracy, assembly accuracy, wear resistance, corrosion, surface roughness, capacity etc. 2. Take measures to reduce kinetic stress 3. Design safety relief against excess stress 4. Treat weak points to prevent overloading	Prevent miss-operation 1. Analyze causes of miss operation 2. Improve design of control panels 3. Provide interlocks 4. Foolproof operations 5. Visually control equipment conditions 6. Standardize operating and adjustment methods Prevent repair errors 1. Analyze causes of repair errors 2. Improve confusing part shapes and fitting methods 3. Spare parts storage methods 4. Improve repair tools and apparatus 5. Simplify and standardize troubleshooting procedures (Visual controls for equipment conditions

4.10 SEIRI AND SEITON IN SETUP IMPROVEMENT

Seiri (organization) and seiton (tidiness) are two of the 5S's; which can be used to improve setup. It can be used to cut setup time drastically thus improving productivity. Five S, is a common practice in Japanese companies to maintain organization, neatness, cleanliness, standardization and discipline.

Seiri refers generally to the removal of unnecessary item (cleaning) and the allocation of required space (setting the things in order) through workplace standards for placing, stacking and storing. Seiton refers to the development of control techniques to ensure strict adherence to organizational standards (e.g. visual control)

These simple rules should be kept in mind:

a) Don't search for parts or tools
b) Don't move unnecessarily; establish proper workbenches and storage area
c) Don't use the wrong tools or wrong parts

4.11 REDUCING SPEED LOSSES

A speed loss is the production loss caused by the difference between the designed (or standard) speed of a machine and its actual operating speed. This loss can be prevented by keeping the machine operating at the speed set by operating standards.

There are often problems associated with the speed set at the design stage. For example, lack of care may have generated inherent weakness in the design that prevents it from operating at the standard speed. Changes in the product line or increased complexity in product shapes may also prevent equipment from maintaining the rated speed.
The first step, is to expose the hidden problems and determine whether they correspond to any of the items below:

1. Unresolved defects due to insufficient debugging during the engineering stage.
2. Defects in equipment mechanisms or systems
3. In adequate daily maintenance
4. Insufficient precision and so on.

Table 4.4 Strategies for increasing operating speed of Machine (Source: Shekran, 1993)

Strategies for increasing speed	
Determine Present Levels	• Speed • Bottleneck processes • Downtime/ frequency of stoppages • Conditions producing defects
Check Difference between specification and present situation	• What are the specifications? • Difference between standard speed and present • Difference in speeds for different products
Investigate past problems	• Has the speed ever been increased • Types of problems • Measures taken to deal with past problems • Trends in defect ratio • Trends in speeds over time • Difference in similar equipment
Investigating processing theories and principles	• Problems related to processing theories and principles • Machining condition • Processing condition • Theoretical values
Investigate mechanism	• Mechanisms • Rated output and load ratio • Investigate stress • Revolving parts • Investigate specification of each part
Investigate present situation	• Processing time per machine (cycle diagram) • Loss time (idling times) • C_p value of quality characteristics • Check precision of each part • Check using five senses
List problems	• List problems and identity conditions that should exist • Compare with optimal conditions • Problems with mechanism • Problems with precision • Problems with processing theories and principles
List predictable problems	• Mechanical • Quality
	•
Take remedial action against predictable problems	• Compare predictable problems with present conditions • Take action against predictable problems
Correct problems	•
Perform test run	•
Confirm phenomena	• Mechanical • Quality • Change of Cp Values
Review analysis of Phenomena and cause/effect relationship and carry out activities	• Physical analysis of phenomena • Conditions producing phenomena • Related causes
Perform test runs	

4.12 PREVENTIVE MAINTENANCE

Preventive maintenance is periodic inspection to determine conditions that might cause breakdowns, production stoppage or detrimental loss of function combined with maintenance to eliminate, control or reverse such condition in their early stages. It is the rapid detection and treatment of equipment abnormalities before it causes defects or losses.
Preventive maintenance consists of three main activities:

1. Periodic inspection
2. Planned restoration of deterioration based on the result of inspection.
3. Daily routine maintenance

Preventive maintenance system comprises of two:

