Manufacturing Equipment Reliability Improvement using Total Productive Maintenance (TPM) Implementation : A Review

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ABSTRACT

To ensure the continuity of the operation, the reliability of assets must be taken into account. Maintenance is one important aspect that contributes to efficient and effective asset performance. Lack of managing maintenance program can result low productivity and higher operational cost. Due to the limited amount of resources and large number of assets that have to be maintained, the maintenance activity has to be strategize and supported by all company organization level with respect of their capabilities. Total Productive Maintenance (TPM) is a logical and simple concept that can improve performance. It aims zero failures, zero defects, and zero accidents to gain the maximum overall equipment effectiveness (OEE) of assets. The aim of this research is to determine the core concepts and its practice of TPM from the various literature and use them to assess the current policy related to maintenance in the hydropower plant, whether it embrace TPM practices or not. It also investigate and identify the success factors and barriers in implementing TPM. The purpose of this research is to find the correlation between reliability improvement, maintenance activities, and aspects of TPM implementation. It is found that TPM theoretically can improve overall reliability of equipment by executing maintenance strategy model which is supported by all level of employee and functional divisions of manufacturing organization. Future empirical research is required to prove the concept of TPM implementation in improving equipment reliability.

Keywords: reliability; maintenance; total productive maintenance (TPM)

1. Introduction

Manufacturing industries consist of many systems and their corresponding assets and components. To ensure the continuity of the production operations, equipment has to run in an optimal condition to produce required output with high level of quality. In this condition, the role of reliability comes to play. According to (Pham, 2003) reliability can be defined in two terms, the traditional one is the binary which a system and its components are allowed to take only two

possible states, either working or failure. The other term is the multi-state which has more than two possible states, these are completely working, partially working or failed, and completely failed. Reliability, which is the consistency of component performance over time or the average time within its tolerated time (Slack & Chambers, 2007), is one of the elements within the concept of quality beside functionality (how well the product or service does its job, it's calculated by performance and features), appearance (sensory characteristics of components, such as appeal, look, feel, sound, smell), durability (total useful life), recovery (the ease with which problems can be rectified or resolved), and contact (nature of the person-to-person contact might take place).

Most important strategies and management technique related to reliability are maintenance strategies, determination of component condition, asset simulation, statistical fault analysis & statistical asset management approach (distribution), life management (transmission) (Schneider et al., 2005). (Ben-Daya et al., 2009) Maintenance is a function of the management process. A leader must have influence on planning (setting performance objective, make decision on how to achieve them), organizing (setting tasks, resource allocation, coordinating activities), implementing (executing the plans to meet performance objective), and controlling (measuring performance of equipment and taking preventive and corrective to restore specifications). The purpose and responsibility of maintenance are (1) keeping assets in good condition (2) perform all maintenance activities including preventive, predictive, corrective, overhauls, design modification, and emergency maintenance (3) conserve and control spare parts and material (4) commission new plants and its expansions (5) operate utilities and conserve energy.

According to (Nakajima, 1988), TPM is a combination of American Preventive Maintenance and Japanese Total Quality Management (TQM) and Total Employee Involvement (TEI). TPM is used and proved by industries to improve the maintenance activity performance in competitive environment. It is one of the components of World Class Manufacturing beside TQM, TEI, and Just-in-Time (JIT). Companies have benefitted with improved operation and maintenance system in terms of delivery, reliability, cost, quality, and flexibility (Alseiari & Farrell, 2020). TPM integrate organizational culture, process, and technology. It involves everybody in the organization from top to bottom, emphasis to implement its method while the production is still running, and promotes autonomous maintenance (repair, clean, and grease).

