Project Dissertation Report on

ACHIEVING COMPETITIVE ADVANTAGE THROUGH TPM-DRIVEN OPERATIONAL EXCELLENCE IN THE AGE OF INDUSTRY 5.O

Submitted by:

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CERTIFICATE

This is to certify that Saurabh Sharma Roll No.: 23/EMBA/32 student of Master of Business Administration (Executive 2023-2025) at Delhi Technological University, Delhi has accomplished the project titled **"ACHIEVING COMPETITIVE ADVANTAGE THROUGH TPM-DRIVEN OPERATIONAL EXCELLENCE IN THE AGE OF INDUSTRY 5.O**" under my guidance and to the best of my knowledge completed the project successfully, for the partial fulfilment of the course- Dissertation in 4th semester of the course Executive MBA.

MENTOR NAME AND SIGNATURE

Mr. Anil Kumar

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DECLARATION

I hereby declare that the submission is my own and that, to the best of my knowledge and belief, it contains no material previously and return published or written by any other person nor material which to a substantial extent has been accepted for the word of any other degreeor diploma of the university and other institute of higher except where due acknowledgement has been made in the text.

Saurabh Sharma
23/EMBA/32

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I, Saurabh Sharma, wish to show my deep sense of gratitude to my project guide **Mr. Anil Kumar**, for his support and guidance. First, especially for his support and secondly for providing necessary information during the project work.

Saurabh Sharma

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Executive summary:

This project aims to integrate the core principles of the **Industry 5.O** 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**.

I n 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.O—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

Methodology:

This study employed a mixed-method research 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
- 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.O integration.

Key Findings:

Industry 5.0 and Human-Machine Collaboration

- Industry 5.0 emphasizes human-centric approaches—enabling skilled workers to collaborate with 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.
    - Move from reactive to predictive and autonomous maintenance models.

2. Build Smart Maintenance Systems:
    - 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, MTTR (Mean Time to Repair), MTBF (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 the shop floor level by rewarding small improvements and involving everyone in improvement efforts.
    - Regularly audit processes to ensure alignment with long-term operational goals.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In today's evolving industrial landscape, the pursuit of **operational excellence** has become a cornerstone for organizations striving to maximize efficiency, minimize downtime, and secure sustainable competitive advantages. At the nexus of this transformation is **Industry 5.0**, an emerging paradigm that harmonizes advanced digital technologies with human-centric innovation. In alignment with this shift, **Total Productive Maintenance (TPM)** emerges as a strategic enabler—transcending traditional repair practices to foster a culture of continuous improvement, autonomy, and reliability in manufacturing systems.

Originating in Japan, TPM has gained global recognition as an essential pillar of **Lean and Smart Manufacturing philosophies**. It embodies a **holistic and proactive approach to asset management**, promoting cross-functional collaboration and driving operational efficiency. With the guiding principle that every individual in the organization contributes to machine performance, TPM aims to achieve the highest levels of **Overall Equipment Effectiveness (OEE)**.

The core philosophy of TPM resonates strongly with Industry 5.0's human-machine collaboration ethos. It involves instilling a deep sense of ownership and accountability across all organizational levels—from frontline operators to top management. By bridging the gap between maintenance and production, TPM supports autonomous maintenance, proactive problem solving, and continuous skill enhancement—key components of the operational excellence framework.

A critical feature of TPM is its systematic focus on **eliminating the six major losses in manufacturing**: equipment downtime, setup and adjustment time, minor stoppages, reduced speed, defects in process, and yield loss. Addressing these areas enables organizations to significantly enhance **OEE**, a comprehensive metric that reflects availability, performance, and product quality.

As industries globally transition toward **Industry 5.0**, embedding TPM into this framework is essential for human-centric, resilient, and digitally connected operations. The effectiveness of TPM relies heavily on workforce capabilities. In this context, **skill**

development and competency-building emerge as vital enablers of TPM success.

This approach underscores the need to assess how workforce skills impact the success of TPM implementation, particularly within the context of Industry 5.0.

This study explores the interdependency between personnel proficiency and TPM effectiveness, offering actionable insights into workforce training, human-machine interaction, and the development of smart, autonomous systems. By integrating TPM with Industry 5.0 principles, organizations can achieve **greater resilience, adaptability, and innovation in their operational strategies**, reinforcing the path to long-term operational excellence

