Review of Total Productive Maintenance Using Failure Mode Effect Analysis across Various Industries

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Abstract— This paper reviews about significant application of FMEA in TPM in different types of industry to improve quality, reliability and productivity. The goal of quality and reliability systems is the same: to satisfy customers. A system cannot be trusted if it is not of high quality. Similarly, if a system is not reliable, it cannot be of high quality. The dependability of a firm's equipment or machinery is frequently used to assess its quality performance. When a system is unreliable, it is unpredictable, and when it is unpredictable, it is of poor quality. One of the most important quality management techniques is FMEA. Total Productive Maintenance is a useful technique for increasing plant and equipment productivity with a small investment in maintenance. The paper examines various approaches to Failure Mode Effect Analysis and Total Quality Management. So far, Productive Maintenance has been developed, and there has been discussion about the use of FMEA-TPM in an integrated approach.

Keywords: FMEA, TPM, Quality, Reliability, Productivity, OEE, RPN

I. Introduction

Total Productive Maintenance (TPM) is a unique Japanese philosophy, which has been developed based on the productive maintenance concepts and methodologies. This concept was first introduced by M/s Nippon Denso Co. Ltd. of Japan, a supplier of M/s Toyota Motor Company, Japan in the year 1971. Total productive maintenance is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns and promotes autonomous maintenance by operators through day-to-day activities involving total workforce.

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

A. *Eight Pillars of TPM*

1) 5S: TPM starts with 5S. Problems cannot be clearly seen when the work place is unorganized. Cleaning and organizing the workplace helps the team to uncover problems. Making problems visible is the first step of improvement. The meaning of 5S is SEIRI- Sort out, SEITON – Organize, SEISO - Shine the workplace, SEIKETSU – Standardization, SHITSUKE - Self-discipline.
2) Autonomous Maintenance : This pillar is geared towards developing operators to be able to take care of small maintenance tasks, thus freeing up the skilled maintenance people to spend time on more value added activity and technical repairs. The operators are responsible for upkeep of their equipment to prevent it from deteriorating.
3) Continuous Improvement (KAIZEN): Kai" means change, and "Zen" means good (for the better). Basically kaizen is for small improvements, but carried out on a continual basis and involve all people in the organization. Kaizen is opposite to big spectacular innovations. Kaizen requires no or little investment. The principle behind is that "a very large number of small improvements are more effective in an organizational environment than a few improvements of large value. This pillar is aimed at reducing losses in the workplace that affect our efficiencies. By using a detailed and thorough procedure we eliminate losses in a systematic method using various Kaizen tools. These activities are not limited to production areas and can be implemented in administrative areas as well.
4) Planned Maintenance: It is aimed to have trouble free machines and equipments producing defect free products for total customer satisfaction. This breaks maintenance down into 4 "families" or groups such as Preventive Maintenance, Breakdown Maintenance, Corrective Maintenance, Maintenance Prevention
5) Quality Maintenance: It is aimed towards customer delight through highest quality through defect free manufacturing. Focus is on eliminating non-conformances in a systematic manner, much like Focused Improvement. We gain understanding of what parts of the equipment affect product quality and begin to eliminate current quality concerns, then move to potential quality concerns.
6) Education & Training: It is aimed to have multi-skilled revitalized employees whose morale is high and who has eager to come to work and perform all required functions effectively and independently. Education is given to operators to upgrade their skill.
7) Office TPM: Office TPM should be started after activating four other pillars of TPM (JH, KK, QM, PM). Office TPM must be followed to improve productivity, efficiency in the administrative functions and identify and eliminate losses. This includes analyzing processes and procedures towards increased office automation. Office TPM addresses twelve major losses. They are Processing losses.
8) Safety, Hygiene and Environment Control: In this area focus is on to create a safe workplace and a surrounding

area that is not damaged by our process or procedures. This pillar will play an active role in each of the other pillars on a regular basis. A committee is constituted for this pillar which comprises representative of officers as well as workers. The committee is headed by Senior vice President (Technical). Utmost importance to Safety is given in the plant. Manager (Safety) is looking after functions related to safety.