2. Literature Review

2.1. Reliability

Reliability is the probability that a machine part or product will function properly for a specified time under stated duration (Heizer et al., 2020). There are two tactics of reliability, these are (1) improving individual components (2) providing redundancy. According to (Kececioglu, 2002) reliability is the probability that parts, components, products, or system will perform their designed-for functions without failure in specified environments for desired periods at a given confidence level. It is the best quantitative measure of the integrity of a designed part, component, product, or system. Reliability is very important because, the survived companies will be those who know and are able to control reliability, the higher the complexity of a system (increased components) the lower the reliability will be, customers are becoming aware of reliability, and companies advertise and compete the reliability of their products. (Ben-Daya et al., 2009) Every item degrades with age and usage and ultimately fails. Failures occur in an uncertain manner and are influenced by factors such as design, manufacture (or construction), maintenance, and

operation. The reliability of an item is the probability that it will perform its intended function for a specified time period when operating under normal (or stated) environmental conditions.

2.2. Maintenance

(Heizer et al., 2020) There are two types of maintenance, (1) preventive maintenance (2) breakdown maintenance. Preventive maintenance. Preventive maintenance involves equipment monitoring, routine inspections, and servicing to reduce system variability, find potential failures, and repair of make changes that will maintain efficient processes. On the other hand, breakdown maintenance occurs when equipment fails and must be repaired incidentally or in an emergency situation, outside the planned preventive maintenance. Maintenance has two tactics, these are (1) preventive maintenance implementation (2) increasing repair capabilities.

The implementation of preventive maintenance can reduce maintenance cost if it is done effectively. There are two conditions of this situation. The first one is when the company decreases the preventive maintenance cost so that there must be more breakdown maintenance which will cost higher. The second condition is when the company increases its preventive maintenance which will decrease breakdowns, will also increase the total cost of maintenance because the lower cost of breakdown maintenance is less than the increase of the preventive maintenance. Maintenance Manager must decide the maintenance strategy wisely according to the situation to gain the optimal cost of maintenance.

According to (Schneider et al., 2005) maintenance strategy can be divided into different approaches based on maintenance cost and asset availability (Table 1). The core variables of maintenance are asset condition and asset importance.

Table 1. Maintenance approaches

<table>
<tr><td rowspan="3">Condition</td><td>Considered</td><td>CBM
(Condition Based Maintenance)
based on continuous monitoring or when required</td><td>RCM
(Reliability Centered Maintenance)
Based on priority list, failure effect, risk management</td></tr>
<tr><td>Not Considered</td><td>CM
(Corrective Maintenance)
No inspection and until breakdown</td><td>TBM
(Time Based Maintenance)
Fixed time based</td></tr>
<tr><td colspan="2"></td><td>Not Considered</td><td>Considered</td></tr>
<tr><td colspan="2"></td><td colspan="2">Importance</td></tr>
</table>

Corrective maintenance (CM) is considered the simplest form of maintenance strategy because it waits until component or asset fails or breakdown, then it is decided whether the component can be repaired or must be replaced. Preventive maintenance (PM) is required to prevent failures, significant damage, and even the destruction of equipment. Time based maintenance (TBM) is the easiest PM strategy because it only depends on the fixed time or by an interval (routines). The interval usually derived from the manufacturer's manual book of the component, past contractors, or other considerations based on technical or budgetary concern. Condition based maintenance (CBM) or predictive maintenance is triggered when component's conditions has reached certain threshold. While CBM only consider the conditions of the

component, reliability centered maintenance (RCM) also consider the rank and priority of the components.

Based on (Ben-Daya et al., 2009), there are four programs that can improve maintenance control,

- Emergency maintenance

  Emergency maintenance must be attended immediately, however it should not exceed 10% of the total maintenance work and organization must have a clear policy for handling emergency maintenance. There are two approach for carrying out the emergency maintenance : (1) Preempt the regular schedule and perform emergency maintenance and then finish backlog with overtime, temporary workers, or outsourcing. This approach will increase the workforce utilization (2) Assign 10-15% load capacity to do emergency maintenance with dedicated crafts. This approach offers the quick response ability.
- Reliability improvement

  Reliability of equipment can be improved with two techniques, (1) Calculate and store mean time between failure (MTBF) historical data of equipment. The longer the MTBF, the least the maintenance (2) Utilize the reliability centered maintenance (RCM) that has a concept of restoring equipment function rather than bringing the equipment to an ideal condition. RCM method has successfully implemented in industries.
- Total productive maintenance