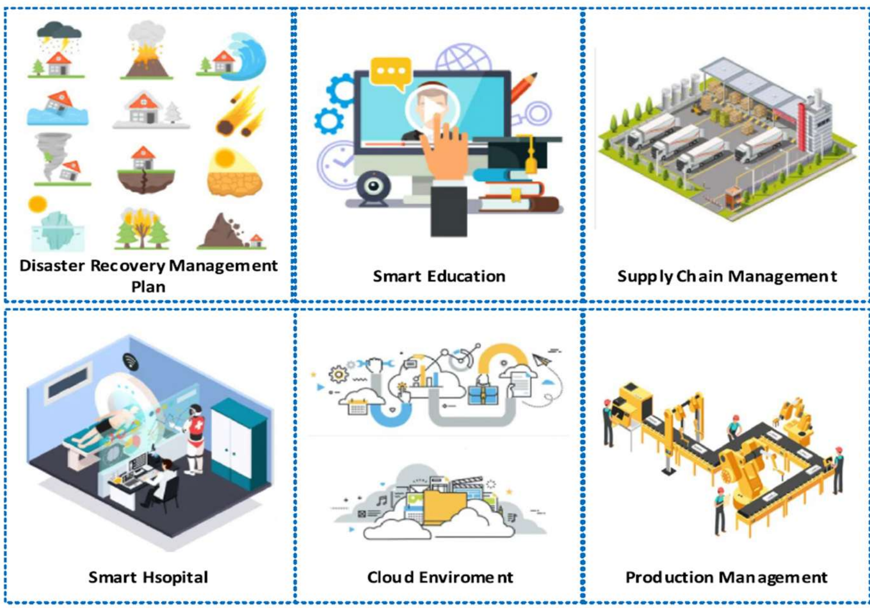

Figure 1a Applications of Industry 5.0

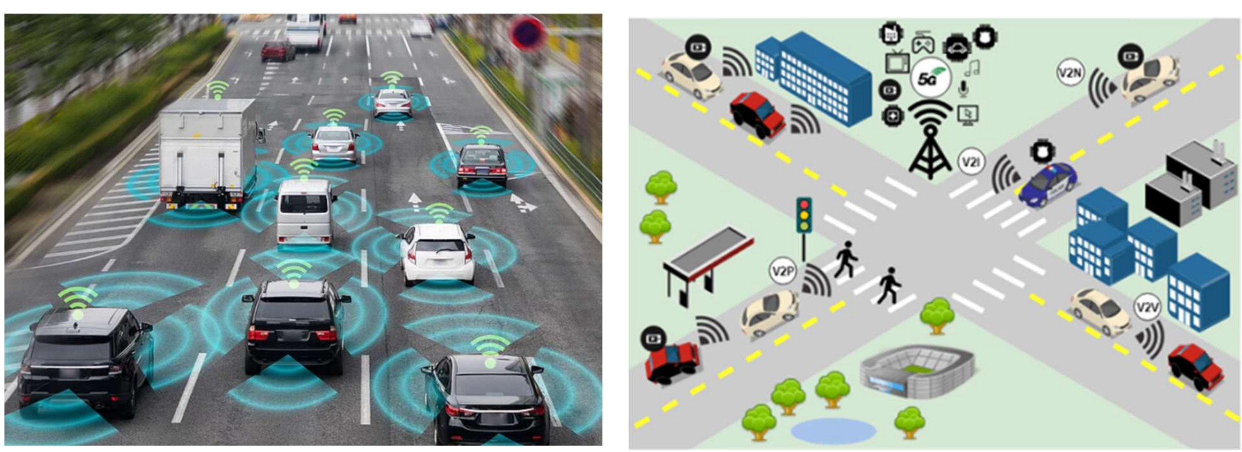

Figure 1b Applications of Industry 5.0

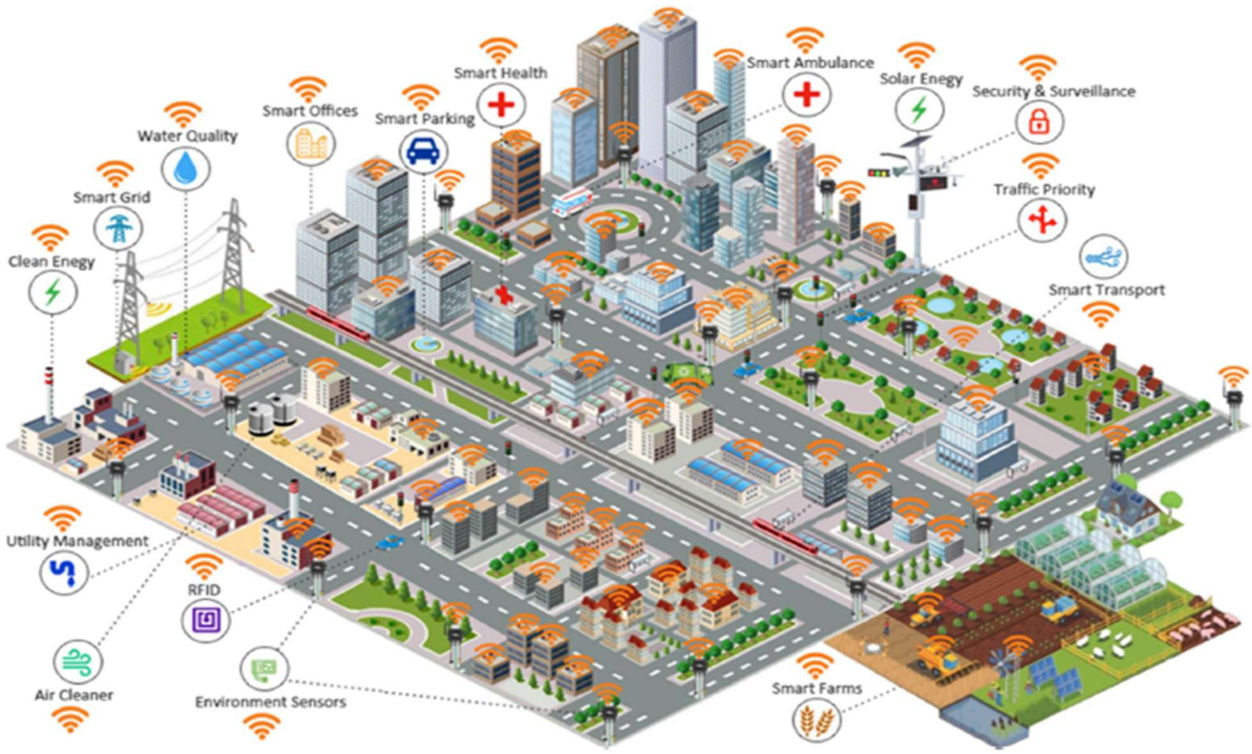

Figure 1c Applications of Industry 5.0

1.2 Define the key terms and concepts:

Skills:

Skills refer to the abilities, knowledge, and expertise possessed by individuals that enable them to perform tasks, solve problems, and achieve specific objectives. In the context of Industry 5.0, operational excellence and Total Productive Maintenance (TPM), skills may encompass technical proficiencies, problem- solving capabilities, communication skills, and other competencies relevant to the effective operation and maintenance of equipment.

1. Industry 5.0 Integration:

Data Analytics and AI: Utilize data analytics and AI algorithms to predict equipment failures, optimize maintenance schedules, and identify areas for improvement.

IoT Sensors and Monitoring: Implement IoT sensors on equipment to collect real-time data on performance, vibration, temperature, etc., enabling predictive maintenance and proactive troubleshooting.

Automation and Robotics: Explore the use of robotic arms and automation systems for tasks like inspections, lubrication, and minor repairs, reducing human error and freeing up maintenance personnel for strategic tasks.

