

# Saurav

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### Executive summary:

This project aims to integrate the core principles of the **Industry 5.0** into **Total Productive Maintenance (TPM)** to elevate operational efficiency and equipment reliability. By embedding **advanced technologies such as** an **Artificial Intelligence (AI)** and the **Internet of Things (IoT)** within the TPM framework, the initiative seeks to enable **predictive maintenance, smarter resource utilization**, and the culture of **continuous improvement**.

In today's fast-changing industrial environment, **achieving sustainable operational excellence** has become a strategic imperative rather than a choice. With the rise of Industry 5.0—emphasizing **human-centricity, sustainability, and resilience** organizations must go beyond the digital transformation of Industry 4.0. This project explores the **synergistic alignment** of **Operational Excellence, Industry 5.0, and TPM** as an integrated approach to **boost performance, minimize inefficiencies, empower human talent, and drive productivity growth**

### Objective:

- To assess how **Industry 5.0** principles can be integrated into existing manufacturing operations to foster human-machine collaboration and sustainable production.
- To analyse the role of **Total Productive Maintenance (TPM)** as a foundational pillar of operational excellence.
- To develop a practical framework and identify success factors that contribute to measurable improvements in productivity, equipment reliability, and employee engagement

### Method-ology:

This study employed a mixed method re-search approach, combining:

- **Literature Review:** A comprehensive review of research articles, industry whitepapers, and case studies from sources such as Springer, McKinsey, and the World Economic Forum.
- **Case Study Analysis:** In-depth examination of leading manufacturing firms that implemented Industry 5.0 principles alongside TPM and Lean Six Sigma.
- **Data Collection:** Quantitative data from equipment downtime, OEE (Overall Equipment Effectiveness), and maintenance KPIs, along with qualitative insights gathered through interviews with plant managers and maintenance teams.

- **Mathematical Modeling:** A supply chain and TPM model was used to simulate the impact of proactive maintenance on operational performance.
- **Flow Chart Mapping:** Process flow mapping to visualize current and future state workflows under TPM and the Industry 5.0 integration.

## Key Findings:

### Industry 5.0 and Human Machine Collaboration

- Industry 5.0 emphasizes human -centric approaches—enabling skilled workers to collaborate with the smart machines and robots.
- Organizations that invested in cobots (collaborative- robots) and digital twins achieved up to 20% higher flexibility and reduction in changeover times.

### Total Productive Maintenance (TPM) and Equipment Reliability

- **Implementation of TPM led to a significant reduction in** unplanned downtime (average 30-40%) and improvement in OEE by 15-25%.
- Autonomous maintenance by operators increased ownership and led to better equipment condition monitoring.

### Digital Integration and Data-Driven Decisions

- Companies leveraging real-time analytics, RFID, and IoT sensors for predictive maintenance achieved better maintenance planning and avoided costly breakdowns.
- The use of AI-based failure detection systems helped in early fault diagnosis and reduced corrective maintenance effort.

### Cultural and Organizational Shift

- Successful organizations fostered a Kaizen-based culture with continuous improvement circles and cross-functional collaboration.
- Training and employee empowerment were key in sustaining TPM initiatives and integrating new digital technologies.

## Recommendations

Based on the findings, the following key recommendations are proposed:

1. Adopt a Hybrid Operational Excellence Model:
  - Combine Lean, TPM, and Industry 5.0 strategies to optimize both human and technological capabilities.

- Invest in AI and IoT-based predictive maintenance platforms for real-time monitoring and analytics.
  - Integrate digital twins for simulation and diagnostics of asset performance.
3. Develop Human-Centric Workflows:
- Redesign operations to empower employees through training, autonomous decision-making, and digital tools.
  - Establish Kaizen circles and cross-functional teams focused on operational excellence.
4. Establish KPI and TPM Dashboards:
- Monitor performance through OEE, **M T T R (Mean Time to Repair)**, **M T B F (Mean Time Between Failures)**, and other TPM metrics.
  - Use visualization tools for data transparency and team-based reviews.
2. Foster a Culture of Continuous Improvement:
- Encourage innovation at shop floor-level by rewarding small improvements and involving everyone in improvement efforts.
  - Regularly audit processes to ensure alignment with long-term operational goals.

## CHAPTER 1 INTRODUCTION

### 1.1 Introduction

In the modern industrial era, a pursuit of **operational excellence** has become a strategic imperative for organizations seeking to enhance efficiency, reduce downtime, and maintain long-term competitive advantage. At the heart of this evolution lies **Industry 5.0**—a forward-thinking paradigm that blends cutting-edge digital technologies with strong emphasis on human-centered innovation. An alignment with this shift, **Total Productive Maintenance (TPM)** serves as a vital strategic tool, evolving beyond conventional maintenance practices to foster the culture grounded in continuous improvement, workforce empowerment, and system reliability.

First developed in Japan, TPM has earned widespread global adoption as a foundational element of **Lean and Smart Manufacturing**. It promotes a comprehensive and anticipatory approach to asset management, emphasizing collaborative engagement across departments to drive operational improvements. Built on the principle that every employee—regardless of role—plays a part in maintaining equipment performance, TPM strives to maximize **Overall Equipment Effectiveness (OEE)** by enhancing availability, performance, and product quality.

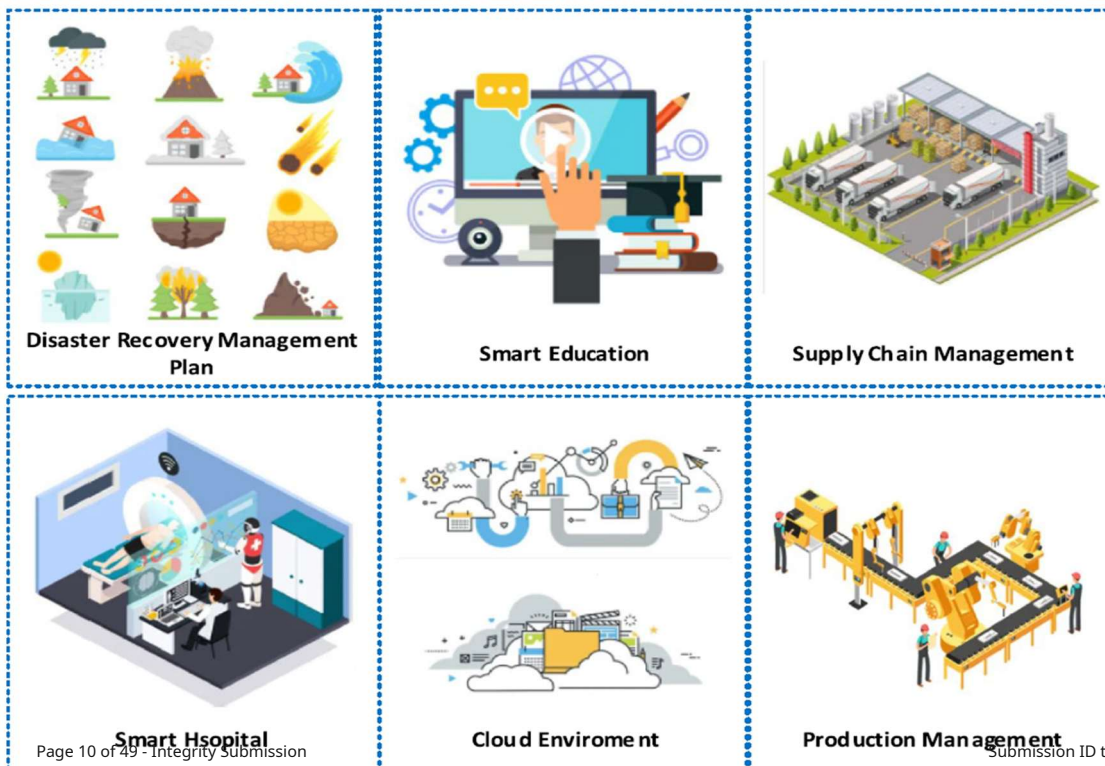
A core tenet of the TPM aligns closely with the human-machine synergy that defines Industry 5.0. By encouraging shared ownership, accountability, and proactive involvement across all organizational levels—from shop floor workers to senior leadership—TPM bridges the divide between maintenance and production. It empowers frontline teams through **autonomous maintenance**, **problem-solving capabilities**, and **ongoing skill development**, all of which are integral to achieving operational excellence.

A defining component of TPM is its structured approach to eliminating the **six key losses** in manufacturing: unplanned equipment downtime, set up and adjustments delays, minor stoppages, reduced operational speed, production defects, and yield losses. Systematically addressing these inefficiencies leads to significant improvements in OEE and supports a more resilient and agile manufacturing environment.

in to this new paradigm is crucial for building **human-centric, adaptive, and technologically integrated operations**. The success of TPM initiatives, however, hinges on the capabilities and commitment of the workforce. In this context, **skill development and competency enhancement** become critical factors, highlighting the importance of assessing how employee expertise influences the effectiveness of TPM deployment within an Industry 5.0 framework.

This approach calls for a focused investigation into how workforce skill levels affect the success and the sustainability of TPM practices in Industry 5.0-driven environments.

This study examines the **interrelationship between workforce proficiency and the effectiveness of Total Productive Maintenance (TPM)**, providing practical insights into areas such as employee training, human machine collaboration, and the advancement of intelligent, autonomous systems. By aligning TPM with the guiding principles of **Industry 5.0**, organizations do foster greater **resilience, flexibility, and innovation** within their operational strategies. This integrated approach not only strengthens the foundation for **long-term operational excellence** but also ensures that technological advancement is effectively supported by human capability and engagement.



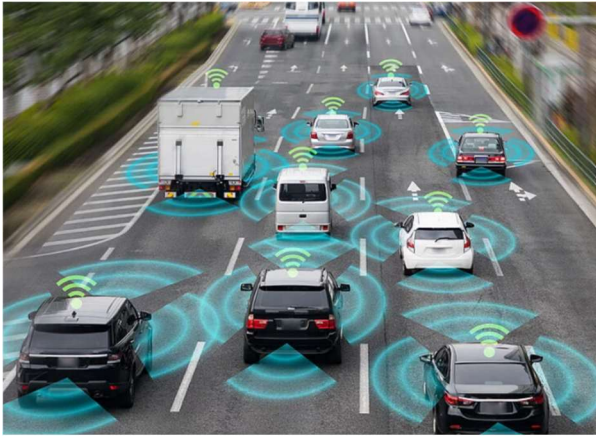


Figure 1b Applications of Industry 5.0

## 1.2 Define the key terms and concepts:

### Skills:

**Skills** are defined as the combination of abilities, knowledge, and expertise that empower individuals to carry out tasks, resolve issues, and accomplish defined goals. Within the framework of **Industry 5.0**, **Operational Excellence**, and **Total Productive Maintenance (TPM)**, skills extend beyond basic technical know-how to include critical **problem-solving abilities**, **effective communication**, and other competencies essential for the efficient operation, monitoring, and maintenance of industrial systems. These multidimensional skill sets are pivotal in enabling a workforce to adapt to advanced technologies and contribute meaningfully to performance improvement initiatives

### 1. Industry 5.0 Integration:

#### Leveraging Industry 5.0 Technologies in TPM

##### 1. Predictive Insights through Data Analytics and AI:

Advanced data analytics and artificial intelligence play the vital role in forecasting equipment malfunctions, fine-tuning maintenance routines, and pinpointing inefficiencies. These technologies support data-driven strategies that minimize downtime and enhance the overall performance of maintenance operations.

##### 2. Real-Time Monitoring with IoT Sensors:

Installing IoT-enabled sensors on critical machinery allows for the continuous capture of operational metrics such as temperature, vibration, and performance levels. This realtime data empowers organizations to shift from reactive to **predictive maintenance**, facilitating early detection of anomalies and faster resolution of potential issues.