1. Main system
- Maintenance standards
- Maintenance plan
- Maintenance records
- Schedule for maintenance restoration activities
2. Sub system
- Spare parts control
- Lubrication control

Table 4.5 Maintenance records and their uses (Source: Shekran, 1993)

MAINTENANCE RECORDS AND THEIR USES						
	FUNCTION	**TYPE OF RECORD**	**CONTENTS**	**USE**	**PERSONAL RESPONSIBLE**	**REMARK**
1	Prevent equipment deterioration	Daily inspection check sheet	Daily records of presence or absence of abnormalities inspection of equipment during operating	Deal with abnormalities and report to superiors and maintenance department	Line operation	Can also be used for lubrication records
2		Lubrication record	Records replenishment of lubricants replacement of contaminated lubricants	Improve lubricating methods and check lubricant consumption	Line operation	
3	Periodic inspection record	Periodic inspection record	Records of measured breakdowns, planned maintenance, and maintainability improvement	Carry out repair and maintenance if measurements show that control limits have been reached	Designated maintenance personnel	Control limits are specified in inspection standards
4	Restore equipment	Maintenance report	Details of repair of sporadic breakdowns, planned maintenance, and maintainability improvement	Obtain breakdown statistics and decide priorities for maintenance work	Maintenance personnel responsible	
5		Maintainability improvement record	Record of maintainability improvement plans, execution, and results	Promote standardization of improved procedures and revise original drawing Use as improvement oases study material	Maintenance or engineering personnel or staff	Deal with similar items of equipment together
6		MTBF analysis chart	Record of all types of maintenance work, e.g. repair of sporadic breakdowns, replenishment and replacement of lubricants	Extending maintenance intervals and improving efficiency or repair work	Line operators, maintenance department, resident sub-contractors	
7	Document equipment lifetimes	Equipment log	Details and cost records for major breakdown repair, periodic maintenance, and maintainability improvement	Providing cost data on which to make decisions about equipment replacement and investment based on life cycle costs	Maintenance department personnel or staff	

8	Control maintenance budget	Maintenance cost record	Breakdown of maintenance labor costs, materials costs and sub controlling costs Cost breakdown for each equipment	Control maintenance budget, identifying priorities for reducing costs	Maintenance materials and purchasing department personnel and staff	Data forwarded to accounting dept.

4.13 STANDARDIZATION OF MAINTENANCE ACTIVITIES

Maintenance standards can be divided into two:

1. Equipment maintenance standard
a) Inspection standards- for measuring equipment deterioration
b) Overhaul standards- for preventing equipment deterioration
c) Repair standards- for restoring equipment

2. Maintenance work procedures- are the work procedures, methods, and frequency of inspection, servicing, repairs and other types of maintenance work.

The entire TPM program activities, which may otherwise look complicated to a beginner can actually be summarized as an activity to

a) Prevent deterioration- (Routine maintenance)
b) Measure deterioration- (inspection and measurement)
c) Restore Equipment- (repairs and maintenance)

4.13.1 MAINTENANCE PLANNING

Types of maintenance planning:

1. Annual maintenance plan- guarantee's the reliability of equipment over its predicted life span, from installation to scraping.

2. Monthly maintenance plan- based on annual maintenance plan and includes improvement activity as well as specific actions to prevent breakdowns.

3. Weekly maintenance plan- to manage the work of individual maintenance personnel.

4. Major maintenance project plan- individual plans for turnaround, large scale revamping, or overhaul of specific equipment of plant areas.

4.13.2 MAINTENANCE RECORDS

Documenting the results of maintenance is one of the most important maintenance activities. The quality of a factory's maintenance is revealed by its maintenance records. The result of the maintenance activity must be recorded quickly into the recording system so that the results can be incorporated in subsequent maintenance plans. Maintenance quality and performance level can be continuously raised by repeating the Plan-Do-Check-Action management cycle.