Figure 1c Industry 5.0

2. Operational Excellence:

Continuous Improvement:

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

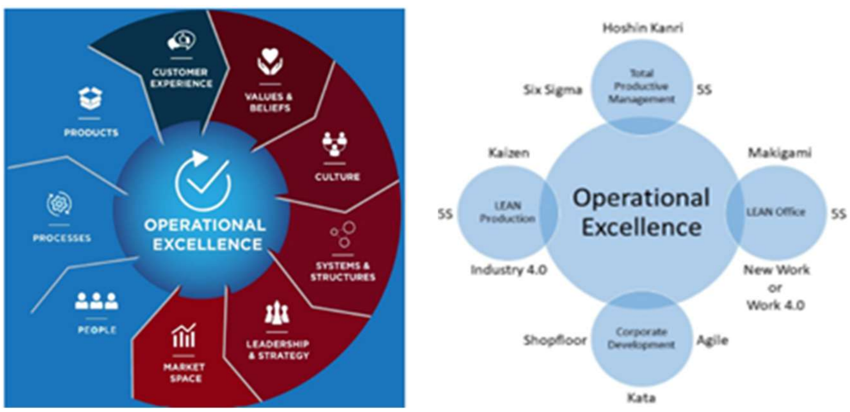

Figure 1d Operation Excellence

Overall Equipment Effectiveness (OEE):

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

Cost Reduction:

Implement TPM and Industry 5.0 technologies to reduce maintenance costs, minimize downtime, and improve 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 enhance customer satisfaction

3. Total Productive Maintenance (TPM):

TPM is a comprehensive maintenance philosophy and strategy originated in Japan. TPM target to optimize the operational productivity of any equipment by involving whole organization in the equipment repair process. It focuses on proactive and preventive maintenance, employee empowerment, and continuous improvement to eliminate losses and to enhance overall equipment effectiveness (OEE).

I) TPM Effectiveness:

TPM effectiveness refers to the degree to which Total Productive Maintenance strategies and practices achieve their intended goals. It involves assessing the positive results of TPM on major performance indicators such as OEE, reduced downtime, increased productivity, improved quality of product on global benchmarks.