  The purpose of total productive maintenance (TPM) is to increase overall equipment effectiveness (OEE) by reducing the six major cause of equipment losses according to (Nakajima, 1988) : (1) Failure, (2) Set-up and adjustments, (3) Idling and minor stoppage, (4) Reduced speed, (5) Process defects, (6) Reduced yield. TPM empowers operators and uses multi-skilled crafts to minimize response time and perform productive maintenance and it is expected to improve maintenance effectiveness and control.
- Computerized maintenance management

  It is the use of information technology to implement computerized maintenance management system (CMMS). CMMS can be integrated with enterprise resource planning (ERP) to cope the maintenance program with the availability of organization resources. Training for CMMS users is required to gain the effectiveness of the system used.

2.3. Total Productive Maintenance (TPM)

The definitions of TPM are an innovative approach to optimize equipment effectiveness, eliminates breakdown, promotes autonomous maintenance; a partnership of maintenance and production function to improve product quality, reduce waste, reduce the cost of manufacturing, increase equipment availability, and improve organization's state of maintenance; and a maintenance improvement strategy that involves all employee from top management to line employees and all departments such as maintenance, operations, design engineering, project engineering, inventory, purchasing, accounting finances, and plant management

The focus of TPM (Nakajima, 1988) are (1) Maximize overall equipment efficiency, (2) Establish total preventive maintenance (PM) system for the entire life of equipment, (3) All sector, departments, and employee involvement, (4) Provide mechanisms for realizing "zero accidents, zero defects, and zero failures" of production system, (5) Utilize small group activities to achieve zero losses.

The three ultimate goals of TPM are (1) zero defect, (2) zero accidents, and (3) zero breakdown. It is classified in six categories (Alseiari & Farrell, 2020) including productivity (P), quality (Q), cost

(C), delivery (D), safety (S), and morale (M). (Nakajima, 1988) propose unique eight pillars (basic principal) of TPM which covers excellent planning, organizing, and controlling practices. The eight pillars methodology of TPM (Ben-Daya et al., 2009) are autonomous maintenance, focused improvement, planned maintenance, quality maintenance, education and training, safety, health, and environment, office TPM or Support System (Borris & Steven, 2006), development management or early management (Suzuki, 1994) while 5S as the foundation, as described in (Table 2)

Table 2. TPM Pillars

TPM							
Autonomous Maintenance	Focused Maintenance	Planned Maintenance	Quality Maintenance	Education and Training	Safety Health and Environment	Office TPM / Support System	Development Management / Early Management
5S							

As described in (Borris & Steven, 2006), 5S is a foundation organizational tool that is used to declutter work areas, improve production support, consider minor production layout, and solve productivity issues. It represent Seiri, Seiton, Seiso, Seiketsu, Shitsuke. Every word has equivalent meaning that represent safe, clean, and organized workspace, described in (Table 3)

Table 3. 5S Activities

Seiri	**Seiton**	**Seiso**	**Seiketsu**	**Shitsuke**
Organize	Set	Scrub	Standardize	Sustain
Systemize	Systemize	Sweep	Regulate	Embed
Simplify	Neatness	Clean	Site-Wide	Self-Discipline
Sort	Set in Order	Shine	Standardization	Discipline

This eight pillar methodology will improve maintenance and organization that associated with each pillar , as follows (Table 4)

Table 4. TPM Pillars Improvements

Autonomous maintenance	Preserving operator skills, fostering operator ownership, perform cleaning, lubricating, tightening, adjustment, inspection, readjustment for production equipment
Focused maintenance	Systematic identification and eliminate losses, mitigation through FMEA analysis, achieve system efficiency, improve OEE
Planned maintenance	Efficient and effective preventive maintenance (PM), predictive maintenance (PdM), and time-based maintenance (TBM) over equipment life cycle, improve mean time between failure (MTBF) and mean time to repair (MTTR)
Quality maintenance	Achieve zero defects, track equipment problems and root cause, setting 3M (machine, man, material) conditions
Education and training	Increase technological, quality control, and interpersonal skills, assign multi skill to employee to gain flexibility and achieve company goals, periodic skill evaluation
Safety health and environment	Ensure safe and appropriate working environment, eliminate incident and accident, provide standard operating procedures
Office TPM	Improve synergy between business functions, eliminate ineffective procedures, apply the concept of 5S in office and working areas
Development management	Minimize problems and time for new equipment setup, gain knowledge of existing system for new system, maintenance improvement initiatives