4.13.3 SPARE PARTS CONTROL

The purpose of spare parts can be described as following:

1. Promote increased equipment reliability and extend equipment life span through the purchase, fabrication, and storage of spare parts.
2. Ensure the necessary spare parts are available whenever needed and then minimizing planned maintenance downtime and production stoppage due to breakdown.
3. Reduce inventories, ordering and acceptance costs and storage costs

4.13.4 MAINTENANCE BUDGET CONTROL AND MAINTENANCE COST REDUCTION

Maintenance costs can be divided into two categories:

1. Capital expenditure- cost of new, expansion, re-planned or revamped equipment or purchase treated as fixed assets.
2. Running cost- expenditure that are treated as the cost of maintaining and restoring equipment to its intended use. These are maintenance costs and include overhaul costs. Repairing cost, and restoring costs.

Maintenance costs can be classified; either by the purpose or by the type of maintenance.
By purpose:

Routine maintenance costs- includes labour and material costs for routine maintenance activities designed to prevent equipment deterioration such as cleaning, lubrication, inspection and adjustment.

Equipment inspection costs- include labour and material costs for inspection to discover abnormalities and determine whether equipment is serviveable or defective.
Repairing cost- includes labour and material costs for repairs to restore equipment to its original condition.

By maintenance method:

1. Preventive maintenance costs
2. Breakdown maintenance costs
3. Maintenance improvement costs

Table below is an example of maintenance costs can be reduced if they are properly classified and their monthly cost by process and machine breakdown are clearly established. These costs are then compared with the budget planned at the beginning of the business year. Table….shows; how maintenance costs can be controlled by the maintenance type as well as with reference to the process type and machine type.

Table 4.6 Maintenance cost breakdown

MAINTENANCE COST BREAKDOWN												
PROCESS	EQUIPMENT	YEAR (PERIOD) BUDGET	TYPE OF COST						USAGE			
			IN HOUSE LABOUR	MATERIALS SPARE PARTS	SUB CONTRACT PARTS	STOPPAGE LOSS	OTHER	TOTAL	PREVENTIVE MAINTCOST	BREAKDOWNMAINTCOST	IMPROVEMENT COST	TOTAL

Table 4.7 Classification of maintenance costs (Source: Shekran, 1993)

	EXPENDITURE	DESCRIPTION	REMARKS
1	Spare parts costs	Cost generated when new parts are issued and used.	Spare Parts
2	Parts repair, restoration, and overhaul costs	Cost of processing parts for re-use, e.g., replacing rubber linings, overlaying, machining and welding	Salvage parts
3	Maintenance labour costs	Inspection, adjustment, repair, parts replacement, and other labour cost	
4	General materials costs	Steel materials, cleaning oil, cotton waste, rubber, paint, seals and miscellaneous materials cost	
5	Lubricant cost	Lubricating oil, hydraulic fluids, etc.	
6	Maintainability Improvement	Cost of accident prevention, lifetime extension, breakdown reduction, and other improvements for maintenance purposes	Maintainability improvement costs
7	Jig and tool costs	Cost of jigs and tools for maintenance work	
8	Commissioning cost	Costs of repairing design weakness and breakdowns in newly installed equipment. Such problems often occur during the commissioning phase due to problems running in process or lack of familiarity of operators and maintenance staff	These costs are essentially different from normal repair costs, so identify separately as commissioning

4.14 AUTONOMOUS MAINTENANCE

Maintenance performed by equipment operators, or autonomous maintenance, can contribute significantly to equipment effectiveness. At the heart of autonomous maintenance is deterioration prevention, which is generally neglected in most factories.

Efficient production depends on both production and maintenance personnel is often somewhat not harmonious.

Two types of activities are required to increase equipment effectiveness:

1. Maintenance activities to prevent breakdown and repair of ailing equipment. They occur in a cycle consisting of normal operation combined with preventive maintenance (i.e. daily, periodic and predictive maintenance) and corrective maintenance.
2. Improvement activities extend equipment life,reduce the time required to perform maintenance, and make maintenance unnecessary. Reliability and maintainability improvement, maintenance prevention and maintenance improvement activities.

Autonomous maintenance is the maintenance activity performed by both production and maintenance personnel to carry out the three activities of deterioration: Prevention , measurement and restoration. Autonomous activity for production department should be constructed based on the following activities.