II) TPM Factors:

TPM factors are the key components or elements that contribute to the success and effectiveness of Total Productive Maintenance. These factors can include, but are not limited to, autonomous maintenance, planned maintenance, focused improvement, skills development, early equipment management, and safety, among others. Each factor plays a specific role in achieving the overarching objectives of TPM.
These definitions provide a foundational understanding of the key terms and concepts related to the assessment of the impact of skills on selected factors of Total Productive Maintenance effectiveness. It's essential to refer to authoritative sources and scholarly literature to ensure accuracy and depth in understanding these concepts within the specific context of your 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 the performance and reliability of production assets.

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 the 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 sharedresponsibility for equipment maintenance. The philosophy rests on the belief that by involving every employee, from frontline operators to upper management, organizations can achieve higher levels of overall equipment effectiveness (OEE) and minimize losses associated with equipment breakdowns, setup times, and other inefficiencies.

The pillars of TPM serve as the foundational principles guiding its implementation. Autonomous Maintenance empowers operators to take charge of routine maintenance tasks, Planned Maintenance introduces scheduled and systematic approaches to minimize unplanned downtime, and Focused Improvement (Kaizen) fosters a culture of continuous improvement through small, incremental changes.

As industries evolve, the role of skills in TPM effectiveness has garnered increased attention. Technical proficiency, problem-solving abilities, and commitment to ongoing education are now recognized as essential components for successful TPM implementation. Organizations acknowledge that the effectiveness of autonomous maintenance, planned maintenance, and continuous improvement initiatives is intricately tied to the skills and competencies of their workforce.

Despite the proven benefits of TPM, challenges persist in its adoption. Resistance to change, a lack of understanding or commitment at various organizational levels, and the need for a cultural shift towards proactive maintenance practices are common hurdles. This underscoresthe importance of not only robust TPM frameworks but also a workforce equipped with the requisite skills to navigate the complexities of modern industrial environments.

Considering these considerations, assessing the impact of skills on selected factors of TPM effectiveness becomes a crucial endeavor. The objective is to unravel the intricate relationship between skills and key performance indicators such as OEE, MTBF, and MTTR. This assessment aims to provide actionable insights, guiding organizations in tailoring trainingprograms, fostering a culture of continuous improvement, and addressing skill-related challenges to unlock the full potential of TPM in optimizing maintenance practices. In the dynamic landscape of industrial operations, this exploration of skills within the context of TPM stands as a cornerstone for achieving sustained operational excellence.

Overview of Total Productive Maintenance:

Total Productive Maintenance is a comprehensive an 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:

Focused on Employee Involvement: TPM emphasizes the active involvement of all employees, fostering a sense of ownership and responsibility for equipment maintenance. Preventive and Predictive Maintenance: TPM advocates proactive maintenance strategies, including preventive and predictive maintenance, to prevent equipment failures and reduce unplanned downtime.

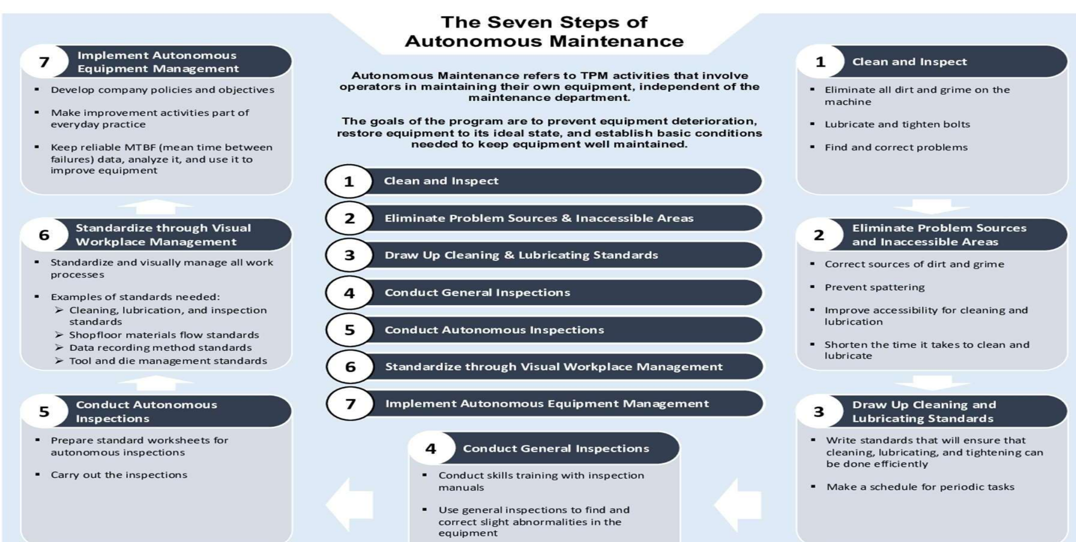

Figure 2 JH (Jishu Hozen - Autonomous Maintenance)