To create awareness among employees various competitions like safety slogans, Quiz, Drama, Posters, etc. related to safety can be organized at regular intervals.

TPM evolved from TQM, which evolved as a direct result of Dr. W. Edwards Deming's influence on Japanese industry. Dr. Deming began his work in Japan shortly after World War II. As a statistician, Dr. Deming initially began to show the Japanese how to use statistical analysis in manufacturing and how to use the resulting data to control quality during manufacturing. The initial statistical procedures and the resulting quality control concepts fueled by the Japanese work ethic soon became a way of life for Japanese industry.

A well-conceived TPM implementation program not only improves the equipment efficiency and effectiveness but also brings appreciable improvements in other areas of the manufacturing enterprise. TPM is based on three interrelated concepts:

1) Maximizing equipment effectiveness;
2) Autonomous maintenance by operators; and
3) Small group activities.

Objectives of TPM

The objectives of TPM are:

1) Achieve Zero Defects, Zero Breakdown and Zero accidents in all functional areas of the organization.
2) Involve people in all levels of the organization.
3) Build different teams to reduce defects and Self-Maintenance.

Measurement of the success of TPM in evaluating and measuring the extent to which the successful implementation of TPM, the primary measurement tool used is the Overall Equipment Effectiveness (OEE). Mathematically, OEE formula is as follows:

OEE = Availability x Performance Rate x Quality

Overall Equipment Effectiveness (OEE) is a calculation carried out to determine the extent of the effectiveness of an existing machine or equipment. OEE is used as an indicator of the performance of a machine or equipment. The purpose of OEE is as a measure of the performance of a maintenance system, by using this method it can be seen the availability of machines or equipment (availability), production efficiency (performance), and the quality of the output of the machine/ equipment (quality).

Failure Mode and Effect Analysis (FMEA) were first developed as a formal design methodology in the 1960s by the aerospace industry with their obvious reliability and safety requirements. Later, its use spread to other industries, such as the automotive, oil and natural gas. FMEA aims to identify and prioritize possible imperfections in products and processes. FMEA analyses

1) Potential failure modes of product or machine,
2) Potential effects of failure,
3) Potential causes for failure (like Material defects, Design deficiencies,
4) Processing and manufacturing deficiencies, and Service condition etc.)
5) Assesses current process controls, and
6) Determines a risk priority factor.

FMEA is an essential function in design, from concept through development. Quality and reliability of products and manufacturing processes are critical to the performance of the final products. They are also important indices for meeting customer satisfaction. In order to fulfill customer requirement for quality and reliability, some actions for assuring the quality and reliability of products or processes should be taken by all engineers involved. One of the most powerful methods available for measuring the reliability of products or process is FMEA. Customers are placing increased demands on companies for high quality, reliable products. The increasing capabilities and functionality of many products are making it more difficult for manufacturers to maintain the quality and reliability. Traditionally, reliability has been achieved through extensive testing and use of techniques such as probabilistic reliability modeling. These are techniques done in the late stages of development. The challenge is to design in quality and reliability early in the development cycle. The cause and effect diagram is used to explore all the potential or real causes (or inputs) that result in a single effect (or output). Causes are arranged according to their level of importance, resulting in a depiction of relationships and hierarchy of events. This can help you search for root causes, identify areas where there may be problems, and compare the relative importance of different causes. There are several types of FMEA's; some are used much more often than others. FMEA's should always be done whenever failures would mean potential harm or injury to the user of the end item being designed. FMEA is a reliability procedure which documents all possible failures in a system design within specified ground rules. It determines, by failure mode analysis, the effect of each failure on system operation and identifies single failure points, which are critical to mission success or crew safety.

In general FMEA is a systemized group of activities designed to:

1) recognize and evaluate the potential failure of a product/process and its effects,
2) identify actions , which could eliminate or reduce the chance of potential failure occurring,
3) document process.

The purpose of the FMEA is to take actions to eliminate or reduce failures, starting with the highest-priority ones. It may be used to evaluate risk management priorities for mitigating known threat-vulnerabilities. In FMEA, failures are prioritized according to three dimensions:

1) How serious their consequences are,
2) How frequently they occur,
3) How easily they can be detected.