Failure mode and effect analysis (FMEA) is a design tool to study and analyze the reliability of generation system. It provide a mean to compare, from a risk point of view, alternate machine configuration. It is a subjective analysis for the systematic identification of possible root cause and failure modes (RCFA) and the estimation of their relative risk. The purpose of FMEA is to identify and limit or avoid risk within design (Arabian-Hoseynabadi et al., n.d.)

FMEA begins with analysis of the system architecture, characteristic, and function. Then, all potential failure modes of the object will be analyzed and listed based on the cause, impact consequences, and existing control (Wu et al., 2021). The evaluation criteria of the failure mode are severity (S), occurrence (O), and detection (D), and then they become risk priority number (RPN) which is S x O x D. System with frequent failure or breakdown may lead to be carried out RCFA to find the root cause of the problem.

Root Cause Failure Analysis (RCFA) is one of the basic reliability enhancement method because of ease of use and many companies already implement it. RCFA is a process for identifying the true root cause of a particular failure and using that information to set a course for corrective/preventive maintenance. It is a form of continuous improvement in the reliability management, allowing equipment to experience failure twice (Campbell et al., 2011). To implement RCFA successfully, there are 5 critical factors to consider (Hussin et al., 2016) : management support, resources, data and information, technical factors, and failure data management system (database).

However, TPM is not a quick fix strategy for manufacturing problems. It is a long-term process to be implemented successfully. Usually organizations need two to three years of optimal implementation and establishment accompanied with teamwork approaches from shop floor operators to senior managers (Alseiari & Farrell, 2020). There is no single-right method for implementing TPM program, but it is adapted for every company problems and environment. One that certain is that a structured implementation process is a success factor to TPM implementation. According to (Ben-Daya et al., 2009), there is an ideal TPM methodology as a roadmap to implement in company or organization. It consist of three main phase, (phase 1) Introduction, (phase 2) TPM Initiative implementation, and (phase 3) Standardization, as described in (Table 5)

Table 5. Ideal TPM Methodology

Phase 1 : Introduction Phase	
Top management commitment	Management must lay out procedures that holistically implemented in organization and review its progress to ensure successful TPM implementation. Periodic of amendments may be necessary to ensure effective implementation of TPM programs
Managing successful organizational cultural transformation	Management has to make a radical change of organization culture and people mindset that correspondent to TPM. This can be done by creating favorable policies and reward system, build sense of operator ownership, and conducting training and education.
Employee empowerment	Total employee involvement is a prerequisite for TPM implementation. This can lead to greater acceptance of decisions, commitment to improvement ideas, understanding of objectives, team identity, cooperation and coordination, conflict resolution, employee empowerment and training, knowledge sharing, and employee participation and ownership.
Continuous improvement and Kaizen	Organization must train, motivate employee and build culture towards continuous improvements (inventory reduction, setup time, housekeeping and cleanliness, safety and hygiene, equipment for improvements, autonomous check for abnormalities, and deployment of visual control at workplace)