The Four Main Pillars of TPM (for 1st phase):

1. **JH (Jishu Hozen - Autonomous Maintenance):** Jishu Hozen involves empowering equipment operators to take responsibility for routine maintenance tasks on their machines. Operators are trained to conduct inspections, clean equipment, and address minor issues. The goal is to develop a sense of ownership among operators, reduce the likelihood of breakdowns, and create a proactive culture of self- maintenance on the shop floor.
2. **KK (Kobestsu Kaizen –** Focus Improvement) Total Productive Maintenance (TPM) is a strategy designed to the 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 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.

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:

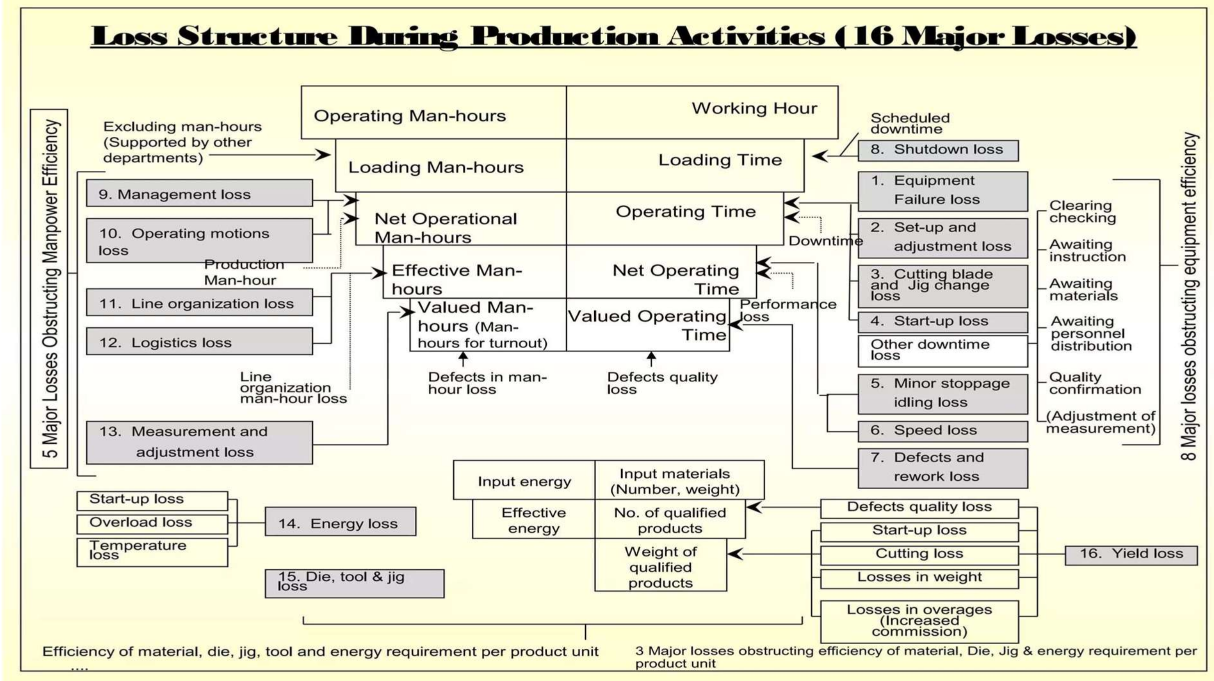

Figure 3. 16 types of loss definition

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):**

Integrates quality control into the maintenance process to prevent defects and ensure that equipment operates at peak performance. Quality Maintenance integrates quality control principles into the maintenance process. This pillar emphasizes preventing defects and ensuring that equipment operates at peak performance to produce high-quality products. QM involves the incorporation of quality checks and measures into routine maintenance tasks, minimizing variations in equipment performance that could impact product quality.