Good FMEA methodology allows for the identification and documentation of potential failures of a system and their resulting effects. It also allows for the assessment of the potential failure to determine actions that would reduce severity, reduce occurrence, and increase detection.

The composite risk score for each unit operation step is the product of its three individual component ratings: Severity (S), Occurrence(O) and Detection (D). This composite risk is called a risk priority number (RPN). This number is then used to rank order the various concerns and failure modes associated with a given design as previously identified in the FMEA.

$$RPN = (S) \times (O) \times (D).$$

The RPN is a measure of design risk. The RPN is also used to rank order the concerns in processes (e.g., in Pareto fashion). The RPN will be between "1" and "1,000." For higher RPNs the team must undertake efforts to reduce this calculated risk through corrective action(s).

II. LITERATURE REVIEW

A. TPM

In today's highly dynamic and rapidly changing environment, the global competition among organizations has lead to higher demands on the manufacturing organizations (Miyake and Enkawa, 1999).

Moubray (as quoted by Eti et al, 2000) states that developing and executing a maintenance strategy consists of three steps;

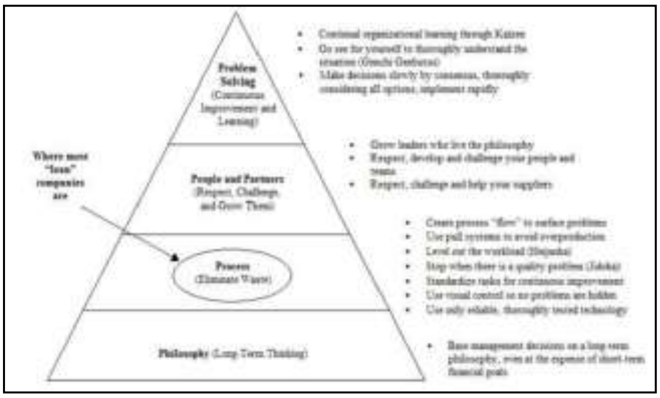
1) Formulate a plan of what needs to be done for each component (i.e. work identification).
2) Acquire the resources (skilled personnel, spares and tools) needed to execute the proposed procedure effectively.
3) Implement the strategy (i.e. acquire and deploy the systems needed to manage the resources effectively).

The global marketplace has witnessed an increased pressure from customers and competitors in manufacturing as well as service sector (Basu, 2001; George, 2002

All the main ideas constituting the fourteen principles presented in the book "The Toyota Way" (Liker, et al., 2004) where developed by Sakichi Toyoda, his son Kiichiro Toyoda and his nephew Eiji Toyoda supported all the way long by Taiichi Ohno. The fourteen principles are summarized in the "4 P" model Figure. This model is actually representing the vision of which steps need to be accomplished, in order to become a state-of-the-art industry.

In today's fast-changing marketplace, slow, steady improvements in manufacturing operations do not guarantee sustained profitability or survival of an organization (Oke, 2005)

This has provided the impetus to the leading organizations worldwide to adopt effective and efficient maintenance strategies such as Condition Based Maintenance (CBM), Reliability Centered Maintenance (RCM) and Total Productive Maintenance (TPM), over the traditional firefighting reactive maintenance approaches (Sharma et al., 2005).



A coherent, unifying and integrative pattern of decisions in different maintenance strategy elements in congruence with manufacturing, corporate and business level strategies; determines and reveals the organizational purpose; defines the nature of economic and noneconomic contributions it intends to make to the organization as a whole (Pinjala et al, 2006)

The manufacturing industry has experienced an unprecedented degree of change in the last three decades, involving drastic changes in management approaches, product and process technologies, customer expectations, supplier attitudes as well as competitive behaviour (Ahuja et al., 2006).

(A. Salonen, 2011) Through proper and suitable maintenance programmes, major losses due to breakdowns and defects can be avoided. Even though these maintenance program will cost money, but the lack of maintenance will cost even more.