##### 3. Enhancing Efficiency through Automation and Robotics:

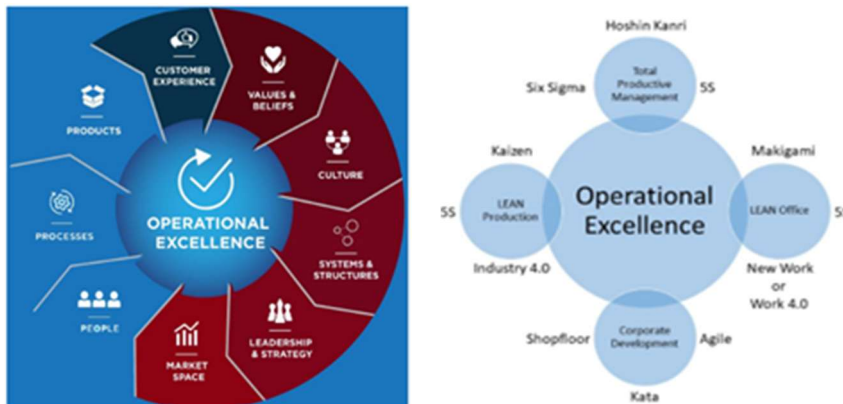
The integration of robotic systems and automation tools can streamline routine maintenance tasks—such as inspections, lubrication, and minor repairs. By reducing human error and handling repetitive work, these technologies free up skilled personnel to focus on strategic, value-added activities.



**2. Operational Excellence:**

**Continuous Improvement:**

Establish a continuous improvement culture by the regularly evaluating performance, identifying areas for optimization, and implementing solutions.



**Figure 1d Operation Excellence**

**Overall Equipment Effectiveness (OEE):**

Use OEE as key performance indicator (KPI) to track equipment performance and identify areas for improvement.

**Cost Reduction:**

Implement TPM and Industry 5.0 technologies to reduce the maintenance costs, minimize downtime, and improve the overall efficiency.

**Safety Enhancement:**

Utilize Industry 5.0 technologies to create a safer work environment by reducing the risk of accidents and injuries.

**Quality Improvement:**

Implement TPM and Industry 5.0 technologies to reduce defects, improve product quality, and

### 3. Total Productive Maintenance (TPM):

**Total Productive Maintenance (TPM)** is a holistic maintenance strategy that originated in Japan, aimed at maximizing the operational efficiency of the equipment by engaging the entire organization in maintenance-related activities. Rather than relying solely on reactive approaches, TPM emphasizes **proactive** and **preventive maintenance**, fostering a culture of employee ownership, cross-functional collaboration, and ongoing improvement. Its primary objective is to **eliminate operational losses** and significantly enhance **Overall Equipment Effectiveness (OEE)** by addressing factors such as availability, performance, and quality.

#### I) TPM Effectiveness:

**Effectiveness of Total Productive Maintenance (TPM)** reflects how well its strategies translate into measurable performance improvements. It involves evaluating the impact of TPM initiatives on critical operational metrics such as **increased equipment availability**, **reduced unplanned downtime**, **higher productivity**, and **improved product quality**. These improvements are often benchmarked against international standards to gauge the overall success and competitiveness of TPM implementation within an industrial setting.

#### II) TPM Factors:

The factors that contribute to the success and effectiveness of the Total Productive Maintenance (TPM) encompass a range of key elements, including but not limited to autonomous maintenance, planned maintenance, focused improvement, skills development, early equipment management, and safety. Each of these factors plays a crucial role in advancing overall objectives of TPM. Understanding these components is fundamental when evaluating how skills impact the effectiveness of selected TPM factors. For a comprehensive and accurate assessment, it is important to consult authoritative sources and relevant scholarly literature within the specific context of this research.

### 1.3 Background

The effective functioning of industrial machinery and equipment is crucial for achieving optimal production output, minimizing downtime, and ensuring overall operational efficiency. In pursuit of these objectives, **Total Productive Maintenance (TPM)** has emerged as a **holistic and proactive approach to** maintenance management. Rooted in the principles of **continuous improvement and employee involvement**, TPM aims to maximize

Total Productive Maintenance (TPM) has emerged as a transformative paradigm in the realm of industrial maintenance, challenging conventional practices and promoting a holistic approach to ensure optimal performance of production equipment. Originating in Japan and gaining prominence in the latter half of the 20th century, TPM represents a departure from traditional reactive maintenance models by emphasizing proactive, preventive, and collaborative strategies.

At its core, TPM seeks to engage the entire organizational hierarchy, instilling a sense of shared responsibility for equipment maintenance. The philosophy rests on the belief that by The effective operation of industrial machinery and equipment is essential for achieving maximum production output, reducing downtime, and ensuring overall operational efficiency. To meet these objectives, Total Productive Maintenance (TPM) has emerged as a comprehensive and proactive approach to maintenance management. Rooted in principles of continuous improvement and employee engagement, TPM aims to enhance the performance and reliability of production assets.

Total Productive Maintenance (TPM) represents a modern evolution in equipment maintenance strategies, moving beyond traditional reactive methods. Originating in Japan and gaining international traction in the late 20th century, TPM promotes a proactive and inclusive approach aimed at enhancing production efficiency and equipment reliability.

Rather than assigning maintenance tasks solely to specialized technicians, TPM encourages involvement from all organizational levels. This inclusive model empowers operators, technicians, and managers alike to take shared responsibility for the upkeep and performance of machinery. The result is an environment where downtime is minimized, productivity is optimized, and waste due to stoppages or inefficiencies is significantly reduced—reflected in improved Overall Equipment Effectiveness (OEE).

The TPM framework is structured around key pillars that support its successful implementation. **Autonomous Maintenance** gives frontline workers the tools and knowledge to manage routine maintenance and early issue detection. **Planned Maintenance** introduces a structured schedule for servicing equipment, helping prevent unexpected failures. **Focused Improvement**, rooted in the Kaizen philosophy, fosters continuous progress by encouraging small, practical changes that lead to long-term gains. With the continuous advancement of industrial practices, the importance of workforce capabilities in ensuring the success of Total Productive Maintenance (TPM) is gaining growing attention. Practical technical know-how, critical thinking abilities, and a strong focus on lifelong learning are now viewed as essential elements in the effective

core TPM practices—such as operator-driven maintenance, scheduled servicing, and ongoing process enhancement—is deeply influenced by the knowledge, skill set, and adaptability of their personnel.

While the benefits of TPM are well-documented, its adoption is not without challenges. Resistance to change, insufficient understanding or commitment across various organizational levels, and the need for a cultural shift toward proactive maintenance practices are common obstacles. This highlights the importance of not only strong TPM frameworks but also a skilled workforce capable of addressing the complexities of modern industrial environments.

In light of these challenges, it becomes essential to assess how workforce skills influence the effectiveness of key **Total Productive Maintenance (TPM)** components. This evaluation seeks to explore the complex connection between employee competencies and critical performance metrics such as Overall Equipment Effectiveness (OEE), Mean Time Between Failures (MTBF), and Mean Time to Repair (MTTR). The objective is to generate meaningful insights that can guide the development of specialized training initiatives, promote a mindset of continuous enhancement, and address skill-related limitations. Through this approach, organizations can fully leverage the advantages of TPM, leading to enhanced maintenance strategies and long-term operational efficiency in today's rapidly changing industrial landscape.

### Overview of Total Productive Maintenance:

**Total Productive Maintenance** is a comprehensive and logical approach to maintenance management that goes beyond traditional practices by involving all employees in the organization. It aims to maximize the effectiveness of equipment, eliminate breakdowns, and enhance overall operational efficiency. TPM started in Japan and is often associated with the manufacturing industry, particularly in the automotive sector.

### Key Principles of TPM:

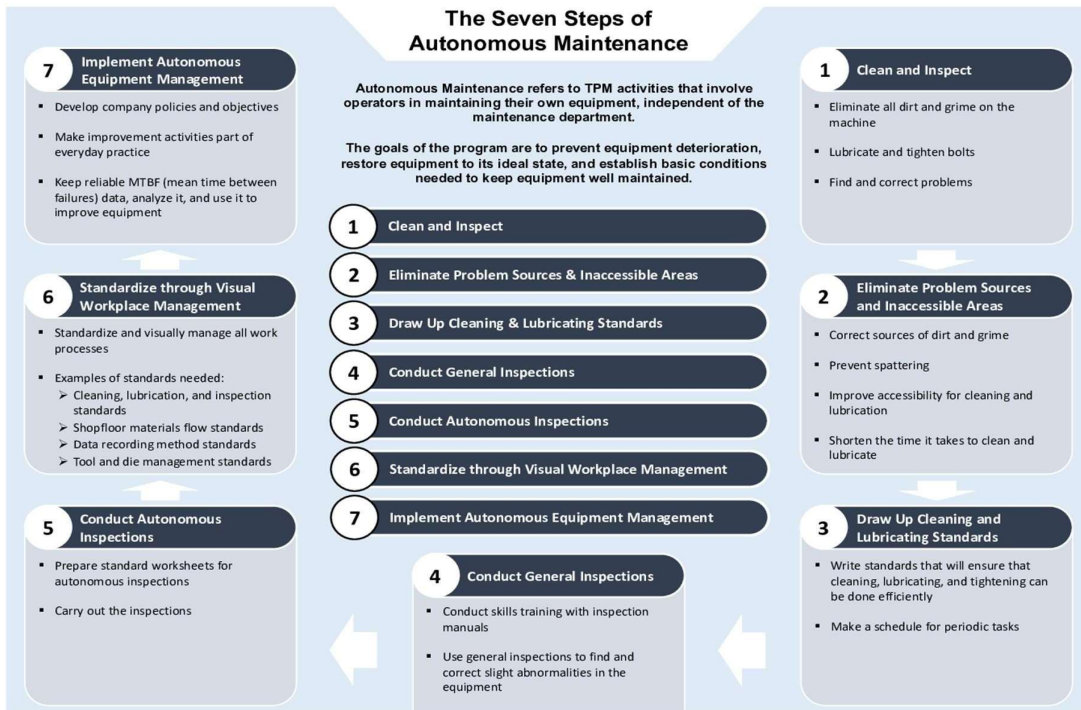
**Central Role of Workforce Engagement:** At the heart of **Total Productive Maintenance (TPM)** is the active engagement of employees across all organizational levels. TPM fosters an environment where individuals—from frontline staff to senior leadership—feel accountable for the upkeep and performance of machinery. This inclusive approach encourages a shared commitment to equipment care, transforming maintenance into a collective organizational responsibility.

**Emphasis on Preventive and Predictive Maintenance:** TPM advocates a proactive stance on equipment maintenance, emphasizing strategies designed to detect and resolve issues before they escalate into breakdowns. By implementing both preventive and predictive techniques, organizations can minimize unexpected equipment failures, boost reliability, and maintain steady production flow. This foresight-driven model supports consistent performance and long-

**The Four Main Pillars of TPM (for 1<sup>st</sup> phase):**

**1. JH (Jishu Hozen – Autonomous Maintenance):**

**Jishu Ho zen** focuses on empowering equipment operator to take charge of the routine maintenance tasks for their machines. This approach involves training operators to conduct inspections, clean equipment, and address minor issues independently. The objective is to cultivate strong sense of the ownership among operators, thereby reducing the likelihood of equipment breakdowns. By fostering a culture of self-maintenance on the shop floor, Jishu Hozen encourages proactive involvement in equipment care, which ultimately enhances the overall reliability and performance of machinery.



**Figure 2 JH (Jishu Hozen - Autonomous Maintenance)**

**2. KK (Kobetsu Kaizen – Focus Improvement):**

2 Total Productive Maintenance (TPM) is a strategy designed to enhance availability of the existing equipment, thus reducing need for additional capital investment. TPM is an integrated approach that involves the participation of everyone within the organization, from the top management to all employees, in implementing the comprehensive maintenance program for the all equipment throughout its lifecycle. This approach leads to the maximum efficiency of equipment, a cleaner and more organized workplace, and a workforce that is ethically engaged and empowered.