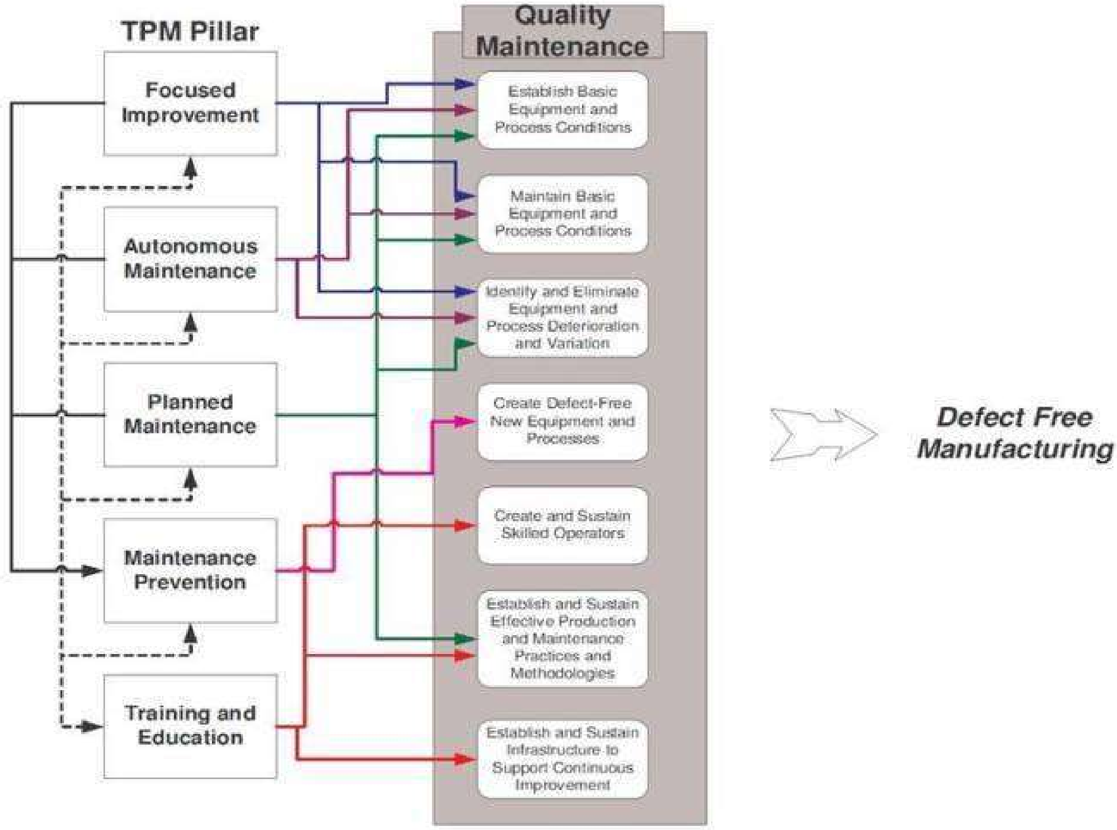

Figure 4 QM (Quality

Maintenance)Benefits of Implementing TPM:

1) **Increased Equipment Reliability:** TPM reduces breakdowns, leading to increased equipment reliability and availability.
2) **Enhanced Productivity:** Improved efficiency and reduced downtime contribute tohigher overall productivity.
3) **Cost Savings:** Preventive maintenance and reduced breakdowns result in cost savingsassociated 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 maintenance procedures should be executed, and staff members need to be educated on 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 testing and refining the approach before full-scale implementation. In this step we select the manager model machines for the initial primary target.

Step4- Continuous Improvement: Emphasize the culture of continuous improvement. Regularly review and assess the 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 the implementation of TPM, laying the foundation for improved equipment performance and operational excellence.

6.2 Evaluation of Total Productive Maintenance:

TPM originated in Japan and evolved as a key component of the Toyota Production System, gaining prominence in the latter half of the 20th century. The philosophy of TPM shifted the paradigm from traditional reactive maintenance practices, which addressed issues only when they arose, to a more proactive and preventive approach. The core philosophy is based on the belief that everyone in the organization, from shop floor employees to top management, has a role a main role plays in equipment maintenance.

Pillars of TPM:

The success of TPM relies on a set of foundational pillars, each addressing specific aspects of maintenance and production. These pillars include:

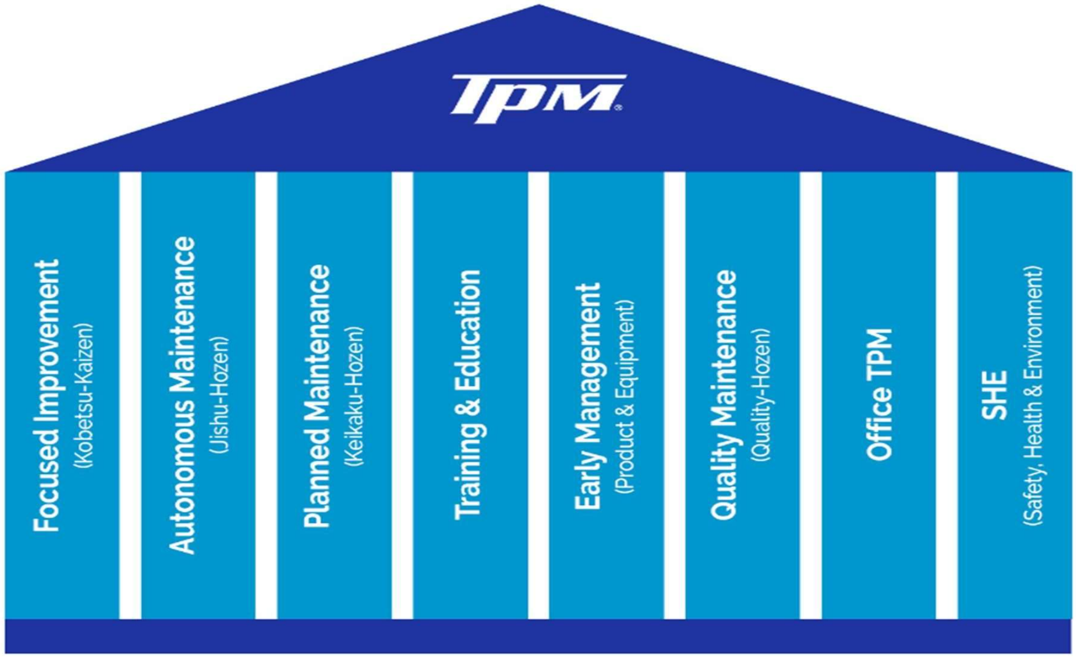

Figure 5 TPM Pillars

The 8 Pillars of Total Productive Maintenance are specific elements within the broader framework of 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 employees at all levels to identify and implement from small, incremental improvements/ kaizen in processes, equipment, and workflows. The goal is to create a culture of continuous learning and enhancement.

2) **Autonomous Maintenance:**

This pillar emphasizes empowering 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.

4) **Education and Training:**

Education and Training are essential pillars to build the 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 the success of TPM initiatives.

5) **Early Equipment Management:**

The Early Equipment Management approach concentrates on 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 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 defects and ensuring that equipment operates at the highest quality standards. This pillar aims to minimize variations in equipment performance that could lead to quality issues in the final product.

7) **TPM in Administration:**

TPM in Administration extends 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 equipment reliability, enhanced quality, and overall operational excellence within an organization.

8) **Safety, Health, and Environment:**

This pillar recognizes the importance of Incorporating safety, health, and blending environmental considerations into maintenance procedures. It emphasizes creating a safe working environment, ensuring the well-being of employees, and minimizing the environmental impact of maintenance activities.

6.3 Challenges in TPM Implementation:

By Implementing the Total Productive Maintenance (T P M) represents paradigm shift for organizations aspiring to optimize their maintenance practices and elevate operational efficiency. While TPM offers a wealth of benefits, the journey toward its successful 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 ongoing support.

Integration challenges with existing systems can disrupt workflow and hinder the 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, organization can unlock the true value TPM, cultivate a culture of ongoing improvement, and drive long-term operational excellence

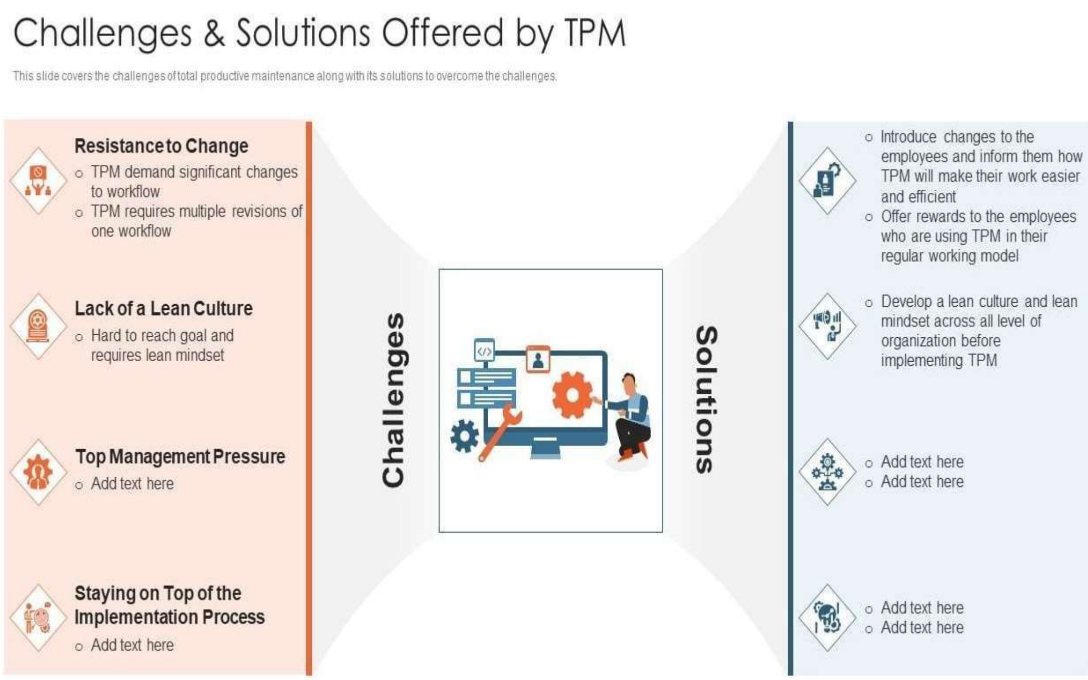

Figure 6A The Challenges of Implementing TPM

6.4 The Significance of Total Productive Maintenance:

Total Productive Maintenance holds paramount significance in the domain of industrial management, playing a pivotal role in enhancing operational efficiency and fostering a culture of improvement in all areas.