The goal of the any TPM program is to improve productivity and quality along with increased employee morale and job satisfaction (R. S. Singh, 2012)

There are few researches being conducted to investigate the relationship between maintenance and technical complexity. Technical complexity has many definitions. In production process, it can be defined as the extent to which human effort is replaced by machines (J. G. Arca, 2008)

TPM is being implemented in industry as a group activity that reduces equipment maintenance, enhances productivity and improves profit by implementing various kaizen projects (Dogra et al. 2011)

Under TPM initiatives, the concept of OEE was introduced (Nakajima 1988) to support TPM activities. OEE is akey performance indicator which has a positive impact in increasing the efficiency of a system (Zammori, Braglia, and Frosolini 2011)

Focused TPM implementation over a reasonable time period can strategically contribute towards realisation of significant manufacturing performance enhancements (Wakjira and Singh 2012)

O'Malley, 2014 et.al. The Losses to machine or equipment effectiveness fall into the following loss categories utilization availability (planned and unplanned) performance.quality.

OEE is a powerful tool for identifying and eliminating losses, thereby developing efficient production system for achieving world-class manufacturing (Hemanand et al. 2012; Gupta, Vardhan, and Al Haque 2015).

It captures day to- day fluctuations with an aim to reduce equipment downtime and improving plant maintenance tasks (Zammori 2014).

Bhattacharjee, 2018 et. Al. Overall equipment effectiveness (OEE) is a framework to measure the efficiency and effectiveness of the manufacturing process. It is a measurement tool used to indicate how effectively machines are running. It measures if machines are utilized, how much of the time machines are operating the speed at which output is manufactured, and the percentage of the output that is of the right quality

B. *Lean Approach*

A. Karim, 2013 et.Al. The process of globalization encourages manufacturers to optimize their manufacturing process that enable them to deliver high quality products in a short period of time

A. J. R. Smith, 2008 et.Al. The pursuit of optimizing manufacturing process has increased the efforts of manufacturing organizations in improving their internal and external performances in order to achieve competitive advantages

R.V.B. De Souza,2014,et. Al. Competitive pressures have been driving companies toward reduction of cost and improvement of operation for providing high quality products to the demanding market.

A. Gurumurthy, 2011. Lean manufacturing has been the buzzword in manufacturing area.

J. P. Womack, 1990 et.Al. The approach of lean manufacturing which focuses on waste reduction and performance enhancement has been gaining importance recently

Total Productive Maintenance (TPM) and Failure Mode And Effect Analysis (FMEA)

Wakjira et al., the engine is an input in the production process that requires energy to carry out the activities of the production process, the energy in question is energy in the form of fuel, lubricating oil, electric power, water for factories, etc.

Lazim H M, 2013 et. al Many things cause the cessation of a machine when doing production either due to damage by the device itself or because of something else. Therefore we need a way or method to maintain the function of the machine itself, keeping it able to operate to produce a lot of quality products.

Patidar L, 2015 et. al If a machine cannot function normally, the company will suffer a lot of losses resulting in a decline in the productivity of the company itself. In dealing with this, the company usually carries out certain types of maintenance so that all of its machines can operate normally

According to Reyes et.al, maintenance means improving pre-existing capabilities, whereas repairs are defined as making things better and operating optimally

Ihueze, 2018 et.al In general, the problem that occurs on the production floor is the damage to the opinion machine. A common problem that is often found on the production floor is that production equipment does not operate properly so that it affects the next process.

Hqbek P, 2017 et.al In a sugar mills, there are several workstations in the production process, including the preparation station, grinding station, purification station, evaporation station, cooking station, Lutheran station, and finishing station. In the production process activities, all stations must have their own constraints, but at the grinding station, there are more obstacles due to broken machines or other things. Therefore in this study, measurement of engine performance will be carried out at the grinding station, whether the performance or productivity of the machine within six months of operation is said to be useful.

According to Charles, 2016 et al. support is a primary function in a company that can be defined as an activity to take care of facilities so that the equipment is in a condition that is ready to use as needed.

Eissa, 2019 et.al Total Productive Maintenance (TPM) is one of the maintenance process methods developed to improve productivity in the work area by making the process more reliable and less wasteful [8]. This method is part of lean manufacturing.