3 The primary objective of TPM is to assess performance factors and strengths within industrial organizations, while also evaluating the effectiveness of 5S implementation and Kobetsu Kaizen (a core TPM pillar) on organizational performance. The results of

this research were derived from a comparative evaluation of organizational performance before and after the implementation of 5S, shedding light on the positive impacts of TPM practices on operational outcomes.

Here is a table that summarizes the definition of each loss and its category:

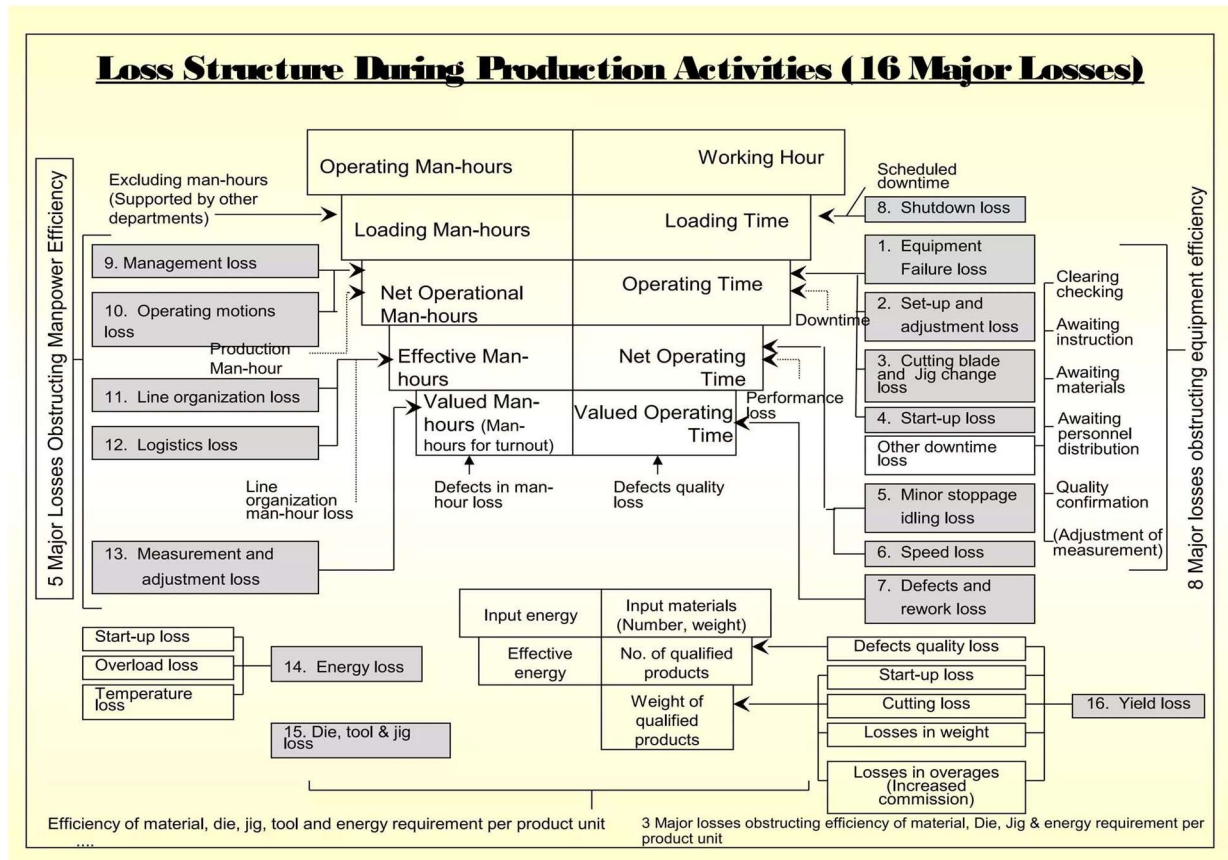


Figure 3. 16 types of loss definition

1. PM (Planned Maintenance):

Targets systematic planning and scheduling of maintenance activities, optimizing resources and minimizing downtime. Planned Maintenance is a broader pillar that encompasses systematic planning and scheduling of all maintenance activities within the organization. It goes beyond equipment-specific planning (KK) to include a comprehensive approach to managing all maintenance tasks. The emphasis is on optimizing resources, preventing unplanned downtime, and ensuring that maintenance activities align with overall organizational goals.

2. QM (Quality Maintenance):

**Quality Maintenance (QM)** integrates quality control principles directly into the maintenance process, aiming to prevent defects and ensure that the equipment operates at optimal performance levels. This pillar emphasizes importance of the maintaining equipment in a way that consistently produces high-quality products. QM involves incorporating quality checks and measures into routine maintenance activities, reducing variations in equipment performance that could negatively impact product quality. By

aligning maintenance practices with quality control standards. OM helps maintain equipment reliability and enhances the overall consistency of production outcomes.

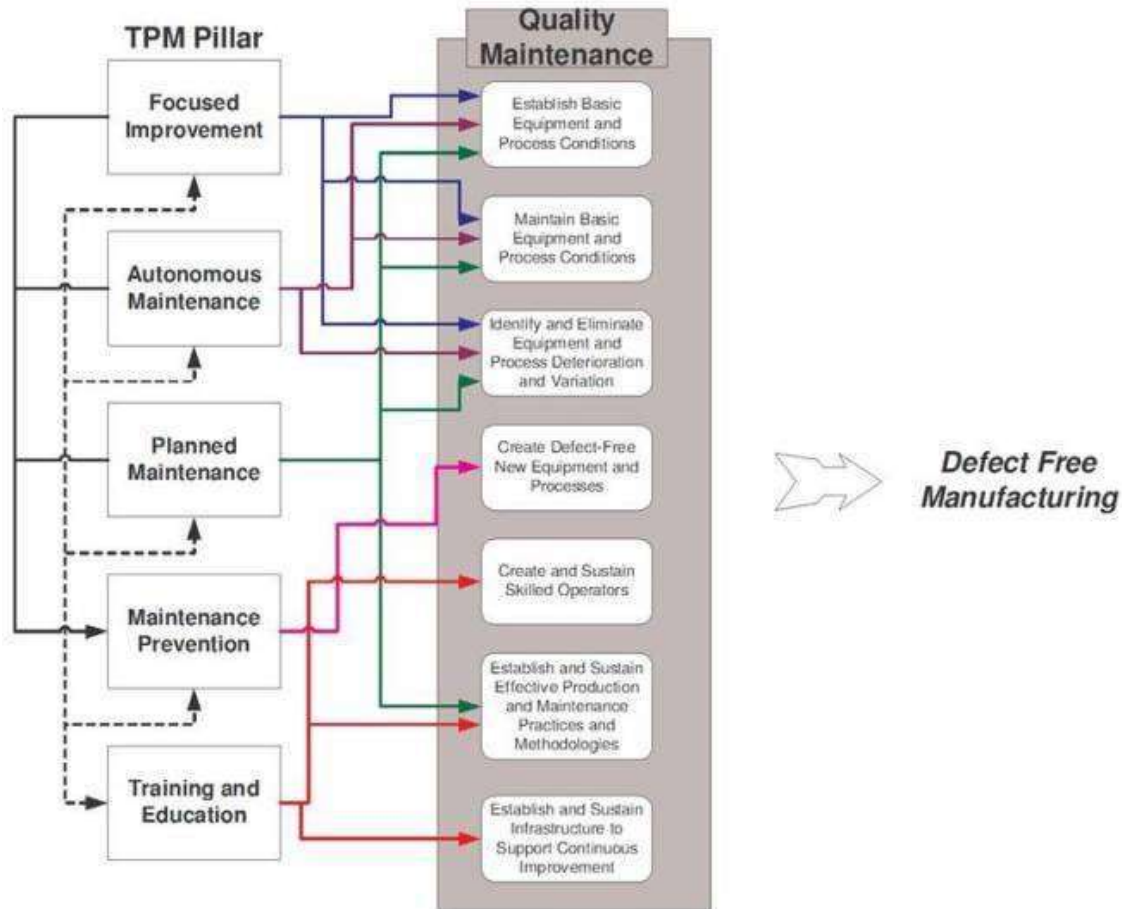


Figure 4 QM (Quality

**Maintenance)Benefits of Implementing TPM:**

- 1) **Increased Equipment Reliability:** TPM reduces breakdowns, leading to increased equipment the reliability and availability.
- 2) **Enhanced Productivity:** Improved the efficiency and reduced downtime contribute to higher overall productivity.
- 3) **Cost Savings:** Preventive maintenance and reduced breakdowns result in cost savings associated with repairs and emergency maintenance.
- 4) **Employee Engagement:** TPM fosters a sense of responsibility among employees, enhancing teamwork and collaboration.

**Kick-off Strategy for Implementing TPM in Company:**

**Step1- Assessment and Awareness:** A comprehensive evaluation of existing

the advantages of TPM.

**Step2- Training and Skill Development:** Provide training sessions to employees on TPM principles and the specific requirements of each pillar. Focus on developing the necessary skills for successful implementation.

**Step3- Pilot Project:** Begin with a pilot project to implement one or two pillars initially. This allows for the testing and the refining the approach before the full scale implementation. In the step we select the manager model machines for the initial primary target.

**Step4- Continuous Improvement:** The emphasis is the culture of the continuous improvement. Regularly a review and assess effectiveness of TPM implementation, adjusting as needed.

**Step5- Communication and Feedback:** Create transparent communication avenues for collecting input from employees, motivating them to express perspectives, difficulties, and accomplishments.

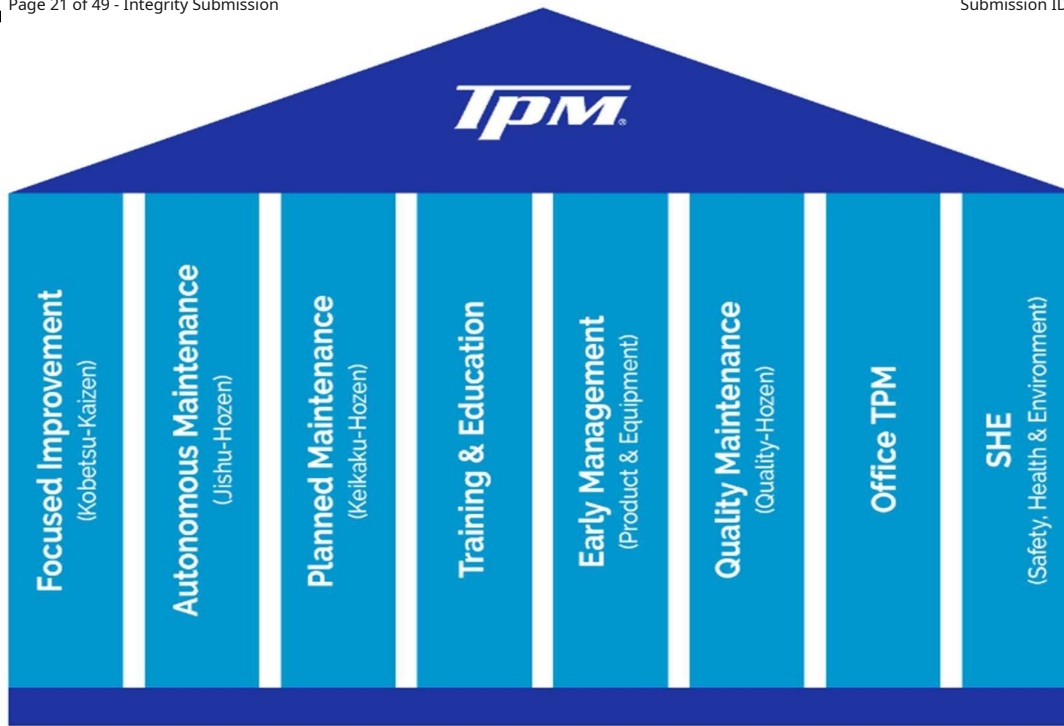
**Step6- Recognition and Rewards:** Acknowledge and reward employees for their contributions to the success of TPM implementation. Recognition boosts morale and motivates further engagement.