1. Deterioration prevention:
- Operate equipment correctly
- Maintain basic equipment condition (cleaning, lubricating, bolting)
- Make adequate adjustments (mainly during operation and set up)
- Record data on breakdown and other malfunction
- Collaborate with maintenance department to study and implement improvement.

2. Deterioration measurement (using the five senses)
- Conduct daily inspection
- Conduct certain periodic inspection

3. Equipment restoration
- Make minor repairs (simple parts replacement and temporary repairs)
- Report promptly and accurately on breakdowns and other malfunction.
- Assist in repairing sporadic breakdown.

When autonomous maintenance is in full swing, maintenance personnel can perform better in periodic maintenance, maintainability improvement and other activities involving deterioration measurement and equipment restoration. They can concentrate on tasks requiring high level of technical skill.

4.15 IMPLEMENTING AUTONOMOUS MAINTENANCE IN SEVEN STEPS

The autonomous maintenance program can be effective if implemented in seven steps. The seven steps are:

1. Initial cleaning
2. Action against sources of dust and contamination
3. Cleaning and lubrication standards
4. General Inspection
5. Autonomous inspection
6. Seiri & Seiton
7. Full autonomous maintenance

Table 4.8 Responsibilities distribution in autonomous maintenance (Source: Shekran,1993)

Target	Methods		Activities			Allocation	
			Prevent deterioration	Measure deterioration	Restore equipment	Operators	Maintenance
Overall equipment effectiveness , at least 85%	Maintenance activity	Normal operation	Proper operation			*	
			Setup adjustments			*	
		Daily maintenance	Cleaning, detecting and correcting hidden faults			*	
			Lubrication			*	
			Tightening bolts and nuts			*	
			Condition of use, daily deterioration check			*	
					Minor servicing	*	
		Periodic maintenance					
				Periodic inspection		*	*
				Periodic testing			*
					Periodic servicing		*
		Preventive maintenance		Trend testing			*
					Non-routine servicing		*
		Breakdown maintenance	Rapid discovery of abnormalities, prompt and accurate reporting			*	
					Repair breakdowns		*
	Improvement activity	Improving reliability	Strengthen			*	*
			Reduce load			*	*
			Increase precision			*	*
		Improving maintainability		Develop condition monitoring		*	*
				Improve testing procedures			*
					Improve servicing procedures		*
					Improve servicing quality		*

4.16 MAINTENANCE PREVENTION

Equipment management can be roughly divided into project engineering and maintenance engineering. Maintenance prevention (MP) is a significant aspect of project engineering that serves as the interface between project and maintenance engineering. The goal of maintenance prevention is to reduce maintenance cost and deterioration losses in new equipment by considering past maintenance data and the latest technology when designing for higher reliability, maintainability, operability, safety etc.

Maintenance prevention activities are conducted during design, fabrication, installation and test run and commissioning (establishing normal operation with commercial production) They include debugging at each stage (detecting and correcting errors and malfunction)

For MP to be effective, data collection is vital. These data collection will be used at the equipment design etc. Without these data the engineers will not be able to make improvements. Such data's are generally collected at the manufacturing plant where the equipment is operating under the demands of production capacity. Therefore, the quality of subsequent productive maintenance is determined largely by whether the latest technology of equipment reliability and maintainability is brought from outside or developed in house through the efforts and experience of production, design and maintenance staff.

It is also determined by whether full use is made of the company's accumulated technical expertise and the exhaustiveness of in house research and investigation.

The quality of company's MP program depends on the following three factors:

a) Technical skills and design sense of the engineering and design engineers
b) Quality and quantity of technical data available
c) Ease with which this technical data can be used

The method for collecting and standardizing MP data is very crucial if, the company desires its MP program to be successful. MP data collection items include: safety, quality, maintenance, and engineering. The activities pertaining to these data accumulation are:

a) Parts life span investigation
b) Routine control activities such as operating condition and defective data's.
c) Initiation of commissioning control
d) Breakdown data
e) Equipment improvement design
f) Process capacity investigation
g) Equipment related accidents

4.17 MAINTENANCE SKILL TRAINING

For, TPM to succeed, it is necessary to have personnel with strong maintenance and equipment related skills. Operators, production front-line workers must become intimately acquainted with their own responsibility and develop practical expertise and the skills necessary to maintain as well as operate the equipment.