Training and multi-skilling for TPM	It is the management's responsibility to identify training needs and targets, make appropriate training plan and schedule, design training programs and material, and evaluate training effectiveness. The first-line maintenance crew and supervisors should be provided with state-of-the art technical skills and competencies such as technical knowledge of crafts, preventive maintenance methods, maintenance scheduling methods, and tools for planning and estimating maintenance work requirements.
Inculcate teamworking culture	The important structure of TPM is cross functional team (CFT) that may consist of maintenance division, R & D, process planning, production, and engineering that produce wide range of problem breakdown and improve equipment availability and reduced maintenance cost. There are two key team in TPM activities, they are maintainability improvement (make equipment easy to maintain) and maintenance prevention.
Computerized maintenance management system (CMMS)	An IT system that can assist planning and scheduling work orders, expediting dispatch of breakdown calls, managing overall, managing overall maintenance workload, tracking maintenance activities, costs, equipment failures, inventory control systems, and asset management capabilities. CMMS must able to record historical maintenance data to support decision system regarding to maintenance activity.
Visual workplace	Visual workspace is a method to facilitate the ease of equipment maintenance, such as marking the proper gauges, temperature indicator, lubrication point label, label the lubrication types, vibration monitoring tool, red and green zone for gauges, label electronic wiring, etc.
Phase 2 : TPM Initiatives Implementation Phase	
Autonomous maintenance	First line maintenance which is executed by operator with scope of cleaning, lubrication, tightening, adjustment, inspection, and re-adjustment (C-L-T-A-I-R)
Focused improvement	Focus on eliminating losses by identification, classification (production equipment related, manpower related, cost related) and elimination
Planned maintenance	The development of maintenance programs
Quality Maintenance	Overcoming deficiencies in quality system to achieve defect free product, setting conditions for zero defects, maintaining optimal machine and tooling conditions, maintaining equipment operation performance within standard ranges, inspecting and measuring conditions in time series, preventing occurrence of defects by periodic measurements and verification of standards, predicting possibility of quality defects by reviewing measured values, and taking counter measures in advance.
Office TPM	Realizing zero functional loss, organizing high efficiency offices and rendering service, and support to production departments by focusing on effective workplace organization and standardized work procedures.
Safety, health, and environment	The necessary steps to eliminate unsafe practices and conditions such as replace missing belts, fire control, slippery floor, the use of safety equipment (glasses, gloves, belt, etc.), and etc., and increase employees awareness of them.
Development management	Development management initiatives facilitate the organization to reduce dramatically the time from initial development to full-scale production and achieve vertical startup through maintenance prevention (MP) and early product management in development of new products.
Tool management	Ensure that tools are available for execute maintenance activities to reduce downtime of equipment and reduce tool consumption cost.
Maintenance benchmarking	The study of best practice maintenance implementation and key performance indicators.
Phase 3 : Standardization Phase	
Deploy key performance indicators for addressing manufacturing performance	Organization must deploy key performance indicators (KPI) as objectives to measure parameters of TPM metrics and demonstrate a real contribution to manufacturing effectiveness.
Deploy lean manufacturing practices	Deploy lean manufacturing practices along with TPM, such as JIT, TQM, Continuous flow manufacturing, cellular manufacturing, benchmarking, levelled manufacturing and reverse

	engineering. However, too many strategies at the beginning may lead to confusion and dilution.
Sustain TPM initiatives	Activities that ensure TPM is regarded as a change process rather than a project, which is continuously anchored and improved by employees. Assessments and audit must be conducted periodically to ensure the effectiveness of TPM implementation.

Beside successful implementation, there are cases where TPM implementation fails. (Ben-Daya et al., 2009) and (Alseiari & Farrell, 2020) state that there are barriers in implementing TPM. These obstacle classified as organizational, managerial, educational, cultural, behavioral, technological and communicational, operational, financial obstacle, departmental, and auditing.

There are also several success factor in implementing TPM in organizations (Ahuja & Khamba, 2008) : managements support to drive continuous improvement in team environment, effective communication, worker empowerment in decision, acceptance of ideas, frequent feedback, education investment to empower workforce, deployment on effective CMMS, maintenance performance evaluation approach based on a quality audit and quantifiable maintenance performance indicators, the organization determination to implement TPM consistently, make a structured approach and its effectiveness measurement, use of mathematical modelling (MTTS-MTTR), discipline planning of maintenance task with scheduling compliance, establish company strategy and basis of competition, and investment of human resources development.