By adopting a systematic and phased approach, your company can successfully kick off an implementation of TPM, laying foundation for improved equipment performance and operational excellence.

## 6.2 Evolution of the Total Productive Maintenance (TPM):

Total Productive Maintenance (TPM) originated in Japan and became fundamental aspect of the (TPS) Toyota Production System, gaining widespread recognition in latter half of the 20th century. TPM introduced a shift in mindset, moving away from traditional reactive maintenance practices—where issues were addressed only after they occurred—to a more proactive and preventive approach. The core philosophy of TPM is rooted in belief that everyone in organization, from the shop floor employees to the top management, plays an critical role in the upkeep, maintenance of equipment. This collective responsibility fosters a culture of ownership, ensuring higher levels of the equipment reliability and operational efficiency. Pillars of TPM:

Success of TPM relies on the set of the foundational pillars, each addressing specific aspects of maintenance and production. These pillars include:



**Figure 5 TPM Pillars**

The eight Pillars of the Total Productive Maintenance are specific elements within broader framework to Total Quality Management that focus on optimizing equipment effectiveness and overall organizational efficiency. Here's an explanation of each pillar:

**1. Focused Improvement (Kaizen):**

Focused Improvement, often referred to as Kaizen, involves continuous improvement efforts within the organization. This pillar encourages the **employees at all the levels to identify the implement from small, the incremental improvements/ kaizen in the processes,** equipment, workflows. The main goal is to create the culture of the continuous learning and enhancement.

**2. Autonomous Maintenance:**

This pillar emphasizes empowering the equipment operators to assume responsibility for the task of routine repair tasks. Operators are well trained to conduct basic maintenance activities, inspect equipment, and address minor issues. The goal is to enhance equipment reliability, prevent breakdowns, and foster a culture of self-maintenance.

**3. Planned Maintenance:**

Planned Maintenance involves systematic, scheduled maintenance activities aimed at ensuring optimal equipment performance. This pillar focuses on reducing unplanned downtime by proactively addressing potential issues. It includes routine inspections, lubrication, and other planned maintenance tasks to keep equipment in peak condition.

Education and the Training are essential pillars for build a skills and knowledge of employees. This includes providing training on maintenance techniques, equipment operation, and the principles of TPM. Well-trained employees are better equipped to contribute to success of TPM initiatives.

#### **5. Early the Equipment Management:**

The Early- Equipment Management approach concentrates on the guaranteeing that new machinery is crafted, installed, and operated with an emphasis on dependability and effectiveness. This pillar aims to address potential issues early in to the equipment lifecycle, reducing the likelihoodof defects and optimizing performance from the outset.

#### **6. Quality Maintenance:**

Quality Maintenance integrates quality control principles into the maintenance process. The focus is on preventing the defects and ensuring that equipment operates at the highest quality standards. This QM pillar aims is the minimize variations in equipment performance that could lead to quality issues in the final product.

#### **7. TPM in Administration:**

TPM in Administration extends to TPM principles beyond the shop floor to administrative functions. This pillar focuses on optimizing administrative processes, reducing paperwork and improving communication and coordination within the organization.

Each of these pillars plays a main important role in the holistic TPM implementation, contributing to increased the equipment reliability, enhanced quality, and the overall operational excellence within an organization.

#### **8. Safety, Health and Environment:**

SHE pillar recognizes an importance of Incorporating safety, health, blending environmental the considerations into the maintenance procedures. It emphasizes creating safe working environment, ensuring the wellbeing of the employees, minimizing an environmental impact the maintenance activities.

### **6.3 Challenges in the T P M Implementation:**

By Implementing the Total Productive Maintenance (T P M) represents paradigm shift for organizations aspiring to optimize their maintenance practices and elevate operational

implementation is fraught with several challenges that organizations must navigate.

One of the primary impediments is the inherent resistance to the change. Employees and management, accustomed to the traditional reactive maintenance models, may find it challenging to embrace the proactive and collaborative principles espoused by TPM. Overcoming this resistance is essential for cultivating a culture that values preventive maintenance and continuous improvement.

A lack of understanding and awareness at various organizational levels poses another significant challenge. TPM involves a holistic approach that requires a deep comprehension of its principles and methodologies. In instances where stakeholders lack comprehensive knowledge, commitment to TPM may falter, limiting its potential impact.

Achieving a cultural shift toward a proactive maintenance mindset is a formidable task. In organizations entrenched in reactive practices, ingrained habits and established norms may resist transformation. Successfully instigating a cultural change requires concerted efforts in education, communication, and fostering a shared commitment to TPM principles. Resource constraints, both in terms of finances and manpower, can impede the smooth execution of TPM activities. Adequate resources are essential for training, implementing new maintenance practices and addressing unforeseen challenges. Limited resources may slowdown the implementation process or compromise the quality of TPM initiatives.

The level of management commitment is crucial to the success of TPM. Without strong leadership support, the prioritization of TPM as a strategic initiative may be lacking. Leadership involvement is vital for driving cultural change, securing necessary resources, and maintaining momentum throughout the implementation process.

Inadequate training and skills development represent a pivotal challenge. TPM success hinges on the competence of the workforce, and without targeted training programs, employees may lack the necessary skills for effective TPM implementation. Addressing this challenge involves investing in comprehensive training initiatives that align with TPM principles. Measuring and demonstrating tangible results poses another hurdle. Quantifying the financial benefits of TPM can be challenging, particularly when the impact is felt across various aspects of production. Establishing clear metrics and effectively communicating the benefits is crucial for sustaining enthusiasm and garnering

seamless adoption of TPM practices. Harmonizing TPM with established production and maintenance systems demands thorough planning and effective coordination to minimize disruptions and facilitate a seamless transition

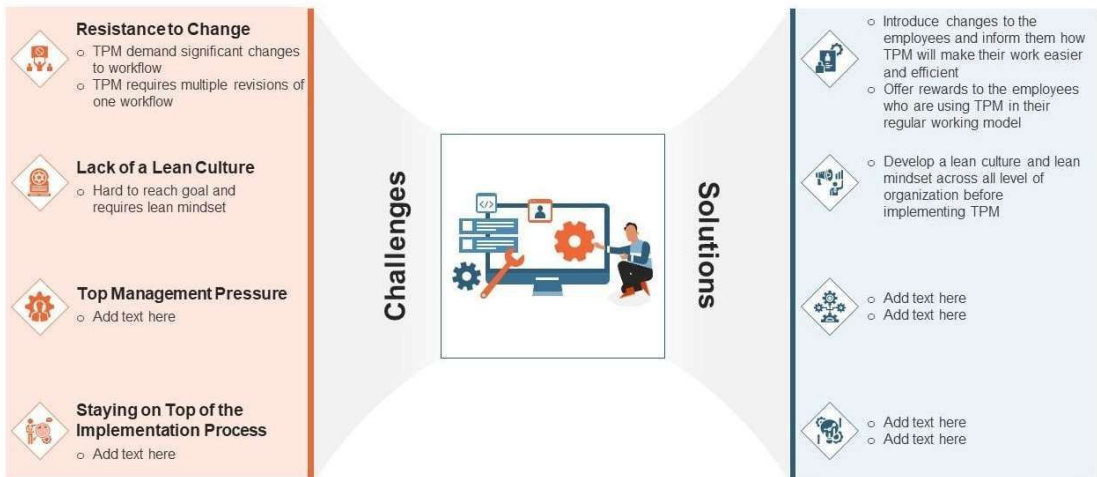
The sustainability of TPM practices is an ongoing challenge. Continuous improvement is integral to TPM, and maintaining momentum over the long term demands persistent commitment and vigilance. Organizations must embed TPM principles into their DNA to ensure sustained success

Lastly, in industries with complex production processes, adapting TPM to fit specific operational intricacies can be particularly challenging. Tailoring TPM to suit the unique needs of the organization requires a nuanced understanding of the complexities involved and a strategic approach to customization.

By addressing these challenges, organisation can unlock the true value TPM, cultivate a

### Challenges & Solutions Offered by TPM

This slide covers the challenges of total productive maintenance along with its solutions to overcome the challenges.



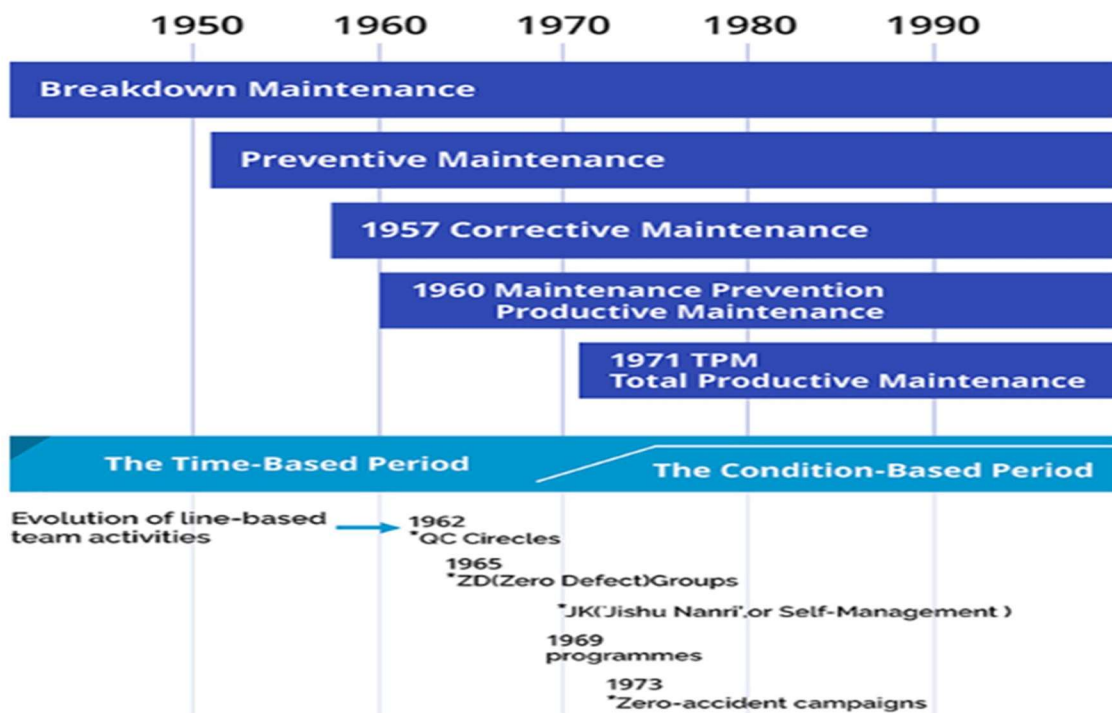
culture of ongoing improvement, and drive long-term operational excellence

**Figure 6A The Challenges of Implementing TPM**

### 6.4 The Significance of Total Productive Maintenance:

Total Productive Maintenance holds paramount significance in the domain of industrial management, playing pivotal role in the enhancing the operational efficiency and fostering a culture improvement in all area. TPM goes beyond traditional maintenance practices, emphasizing a holistic and proactive approach. The significance of TPM can be discerned through several key dimensions.