Thakore, 2015 et.al RPN is a mathematical product of the seriousness of the effects (Severity), the possibility of the cause will cause failure related to effects (Occurrence), and the ability to detect faults before they occur in the customer (Detection).

Anggraini, 2017 et.al In the world of engine maintenance, there are six type of losses that must be avoided by every company that can reduce the level of effectiveness of a machine, known as the Six Big Losses.

Mayangsari , 2015 et.al There are six equipment losses that cause low performance of machines and equipment. the six losses are known as six big losses which are divided into 3 categories of losses: downtime losses (breakdown, set up and adjustment) speed losses (idling and minor stoppages losses, reduce speed), and quality losses (rework and quality defects, start up reject)

Sayuti M, 2019 et.al After the effectiveness of the engine was known, the calculation of the magnitude of the ratio of the six components of the six big losses was equipment failure, set up and adjustments, idling and minor stoppages, reduced speed, scrap and rework and startup losses to find out what categories of losses are causing low OEE value of the machine.

Prabowo, 2020 et.al FTA is a technique used to identify risks that contribute to failure. This method is carried out with a top-down approach, which begins with the assumption of failure or loss from a top event and then details the causes of a top event to a root cause.

III. DISCUSSIONS

At the product, service, process, and/or design stages, an FMEA is an analytical quality planning tool dedicated to the identification of the key probable failure modes and their related repercussions. Its proper application could result in a slew of savings (improvements) of:

- Internal defects (during and after the manufacturing process)
- Customer complaints
- Failures in the field

Furthermore, the successful application of an FMEA could result in increased customer satisfaction and services produced by dependable manufacturing processes. Every industry must improve productivity by utilising resources such as machinery, labour, and materials as efficiently as possible in order to survive.

Every manufacturing industry suffers from massive losses/wastage on the manufacturing shop floor. This waste is the result of problems with operators, maintenance personnel, processes, tooling, and the availability of components on time, among other things. Other types of waste include idle machines, idle manpower, break down machines, rejected parts, and so on.

Quality-related waste is significant because it affects the company in terms of time, materials, and the company's hard-earned reputation. Other invisible wastes include operating machines at less than their rated speed, start-up loss, and break downtime of machines and bottlenecks in the process.

TPM along with FMEA could able to reduce the risk factor involved in machine so it is improving the overall productivity of a plant. As a result, FMEA-TPM aids in the improvement of quality, reliability, and productivity.

IV. CONCLUSION

The quality and reliability of products and manufacturing processes are critical to the final product's performance. They are also important indicators of meeting customer expectations. To meet the quality and reliability requirements of customers, some actions for assuring the quality and reliability of products or processes should be taken by all parties involved.

FMEA is one of the most effective methods for assessing the dependability of products or processes. The FMEA's limited use in improving designs has probably been its most serious criticism. Customers are increasing their expectations of companies to provide high-quality, dependable products. FMEA is a simple tool for determining which risks are the most concerning and, as a result, require action.

Before beginning the actual FMEA, a worksheet containing important system information, such as the revision date or component names, must be created. On this worksheet, all of the subject's items or functions should be listed in a logical order. An FMEA's initial output is the prioritisation of failure modes based on their risk priority numbers; however, this does not eliminate the failure mode. Additional action, possibly outside the scope of the FMEA, is required.

Quality and maintenance of manufacturing systems are two functions that are inextricably linked in any organisation. Over the course of time, the Total Productive Management is a new concept that has emerged.

(TPM) is increasingly being recognised as an appropriate initiative technique for effectively involving the workforce in manufacturing-based organisations in order to increase productivity and add new impetus to quality efforts. TPM is a useful tool for assisting businesses in achieving optimal manufacturing processes.

By achieving this level of maintenance, an organisation will be able to reap the competitive advantages provided by TPM, resulting in the production of quality products that satisfy customers and, as a result, higher profits. The quality of the products improves by preventing equipment breakdown, improving equipment quality, and standardising equipment (which results in less variance and thus better quality).

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