3. Research Methodology

The current study aims to gain the theoretical understanding on how to improve the reliability of asset/equipment to gain the maximum production quality of manufacturing company. Reliability is the main representation of the equipment performance. To maintain the reliability, company must have various maintenance concept and activities. The maintenance activity has to be well defined and planned as a company strategy and culture. Total productive maintenance (TPM) is chosen as a maintenance framework and strategy which increase equipment effectiveness with the support of all employee from all functional division. Further, books and journal which are related to reliability, maintenance, and TPM are identified and reviewed to gain the knowledge especially on how TPM implementation is done in manufacturing organization which can organize maintenance activities to improve the equipment reliability. It also find the barriers and success factor of TPM implementation.

4. Result

From the identification and review of the literatures, maintenance is the key to keep the equipment up and running with the desired and optimal efficiency, that is known as reliability. There are various techniques to measure reliability, such as mean time between repair (MTBR), overall equipment effectiveness (OEE), failure mode effect analysis (FMEA), and root cause failure analysis (RCFA).

In the perspective of maintenance, which is the most important aspect of reliability, has two main category : preventive and breakdown maintenance. Preventive maintenance have types depend on its planning. Breakdown maintenance can also be defined as corrective maintenance, because it doesn't require planning and occur in emergency situation when equipment suddenly breakdown. It is a form of firefighting technique which has to be executed immediately to restore the production operation. Preventive maintenance requires well-prepared planning based on the

historical data of the equipment or the manual guide of the manufacturer. There are three types of preventive maintenance. The first one is condition based maintenance which utilize monitoring sensors of equipment, such as vibration, temperature, and humidity, as the basis of the executed maintenance. It monitor the condition of equipment whether it exceed or below the accepted threshold. The second one is reliability centered maintenance which is based on equipment importance priority list, failure effects, and risk assessment. The last one is time based maintenance or routine maintenance which is a fixed time maintenance. This maintenance is done periodically whether it occurs every ten years, five years, annual, monthly, or daily. Total equipment Overhaul and inspection can be the example of time based maintenance.

Total productive maintenance (TPM) formulate the maintenance function from the strategic perspective to the shop floor technical aspects. The main goal of TPM is to achieve zero defect, zero accidents, and zero breakdown with the focus of maximize OEE, maintenance system for the entire equipment lifecycle, and total employee involvement (cross functional teams). TPM has eight pillars of main activities, which are autonomous maintenance, focused improvement, planned maintenance, quality maintenance, education and training, safety, health, and environment, office TPM or support System, and development management or early management with the support of 5S method to ensure safe, clean, and organized workspace. To implement TPM in organization, there is a three phase of effective TPM implementation. The phase begins with introduction which focus on commitments, cultural transformation, improvement, training, cross functional teams forming, CMMS readiness, and visual workspace. The next phase is initiatives implementation which realize the eight pillars of TPM practices. The final phase is standardization which is an effort to anchor and maintain the TPM and expand its capabilities with other maintenance concepts.

5. Discussion

The literature provides a logical correlation between reliability improvement and maintenance activities. Total productive maintenance will help company strategize the maintenance function to improve equipment reliability. The clear and concise TPM goals and steps of implementation makes this framework and concept is theoretically applicable to any manufacturing organizations which need improvement and remain competitive. Barriers and success factor of TPM can be used as a warning and guidance for companies in the early intention of TPM implementation.

6. Conclusion

The scope of reliability is not only its technical aspect or isolated only in the shop floor section of the manufacture organization. It is the responsibility of all functional department and involves human resource capabilities. Total productive maintenance (TPM) covers all of the maintenance concept and its supporting administrative aspects and provide logical and simple practices which help organization in implementing it to improve equipment performance. However, TPM is a long process of development and companies should identify and analyze both barriers and success factors to ensure a comprehensive TPM implementation that improve the reliability of equipment.

This study requires future empirical and phenomenal research to prove the concept of TPM implementation in improving equipment reliability or to assess companies which have already used TPM as their maintenance framework and organization strategy.

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