# MAINTENANCE EVOLUTION



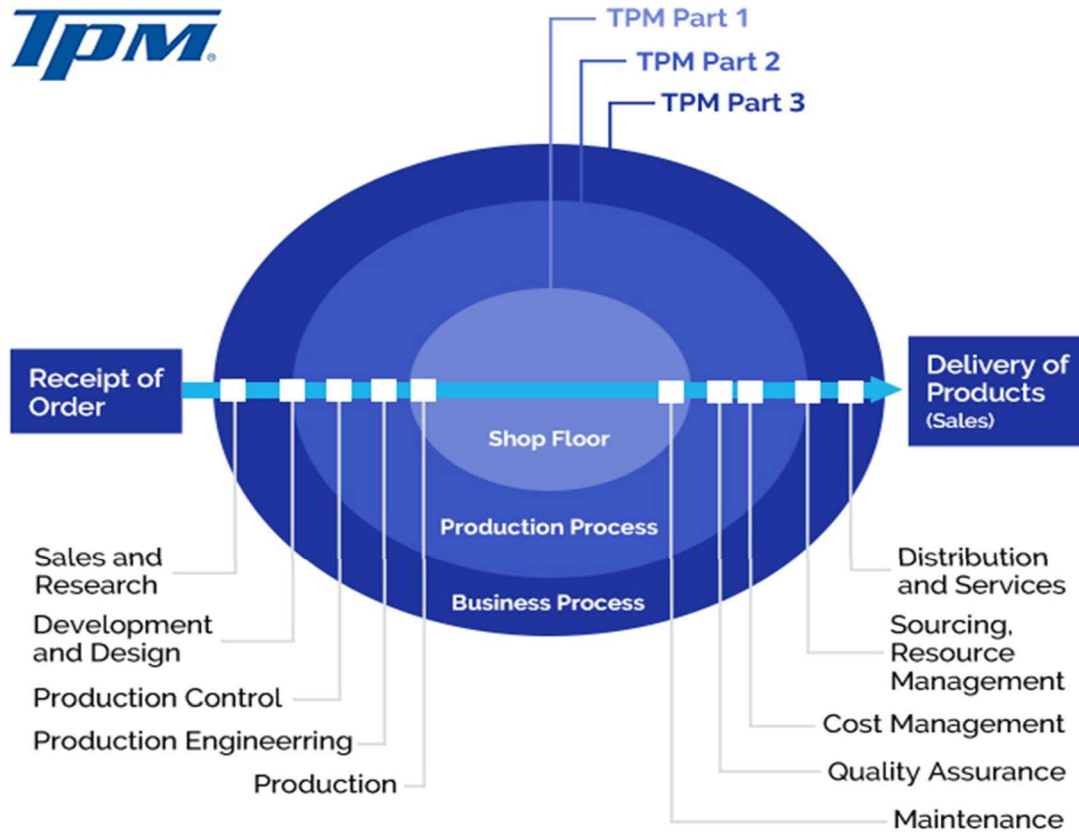






Figure 6B Maintenance Revolution

As TPM expands, it becomes part of daily work. Process led by process owners not maintenance.

Position	Role description	Owens execution for...	Typical daily commitment**
 <b>Operations Manager</b>	<b>Own overall BU results (all systems/lines in BU)</b> <ul style="list-style-type: none"> <li>Lead deployment of Autonomous Maintenance (AM)</li> <li>Drive &amp; maintain OEE / Loss Deployment</li> <li>Build capabilities of line, maint., and process leads</li> <li>Develop and execute daily action plan for the day</li> </ul>	Daily Direction Setting (DDS)	25-50%
 <b>Line / Team Leader</b>	<b>Own results on a particular line(s)</b> <ul style="list-style-type: none"> <li>Drive execution of daily AM action plans</li> <li>Develop and execute daily action plan for the shift</li> </ul>	Clean, Inspect, Lub (CIL) Skill gaps / training	25-75%
 <b>Maintenance Leader</b>	<b>Own overall BU maintenance results</b> <ul style="list-style-type: none"> <li>Drive execution of PM action plans</li> <li>Develop and implement maintenance processes</li> <li>Manage equipment defects and failures</li> </ul>	Defect handling Breakdown elimination	25-75%
 <b>Process / Quality Leader</b>	<b>Own overall BU engineering, process, and system results</b> <ul style="list-style-type: none"> <li>Develop and implement standards for equipment</li> <li>Drive reduction in changeover / clean duration</li> <li>Manage improvements, process settings, and centerlines</li> </ul>	Center-lining Process Control Rapid changeover Specifications	25-50%

\*\* Time commitment expands as more lines adopt and implement TPM practices



**Figure 8 TPM preparation, Kick off and Implementation.**

### 6.5 The Role of Skills in TPM Implementation:

The skill roll in TPM implementation is very important, as it enables the employees to perform their tasks effectively, identify and solve problems, and continuously improve the processes and equipment. TPM is a holistic approach that involves all the levels of the organization, from top management to operators, in the maintenance and improvement of the production system. Therefore, the skills required for TPM implementation are not only technical, but also managerial, communication, and problem-solving skills.

#### **Some of the skills that are essential for TPM implementation are:**

Developing the right skill sets across the workforce is vital for an effective implementation and sustainability of Total Productive Maintenance (TPM). Skill development ensures that employees not only perform their tasks efficiently but also contribute to ongoing improvement initiatives. The following skill areas are foundational to TPM success:

#### **1. Machine Operation and Maintenance Skills**

Operators must be proficient in running equipment safely and efficiently while performing routine the **maintenance tasks such as cleaning, lubricating, inspecting, adjusting machinery.** These capabilities help identify irregularities or defects early, enabling timely interventions. Moreover, such skills support involvement in improvement initiatives like Kaizen and Poka-Yoke, fostering a proactive maintenance culture.

To maintain high product and process standards, employees must be trained to monitor quality metrics and prevent defects. This includes using tools such as 5S, 7 Quality Control Tools (7QC), FMEA, and Statistical Process Control (SPC). These skills are essential for detecting root causes of quality issues and implementing corrective actions.

### 3. Safety and Environmental Awareness

A deep understanding of workplace safety practices and environmental regulations is essential. Employees should be equipped to recognize and mitigate hazards, follow the safety protocols, use Personal Protective Equipment (P P E), and respond effectively to emergencies. These practices help create a safe, compliant, and responsible workplace.

### 4. Communication and Team Collaboration Skills

Effective communication across teams ensures seamless coordination and information sharing. Skills in visual management, Gemba walks, and standard work documentation promote transparency and help teams align their efforts with organizational goals.

### 5. Problem-Solving and Decision-Making Skills

Personnel must be equipped to identify issues, analyse root causes and implement the corrective measures. Tools like the PDCA cycle, A3 reports, Ishikawa (fishbone) diagrams, and the 5 Whys technique are widely used to support structured problem-solving and informed decision-making in TPM environments.

### 6. Leadership and Supervisory Competence

Supervisors and team leaders play a key role in planning, guiding, and monitoring TPM activities. Their responsibilities include setting clear targets, motivating teams, managing change, and fostering a culture of accountability and innovation. Leadership skills are essential for sustaining momentum and ensuring long-term success.

## The Education and Training Pillar in TPM

This pillar focuses on equipping employees at all levels with knowledge and skills necessary to perform by their roles effectively, evolve with technological and operational demands. Training encompasses areas such as equipment handling, quality practices, safety, and data-driven decision-making. Core principles include:

- **Standardization of best practices**
- **Data-supported performance improvements**
- **Leadership development and cultural alignment**

### **Impact of Skills on TPM Success**

The success of a TPM program heavily depends on workforce capabilities. Organizations that prioritize structured training and promote a learning-driven culture see better results in equipment efficiency, reduced downtime, and employee engagement. Recognizing and rewarding skill development further motivates teams to innovate and contribute actively to TPM initiatives.

#### 6.6 Selected Factors of TPM Effectiveness:

##### **1. Overall Equipment Effectiveness (O E E)**

**O E E** is a comprehensive metric that integrates **availability**, **performance**, and **quality** to evaluate how effectively a piece of equipment is being used. A high OEE score reflects optimal machine utilization and effective TPM practices in place.

##### **2. Mean Time Between Failures (M T B F)**

**M T B F** measures the average operational time between two equipment failures. An increased **M T B F** value **indicates the** better machine reliability and reflects the success of preventive maintenance strategies under TPM.

##### **3. Mean Time to Repair (M T T R)**

**M T T R** gauges the avg **time** taken to restore equipment functionality after the breakdown. A lower **M T T R** suggests that maintenance processes are efficient and that downtime is minimized, indicating well-implemented TPM.

##### **4. Equipment Availability Rate**

This metric assesses the percentage of the scheduled time during which equipment is operational and available for use. High availability rates demonstrate strong maintenance planning and machine readiness.

##### **5. First Pass Yield (FPY) / Defect Rate**

**First Pass Yield** measures the proportion of the products that meet quality standards

## 6. Planned vs. Unplanned Maintenance Ratio

This KPI compares the volume of scheduled (planned) maintenance to reactive (unplanned) maintenance activities. A higher ratio of planned maintenance indicates a shift toward proactive maintenance—a core objective of TPM.

## 7. Adoption of Autonomous Maintenance

This indicator measures the degree to which machine operators perform the **basic maintenance tasks such as cleaning, inspection, and lubrication**. Greater adoption signifies cultural integration of TPM and empowered frontline employees.

## 8. Breakdown Frequency

Tracking the number of unexpected equipment failures over time helps determine the effectiveness of preventive actions. A downward trend in breakdowns demonstrates that TPM efforts are reducing disruptions and maintaining equipment health.

## 9. Employee Training and Engagement Levels

This evaluates how actively employees are involved in TPM activities and the effectiveness of training programs. Higher engagement and skill levels lead to better execution of TPM tasks and improved results.

## 10. Safety Metrics Related to Equipment

Monitoring workplace safety incidents, particularly those involving machinery, reflects how TPM contributes to a safer working environment. Fewer accidents suggest well-maintained equipment and adherence to safety protocols.

## 11. Continuous Improvement (Kaizen) Activity

The frequency and success rate of small, incremental improvement initiatives are critical indicators of a TPM culture. A high number of Kaizen actions reflect an organization's commitment to ongoing enhancement and problem-solving.

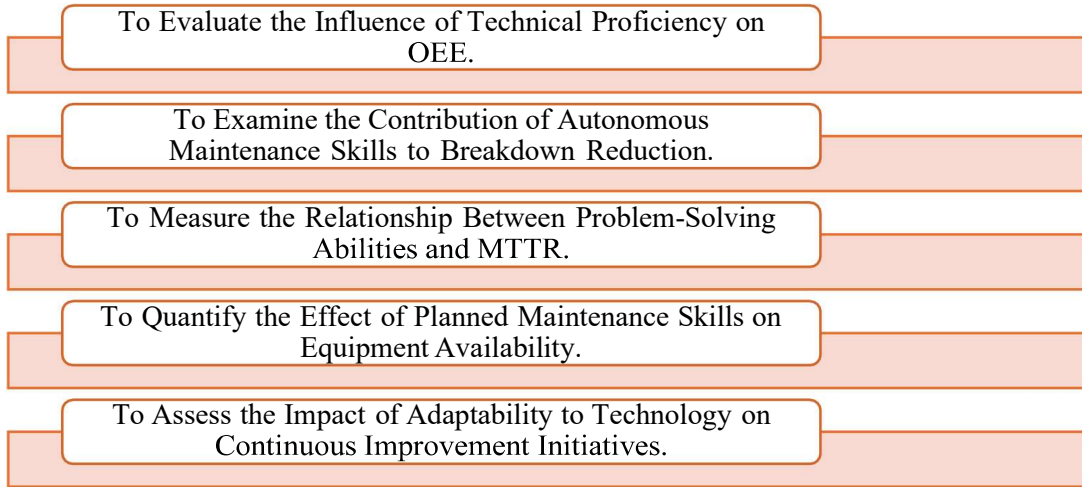
## 12. Alignment with Production Goals

This KPI checks whether TPM efforts are supporting production efficiency and helping Submission ID: 27535:97236147

throughput, quality, and delivery reliability.

### Objectives of the Study

In evaluating the effectiveness of the Total Productive Maintenance (TPM) implementation, several key factors play a crucial role. These selected factors offer insights into the overall health and success of TPM practices within an organization.



**Figure 9 Objectives of The Study**

### 6.7 Expected Contributions

This research needs to provide insights into nuanced relationships between skills, TPM effectiveness. The findings may guide organizations in optimizing their workforce Developing strategies for growth, cultivating a culture of ongoing enhancement, and ultimately driving the overall performance of TPM initiatives in industrial settings. Through a careful assessment of these dynamics, the research seeks to contribute to the advancement of maintenance the practices and operational excellence.