Though, operators handle many types of equipment, all equipment is made up of certain common parts; pneumatics, hydraulics, drive system, lubricating system, electrical system, basic components- bolts, nuts, key. All the operator must be skill full in basic machine maintenance.

Table 4.9 Basic machine maintenance course (Source: Shekran, 1993)

BASIC MACHINE MAINTENANCE COURSE		
UNIT TOPIC	**SUBJECT**	**DESCRIPTION 3 DAYS PER UNIT**
1 BOLTS AND NUTS	Lecture; practice on the shop floor	Opening remarks 1. Orientation 2. How to read drawings 3. Machines and materials 4. Bolts and nuts 5. Material and tightening torque 6. Unit review and comprehension test
2 KEYS AND BEARINGS	Lecture; practice on the shop floor	1. Review unit 1 and answer question 2. Orientation 3. Fits and tolerances 4. Types of keys 5. Bearing 6. Lubrication 7. Unit review and comprehension test
3 POWER TRANSMISSIONS (GEARS,BELTS AND CHAINS)	Lecture; practice on the shop floor	1. Review unit 2 and answer questions 2. Orientation 3. Gears 4. V-belts 5. Chains 6. Aligning and centering 7. Unit review and comprehension test
4 HYDRULICS,PNEUMATICS, PENUMATICS, AND SEALING	Lecture; practice on the shop floor	1. Review unit 3 and answer questions 2. Orientation 3. Hydraulics 4. Pneumatics 5. Sealing 6. Cutaway models 7. Unit review and comprehension test 8. Presentation of cutaway models 9. Closing remarks

CHAPTER 5
CONCLUSION AND RECOMMADATION

5.1 SUMMARY OF THE STUDY

The intention of the study was to provide an insight to Total Productive Maintenance (TPM) methodology in a Manufacturing company and compare it with the Ideal TPM model. In addition, the new and better maintenance practice or any other improvement methods that are more attractive can be integrated into the existing management to improve the effectiveness of TPM implementation in the organization. The conclusion and recommendation are made in the following section.

5.2 CONCLUSION

As a conclusion, status of all the objectives of the study summarized as follow:

- First and foremost objective of the study was to maximize overall equipment effectiveness. OEE matric was used to understand the productivity level in the plant and impact of single change at productivity. Equipment overhauling, minimizing product changeover, reduction of band roll machine contribute to gain at least 50% OEE. Although world class level for OEE is 85% which seems a long shot for the organization. However, it took 20 long years to perfect TPM in Toyota car manufacturing plants.

- Although the organization follow preventive maintenance for its maintenance purpose, it lacks in terms of planned restoration based on inspection result and daily maintenance routine. Other significant thing to mention is not incorporating machine operator in its maintenance activities.

- Maintenance dept. relentlessly working for the welfare of smooth operation of equipment. But reflecting on the effort they make is also necessary to understand where they can add value for their organization and for themselves. Maintenance records represent the level of maintenance activities in a plant.

5.3 RECOMMENDATION

1. Certainly maximizing the equipment effectiveness will remain prime objective for a manufacturing plant. On this purpose, appropriate equipment maintenance policy like TPM can enhance productivity level of the plant. To make a transition from national organization to global one it is imperative to lift and sustain its operation at world class level. Section 4.6-4.9 is dedicated on this purpose.

2. Maintenance records should be organized & utilize those data on Planned restoration and daily/weekly/monthly maintenance plan is required. We proposed a guideline on section 4.10 and 4.11.

3. It is necessary to integrate machine operator into its maintenance activities as they are the first responder in case of machine breakdown or failure. But it is required to educate them about the machine and maintenance activities so that they can perform basic activities like cleaning, lubricating, bolting and machine inspection. This will help maintenance team to work on more specialized issues.

4. This is the responsibility of the maintenance dept. to represent their effort in terms of increased loading time and making production more cost effective. Presenting those results in monetary value is most efficient on this purpose.

TPM is the appropriate maintenance policy. This organization may sincerely consider this for itself as it aspire to be a global organization.

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