#### 1) Skills in the Autonomous Maintenance:

Autonomous the maintenance empowers machine operators to take ownership of routine the maintenance tasks, reducing reliance on specialized maintenance personnel. This approach enhances equipment reliability, supports consistent production quality, and fosters a proactive workplace culture centered on safety and continuous improvement. The key skill areas required for effective autonomous maintenance include:

##### 1. Equipment Operation and Routine Maintenance

Operators must be capable of safely and efficiently running machinery while performing day-to-day upkeep tasks such as cleaning, lubrication, inspection, and minor adjustments. These competencies help identify irregularities early, enabling prompt corrective action. Involvement

## 2. Quality Monitoring and Assurance

Maintaining high product and process quality requires the ability to spot defects, implement corrective measures, and apply quality control tools. Skills in **5S**, **FMEA**, **7QC tools**, and **Statistical Process Control (SPC)** equip operators to proactively manage quality at the source and reduce the risk of non-conformities.

## 3. Safety and Environmental Awareness

Operators must understand and adhere to safety procedures, properly use **Personal Protective Equipment (PPE)**, and be alert to potential hazards. Familiarity with risk identification, hazard mitigation, and emergency response procedures ensures both personal and workplace safety while supporting regulatory compliance.

## 4. Communication and Collaboration

Effective communication supports teamwork and ensures smooth coordination between departments. Skills in **visual management**, **standardized work instructions**, and **Gemba walks** encourage open dialogue, immediate feedback, and shared responsibility for maintenance-related activities.

## 5. Analytical Thinking and Decision-Making

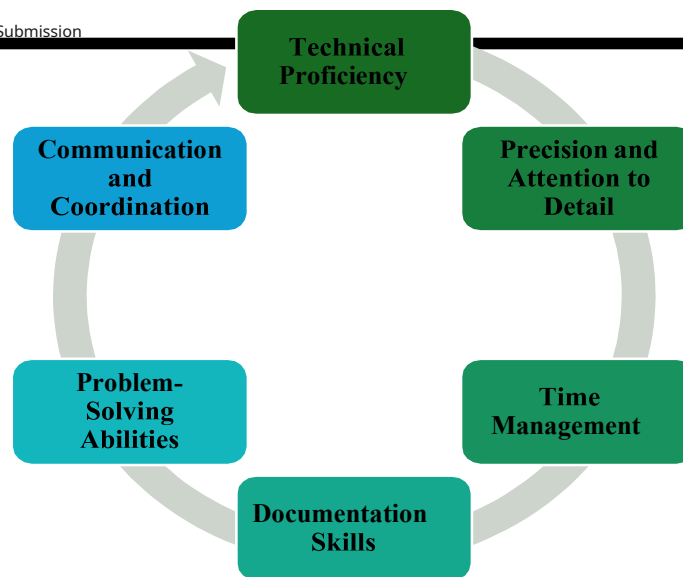
Operators should be equipped to investigate equipment anomalies, troubleshoot problems, and make timely, data-driven decisions. Familiarity with structured problem-solving techniques—such as **Root Cause Analysis**, **PDCA**, and the **5 Whys**—enables quicker resolutions and supports continuous improvement initiatives.

These skill sets form the foundation of a strong autonomous maintenance program, empowering frontline employees to contribute directly to equipment reliability, process efficiency, and operational excellence.

**2) Skills in PM:** PM within the Total Productive Maintenance framework requires a specific set of skills to ensure its effective implementation. Technical proficiency is at the core of these skills, as maintenance tasks often involve intricate procedures such as equipment inspections, lubrication, and component replacements. The ability to execute these tasks with precision is paramount, as it minimizes the risk of errors and contributes to the longevity and optimal performance of equipment.

Time management skills are equally crucial in planned maintenance. Adhering to schedules is essential to minimize disruptions to production. Effective time management ensures that all maintenance tasks are carried out in a timely manner, preventing unexpected downtime and maintaining overall production schedules.

Accurate documentation of planned maintenance activities is another skill of significance. Maintaining detailed records facilitates data-driven decision-making by allowing for analysis of the maintenance trends and the optimization of future maintenance plans. This documentation is vital in tracking equipment history and



**Figure 10 Skills in Planned Maintenance**

Communication skills play a pivotal role in coordinating planned maintenance activities. Effective communication ensures that all relevant stakeholders, including production teams and other maintenance personnel, are aligned with the maintenance schedule.

This coordination is essential to reduce the likelihood of operational disruptions.

Planned maintenance may also uncover issues that require the **problem solving skills** for resolution. **The ability to** **an identify** the **root causes and** **an implement** corrective actions is crucial for proactive problem-solving, contributing to the success of planned maintenance by addressing potential issues before they escalate.

Adherence to Standard Operating Procedures (SOPs) is a fundamental skill in planned maintenance. Following established SOPs maintain consistency and ensures that planned maintenance tasks are carried out in accordance with best practices, enhancing the reliability and effectiveness of these activities.

Risk assessment and mitigation skills are also vital in planned maintenance. The ability to assess potential risks associated with maintenance activities and implement mitigation strategies ensures the safety of personnel and equipment during planned maintenance tasks.

Continuous learning and adaptability round out the skill set for planned maintenance. A willingness to learn and adapt to new technologies, methodologies, and best practices ensures that maintenance personnel stay abreast of advancements, optimizing planned maintenance processes.

Finally, teamwork and collaboration are essential skills in planned maintenance, which often involves coordination with cross-functional teams. Collaborative efforts contribute

expertise, precision, effective communication, problem-solving, and a commitment to continuous improvement. A skilled workforce is indispensable for the successful execution of planned maintenance tasks, contributing to the overall effectiveness of the TPM framework.

### 3) Skills in Focused Improvement (Kaizen):

The successful implementation of Focused Improvement, commonly known as Kaizen, within the Total Productive Maintenance (TPM) framework requires specific skills from the workforce. These skills are pivotal for identifying, analyzing, and implementing continuous improvement initiatives. Key skills in Focused Improvement include:

**Root Cause Analysis:** Proficiency in identifying the root causes of inefficiencies or problems within the production process. This skill is crucial for addressing issues at their source, ensuring sustained improvement.

**Data Analysis:** The ability to collect, analyze, and interpret the data related to production processes. Analytical skills enable the identification of trends, patterns, and areas for improvement.

**Collaboration:** Effective collaboration among team members is crucial for successful Kaizen initiatives. This includes communication, idea sharing, and collective problem-solving. **Continuous Learning:** Kaizen is rooted in continuous improvement. Individuals engaged in Focused Improvement should have a commitment to ongoing learning, staying informed about new methodologies and best practices.

**1. Impact on Key Performance Indicators (KPIs):** This involves understanding how TPM practices influence various performance metrics. Key objectives related to the impact on KPIs include:

**OEE Improvement:** Measure the extent to which TPM contributes to enhancing Overall Equipment Effectiveness, reflecting increased equipment efficiency, and minimized downtime. **Reduction in Breakdowns:** Evaluate the impact of TPM on reducing the frequency of unexpected breakdowns, contributing to improved equipment reliability.

**Quality Metrics:** Assess the influence of TPM on product quality, examining metrics such as first pass yield and defect rates.

**Cost Reduction:** Measure the financial impact of TPM on maintenance costs, including a reduction in emergency maintenance and associated expenses.

**Cycle Time Reduction:** Evaluate how TPM practices contribute to the reduction of cycle times in production processes, enhancing overall operational efficiency.

Within the Total Productive Maintenance (TPM) framework, training and development programs are crucial for building the competencies needed to implement and sustain TPM initiatives effectively. These programs are designed to enhance both technical and soft skills across the workforce. Key areas of focus include equipment maintenance, basic troubleshooting, and autonomous maintenance—enabling operators to perform routine checks and minor repairs independently. Additionally, soft skills such as communication, collaboration, and problem-solving are emphasized to foster a proactive and team-oriented maintenance culture, fostering a proactive mindset. Continuous learning is emphasized, ensuring that employees stay abreast of evolving TPM principles and best practices. The goal of these programs is not only to enhance individual competencies but also to cultivate a culture of continuous improvement where the workforce actively contributes to the success of TPM initiatives. Effective training and development programs play a vital role in creating a proficient and committed workforce capable of steering TPM success and attaining operational excellence. The objectives related to training and development include

**Skill Enhancement:** Provide the main training programs to enhance technical level skills related to maintenance tasks, ensuring that the workforce is equipped for the demands of TPM. **Autonomous Maintenance Training:** Implement training initiatives to empower operators with the skills needed to perform autonomous maintenance tasks, fostering a proactive mindset.

**Continuous Learning and Culture:** Establishing an environment of continual learning through regular training programs, ensuring that employees stay updated on TPM principles and best practices.

### 3. Organizational Culture and Leadership:

The impact of the organizational culture and leadership of TPM effectiveness is substantial. Objectives in this domain include:

**Leadership Commitment:** Ensure leadership commitment to TPM principles and practices, fostering a culture where TPM is integrated into the organization's core values.

**Employee Engagement:** Foster an organizational culture that encourages active employee participation in TPM initiatives, creating a sense of ownership and responsibility.

**Change Management:** Provide leadership with the skills to effectively manage and communicate change, ensuring smooth TPM implementation and acceptance across the

organization.

where every member of the organization is encouraged to contribute ideas and to participate in TPM-related improvement initiatives.

These objectives collectively contribute to the holistic success of TPM, ensuring that the workforce is equipped with the necessary skills, organizational culture aligns with TPM principles, and leadership provides the necessary support for effective implementation.

## CHAPTER 2

### LITERATURE REVIEW

In his 2023 study, Farkhan Fajar Nurdin emphasizes the significance of proper equipment maintenance in preserving machine efficiency and maintaining consistent production output. He observes that prolonged machine operation without adequate upkeep can diminish performance levels. To address this, he discusses the application of Total Productive Maintenance (TPM) alongside the calculation of Overall Equipment Effectiveness (OEE) as a means to boost operational reliability. TPM is designed to minimize the Six Big Losses—common causes of equipment inefficiency—while OEE offers a practical metric to compare actual production to ideal conditions. Based on a comprehensive literature review, Nurdin concludes that implementing TPM practices effectively mitigates recurring maintenance issues and improves overall equipment productivity.

Similarly, Guilherme Luz Tortorella (2022) explores the intersection of TPM practices and Industry 5.0 (I5.0) technologies within the manufacturing sector. Drawing from responses provided by 335 professionals across 16 countries, his research uncovers numerous positive relationships between TPM activities and digital innovations associated with I5.0. By considering variables such as technological maturity, organizational scale, and socio-economic background, the study identifies 67 matched pairs of practices and technologies with statistically significant correlations. These insights suggest that the joint application of TPM and I5.0 tools can modernize maintenance systems and support broader digital transformation goals in industry.

Both studies point to the value of adopting forward-looking maintenance strategies. The integration of TPM with advanced technologies characteristic of Industry 5.0 contributes to reducing downtime, extending machine life, and optimizing production efficiency—key factors for sustaining competitiveness in industrial operations.

#### 1) Operational Excellence:

The primary goal of Total Productive Maintenance (T P M) is to maximize the efficiency of production equipment. TPM achieves this by minimizing downtime, reducing breakdowns, and improving Overall Equipment Effectiveness (O E E). These efforts collectively contribute to operational excellence, ensuring that the production process runs smoothly and efficiently, ultimately enhancing overall productivity and equipment reliability.

#### 2) Proactive Maintenance Culture:

5

8

33

4

36

approach. By prioritizing preventive measures, scheduled maintenance, and autonomous tasks, TPM significantly reduces the occurrence of unplanned downtime. This proactive strategy minimizes disruptions to production schedules, ensuring a more consistent and efficient manufacturing process.

### **3) Employee Engagement and Ownership:**

TPM involves the entire workforce **in the maintenance process**, promoting **a sense of ownership and** responsibility for equipment upkeep. This engagement empowers employees at all levels, fostering a collaborative environment and cultivating a shared commitment to achieving operational success. By encouraging active participation, TPM helps strengthen teamwork and accountability across the organization.

### **4) Addressing Losses Systematically:**

TPM strategically targets the "Six Big Losses" in production, which encompass the breakdown, setup times, measuring and adjustment time, idling and minor stops, slow speeds, defects, and startup losses. By addressing and reducing these losses, TPM improves efficiency and optimizes resource utilization, leading to more streamlined operations. This proactive approach fosters continuous improvements and enhances overall productivity within the production environment.

### **5) Autonomous Maintenance Empowerment:**

The focus on **autonomous maintenance** empowers **operators to take responsibility for** routine tasks, fostering **a sense of pride and** accountability **in their work**. This approach not only enhances equipment reliability but also cultivates a proactive mindset across the organization, encouraging employees to actively contribute to the upkeep and performance of production assets.

### **6) Planned Maintenance for Predictability:**

TPM introduces planned maintenance activities, ensuring that maintenance tasks are conducted systematically. This planned approach enhances predictability, allowing organizations to schedule maintenance during planned downtime, minimizing disruptions.

### **7) Continuous Improvement Philosophy (Kaizen):**

TPM aligns with the philosophy of continuous improvement, encouraging small, incremental changes in processes. This commitment to Kaizen ensures that organizations evolve, adapt to changing conditions, and continuously refine their operational practices.

### **8) Enhanced Equipment Reliability and Lifespan:**

Through preventive maintenance, quality management, and early equipment management, TPM enhances the reliability and lifespan of production equipment. This not only reduces the risk of unexpected failures but also contributes to sustained product quality.

#### **9) Alignment with Lean Principles:**

TPM closely aligns with lean manufacturing principles, emphasizing the elimination of waste and the efficient use of resources. This alignment results in streamlined processes, reduced lead times, and an overall improvement in operational efficiency.

#### **10) Safety and Positive Work Environment:**

TPM places a strong emphasis on safety, creating a work environment that encourages safe practices. A safer work environment not only protects employees but also contributes to stable operations and reduces disruptions due to accidents.

In summary, the significance of Total Productive Maintenance lies in its capacity to revolutionize maintenance practices, instill the proactive mindset, and create the workplace culture committed to the continuous improvement. TPM stands as a fundamental strategy for organizations aspiring to achieve operational excellence and sustain competitiveness in the dynamic landscape of industrial operations.

## CHAPTER 3

### RESEARCH - METHODOLOGY

#### 3.1 Intr- oduction

This -study adopts a structured, multi-dimensional met-hodology to examine the influence of workforce competencies on an effectiveness of Total Productive Maintenance (TPM) within an evolving framework of Industry 5.0. Recognizing the increasing convergence of an advanced digital tech-nologies and human-centric industrial strategies, this methodology integrates both qualitative and quantitative approaches to explore how workforce capabilities affect critical TPM outcomes. Industry 5.0 emphasizes synergistic collaboration between the human intelligence and intelligent systems, thereby underscoring the strategic importance of workforce skill development in achieving Operational Excellence.

#### 3.2 Research and design:

The research follows a mixed-methods design, incorporating exploratory, descriptive, and correlational elements:

- Exploratory: To identify key competencies aligned with Industry 5.0 and TPM best practices.
- Descriptive: To assess the current state of workforce skills and TPM performance.
- Correlational: To examine relationships between workforce competencies and key TPM performance indicators, specifically Overall the Equipment Effectiveness (OEE), Mean Time to Repair (MTTR), and the ratio of planned to unplanned maintenance.

#### 1) Conceptual Framework

- A multi-dimensional assessment model underpins the study, integrating the following core domains:

#### 2) Workforce Competency Areas:

- *Technical Proficiency*: Competence in equipment operation, diagnostics, and routine maintenance.
- *Problem-Solving Ability*: Skills in analytical reasoning and root-cause analysis.
- *Digital Literacy*: Familiarity with digital maintenance platforms, IoT systems, and data analytics.
- *Cross-Functional Collaboration*: Capacity for teamwork across maintenance, production, and quality domains.
- *Learning Agility*: Responsiveness to upskilling and continuous learning initiatives.

#### 3) TPM Pill-ars:

- Autonomous the Maintenance
- Planned the Maintenance

- Focused the Improvement
- Education and Training
- Early Equipment Management

#### 4) Performance Indicators:

- OEE (Overall the Equipment Effectiveness): Measuring availability, performance, and quality.
- MTTR (Mean Time to- Repair): Capturing efficiency of corrective maintenance.
- Planned vs. Unplanned Maintenance Ratio: Reflecting predictability and maintenance planning effectiveness.

### 3.3 Data collection:

Multiple data collection instruments are utilized to capture a rich, triangulated dataset:

#### Structured Interviews -

- **Objective:** To obtain expert insights from key stakeholders, including TPM managers, engineers, and training coordinators.
- **Sample Size:** Approximately 10 to 15 professionals from diverse manufacturing sectors (e.g., automotive, electronics, FMCG).
- **Focus Areas:** Skill development challenges, integration of digital tools, TPM adoption maturity, and perceived barriers.

#### Structured Surveys -

- **Instrument:** A questionnaire developed from the conceptual model, consisting of both closed- and open-ended questions.
- **Participants:** Approximately 150–200 participants, including maintenance staff, production operators, and team leads.
- **Data Captured:** Self-reported competency levels, TPM activity engagement, and perceptions of digital integration.

#### Performance Metrics Analysis -

- **Data Sources:** Internal records including Computerized Maintenance Management System (CMMS) logs and equipment dashboards.
- **Indicators Evaluated:** Historical OEE, MTTR, planned/unplanned maintenance ratios, autonomous maintenance task frequencies.
- **Time Horizon:** A review of data over the past 12 to 24 months to capture performance trends and enable longitudinal insights.

# DATA COLLECTION



Figure 11 Data Collection

## Sampling Strategy -

A purposive sampling strategy is employed to identify manufacturing firms that are actively engaged in TPM programs and have demonstrated commitment to digital transformation and workforce development. Within selected organizations, a stratified sampling approach ensures representation across various job roles and hierarchical levels, thereby enabling analysis of skill impacts across functional layers

### 3.4 Data analysis:

The analysis encompasses both quantitative and qualitative methods:

#### 1) Quantitative Analysis

- Descriptive the Statistics: Means, standard deviations, and frequency distributions of skill levels, TPM outcomes.
- Inferential Analysis:
  - Pearson's correlation coefficients to assess relationships between skill dimensions and performance metrics.
  - Multiple regression models to identify predictors of TPM effectiveness.
  - ANOVA to evaluate performance variations across departments or industries.

#### 2) Qualitative Analysis

- Thematic Analysis: Coding of interview transcripts to identify recurring themes related to workforce development, TPM enablers, and barriers.
- Narrative Synthesis: Integration of qualitative findings with survey and performance data to develop a cohesive interpretation of the workforce-TPM relationship

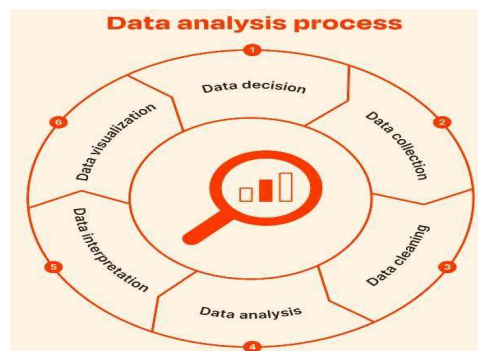


Figure 12 Data Analysis

### 3.5 Research Method and Analysis

The research framework was constructed to investigate the impact of workforce capabilities on critical components of **Total Productive Maintenance (TPM)**, within a context of Industry 5.0 and a pursuit of operational Excellence, is grounded in a robust and multidimensional methodological approach. Employing a mixed-methods design, the study integrates both quantitative and qualitative methodologies to explore the intricate relationship between human skillsets and TPM performance in technologically advanced manufacturing environments. The stratified random sampling strategy is utilized to ensure comprehensive representation across various departments & professional experience levels, thereby enabling detailed analysis of skill variation and its operational implications. The quantitative phase employs structured instruments, including surveys and competency assessments, to evaluate key employee attributes—such as technical expertise, adaptability, and problem-solving capability—positioned as independent variables. TPM outcomes, including Overall the **Equipment Effectiveness (OEE)** and **Mean Time Between Failures (MTBF)**, are treated as dependent variables. Analytical techniques such as correlation analysis and regression modeling are applied to examine relationships and assess predictive significance. Complementing this, the qualitative component draws on thematic analysis of semi-structured interviews and observational data, offering insights into the human-centered elements intrinsic to Industry 5.0. Ethical considerations, instrument validation procedures, and a structured implementation timeline are integral to ensuring the reliability and coherence of the methodology. The study ultimately aims to produce actionable knowledge on how targeted skill development initiatives can optimize TPM practices, strengthen equipment performance, and support the evolution of resilient, intelligent, and human-centric industrial systems. Skill development can enhance TPM strategies, drive equipment reliability, and foster resilient, intelligent, and human-focused industrial systems.

## CHAPTER 4

### ANALYSIS, DISCUSSION AND RECCOMENDATIONS

#### 4.1 Setting the Basic Policy and Goals of Industry 5.0, Operational Excellence and TPM

Total Productive Maintenance (TPM), as a cornerstone of an Operational Excellence, evolves further under the framework of Industry 5.0, where a human-centric innovation & smart technologies converge to achieve sustainable, high-performance manufacturing. TPM is redefined not only as a maintenance strategy but as an integrated system driving reliability, efficiency, and continuous value creation across industrial operations.

The foundational principles guiding TPM in an Industry 5.0 environment include the pursuit of zero unplanned stoppages, elimination of micro-downtimes and speed losses, prevention of quality defects, and assurance of a safe and stable working environment. These objectives collectively support a culture of excellence in production.

A key focus within this modern TPM context is the enhancement of machine effectiveness through data-driven insights and real-time feedback systems. This includes improvements in reliability, performance consistency, and optimization of the maintenance workflow. Strategic planning is applied to maintenance scheduling, with the aim of minimizing premature repair interventions and avoiding unnecessary disruptions to operations.

An essential aspect of this holistic approach is empowering operational personnel to take on responsibility for routine equipment upkeep. By involving frontline teams in daily machine readiness tasks—such as checklist validations during start-up and shutdown—TPM fosters a shared sense of ownership and engagement.

As TPM progresses into its advanced phase within Industry 5.0, it emphasizes proactive maintenance methodologies. These include condition-based monitoring, predictive analytics using AI and IoT, and preventive strategies supported by digital twins and intelligent diagnostics. Together, these techniques target micro-level inefficiencies that, when resolved, yield substantial gains in productivity, asset longevity, and process resilience—core goals of Operational Excellence.

The 3 major losses category an impede efficient use of production resources are typically categorized as follows:

1. **Availability Loss-es:** These are losses- due to equipment fail-ures, planned maintenance time loss, setup loss, tool change loss, and start-up loss.

2. For example, **breakdown losses** (failure losses) occur when equipment fails, leading to unplanned downtime. Another example is **setup- adjustment losses**, which refer to time lost between end of the production of a previous item and the completion of necessary adjustments to begin producing a new item. This time loss continues until the production of the new item reaches satisfactory levels
3. **Performance Losses:** These losses arise from brief interruptions and operating below the equipment's designed speed. For example, **minor stoppages** occur when machines pause momentarily due to issues like sensor triggers or material jams. **Speed losses** happen when the equipment runs slower than its intended or rated speed, leading to reduced productivity.
4. **Quality Losses:** These refer to losses associated with product defects and the need for rework. When defective items are identified during or after production, additional time, resources are required to correct them, which reduce overall efficiency of the manufacturing processes. The Quality-related losses often become key targets for continuous improvement efforts aimed at enhancing product consistency and minimizing waste

#### 4.2 Findings:

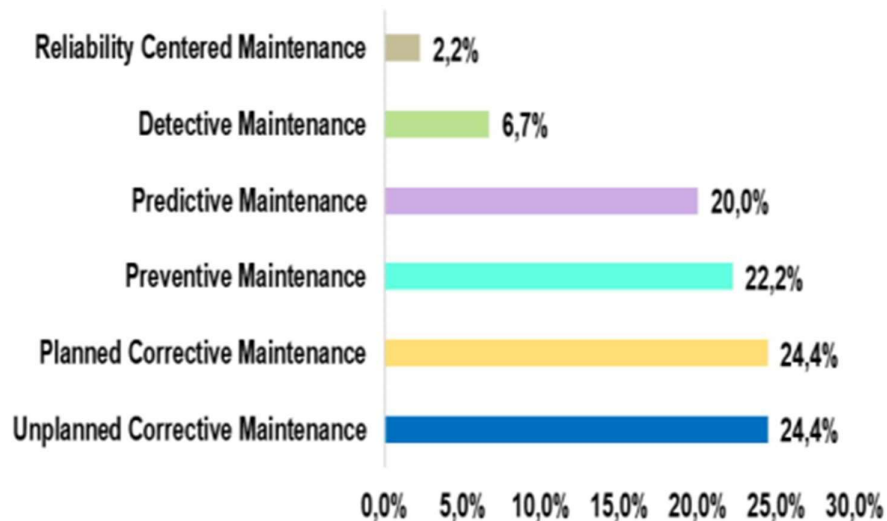
The survey findings highlight several key insights into the perceptions of maintenance personnel regarding the relationship between skills and various aspects of Total Productive Maintenance (TPM) effectiveness. Notably, there is a prevalent consensus on the positive impact of technical proficiency, autonomous maintenance skills, problem-solving abilities, and planned maintenance skills on different performance metrics, such as (OEE), breakdown reduction, MTTR, equipment availability. Additionally, respondents emphasize the critical role of adaptability to technology in the success of continuous improvement initiatives within the maintenance domain. These findings provide valuable insights for organizations seeking to optimize TPM practices by focusing on skill development and technological integration.

#### 4.3 Limitations:

While the survey provides valuable perspectives, it's important to acknowledge certain limitations. Firstly, the findings are based on the self-reported perceptions, which might be subject to bias, subjective interpretation. Assessment also assumes a certain level of understanding and uniformity in interpreting terms like "technical proficiency" or "autonomous maintenance skills," which might vary among respondents. The sample size and composition may not represent the entire diversity of maintenance personnel in different industries. Additionally, the survey does not delve into specific industries or

organizational contexts, limiting the generalizability of findings. Future research could address these limitations by conducting more in-depth qualitative studies, considering diverse industry contexts, and incorporating objective performance metrics.

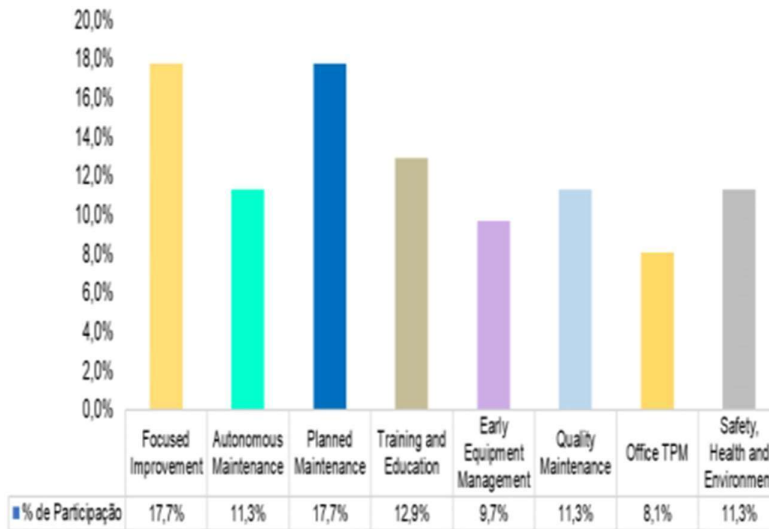
Companies tend to adopt a balanced approach to maintenance strategies. Current practices show a distribution where predictive maintenance accounts for approximately 20%, preventive maintenance makes up 22.2%, while both planned and unplanned corrective maintenance each represent 24.4%. Notably, unplanned corrective maintenance is expected to decrease over time. This anticipated decline is attributed to advancements in technology and the growing expertise of professionals involved in maintenance processes.



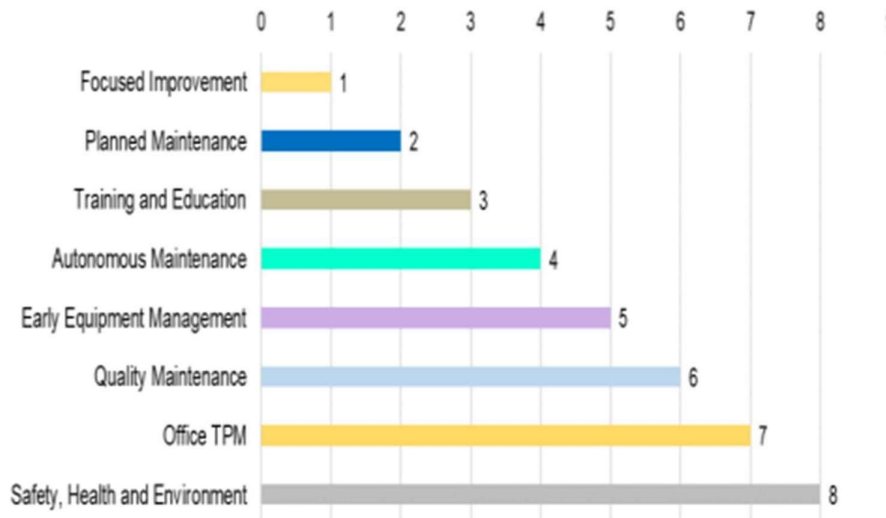
**Fig. 13B Maintenance types used by the company.**

As per Figure 14,

The implemented steps of TPM pillars emphasize Focused Improvement, accounting for 17.7%, which targets overall business enhancement, and Planned Maintenance, also at 17.7%, which focuses on the systematic planning, execution, and management of maintenance activities



**Figure 14: Incidence of an implemented TPM pillars**



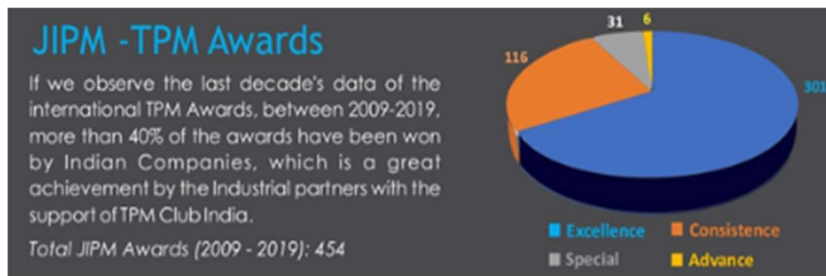
**Figure 15: Sequence of the TPM pillars implementation.**

**Table 1**

Provides a comparison between the TPM implementation sequence proposed in existing literature and the sequence actually adopted by the surveyed organizations. For confidentiality purposes, each company is anonymized and labeled numerically from 1 to 11. The extent of TPM implementation was evaluated using the Overall Equipment Effectiveness (OEE) indicator, based on the criteria defined in the subsequent statements.

**TPM Methodology for Sustainable Profit Growth in the Indian Process Industry**

Total Productive Maintenance (TPM) originated in 1969 at Nippon Denso, Japan, with the objective of eliminating equipment breakdowns and enhancing overall manufacturing efficiency. In India, the cement sector was among the first to embrace TPM, starting in 1991. To facilitate this transition, the Confederation of Indian Industry (CII), in collaboration with the Japan Institute of Plant Maintenance (JIPM), launched the CII TPM Club under the CII Institute of Quality. This initiative was designed to guide and support Indian industries in the effective adoption of TPM practices.



practices

Fig. 16 TPM award

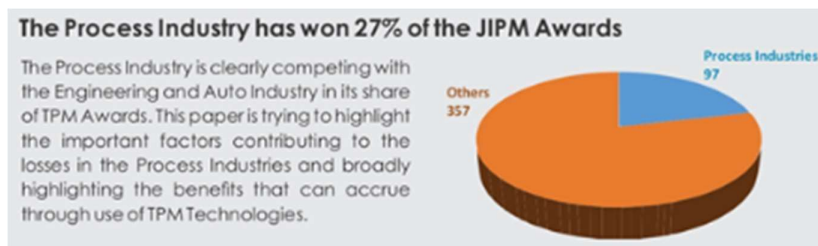


Fig. 17 TPM award

Batch and continuous process industries face distinct challenges, including fluctuations in raw material availability and pricing, variations in yield, operational methods, internal plant losses, workforce expertise, and energy usage. The nature of defects in these industries differs significantly from those in other sectors. Moreover, the potential for enhancing profitability and achieving exponential growth is considerably higher in process industries.

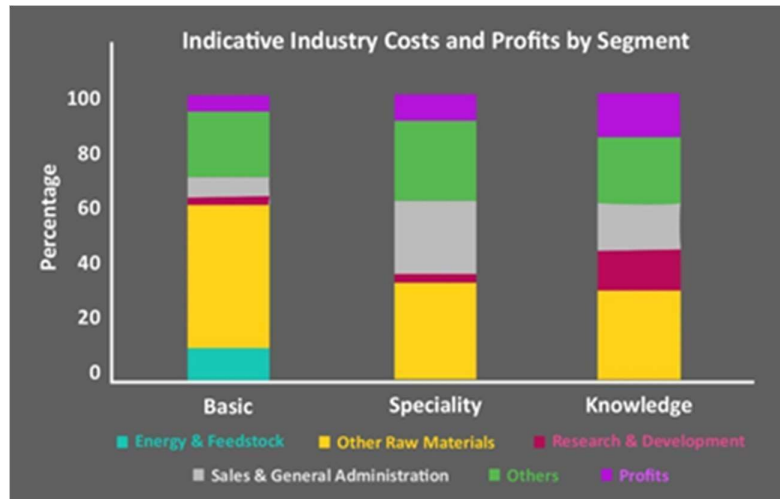
Key characteristics of process industries include:

- Continuous, uninterrupted production flows.

- Management of complex material properties.
- High levels of energy consumption.
- Operators must monitor and control a wide range of parameters and equipment types.

### **The Challenges**

Numerous processes span the entire facility, encompassing crystallization, distillation, refining, furnaces equipped with both the static and rotary equipment. The Detriment Approximately 7 to 10 percent of the total downtime is devoted to equipment maintenance; preventive maintenance contributes an additional 10 to 12 percent; and shut-down maintenance presents yet another formidable obstacle.



**Fig.18 Cost and profit segment**

#### 4.4 Future Research:

Building upon the current insights, future research should investigate the specific pathways through which workforce competencies influence the success of TPM initiatives within the broader scope of Industry 5.0 and Operational Excellence. Employing qualitative approaches such as cross-sectoral case studies and in-depth interviews could help uncover how different industrial contexts shape the effectiveness of skill-driven TPM strategies. Furthermore, exploring the influence of organizational culture—particularly in fostering skill advancement and collaborative maintenance ownership—could provide a richer understanding of how TPM is embedded and sustained.

Longitudinal research could also prove valuable in tracking how the impact of workforce capabilities on TPM outcomes evolves over time, especially in dynamic environments where technology and processes are continuously advancing. As Industry 5.0 places greater emphasis on the human machine interface (HMI), it is vital to study how emerging digital tools and intelligent systems redefine the skills required for effective maintenance and reliability management.

Additionally, future investigations should consider the external pressures shaping TPM practices, such as evolving regulatory frameworks, digital compliance standards, and rapid technological innovation in maintenance tools and diagnostics. These factors may significantly influence the strategic alignment of TPM with organizational excellence goals. Overall, there remains a critical need for targeted, industry-specific research that captures the complexity of skill development, technology integration, and performance optimization in next-generation industrial ecosystems.