TPM goes beyond traditional maintenance practices, emphasizing holistic and proactive approach. The significance of TPM can be discerned through several key dimensions.

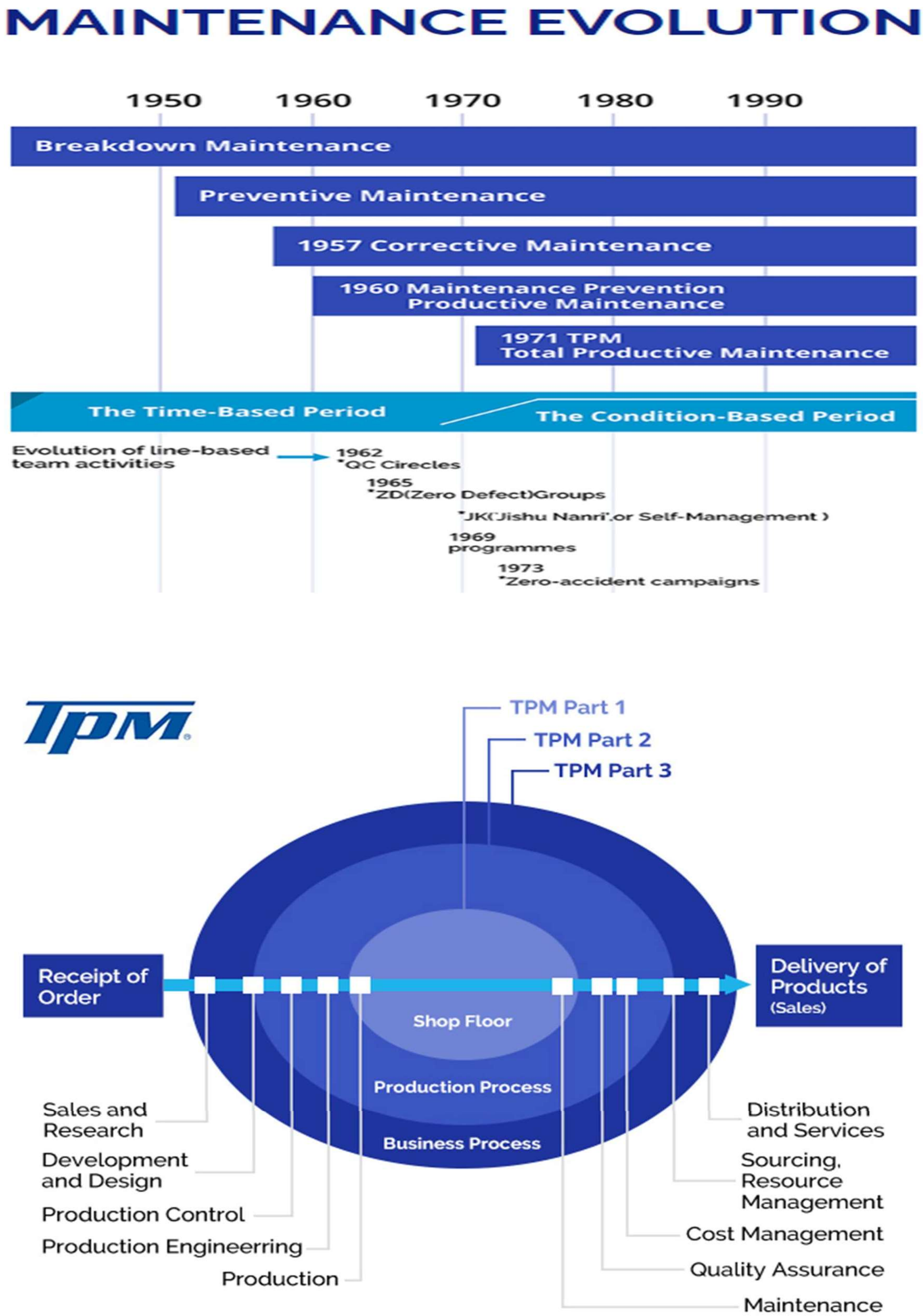

Figure 6B Maintenance Revolution

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

Position	Role description	Owns execution for...	Typical daily commitment**
Operations Manager	**Own overall BU results (all systems/lines in BU)** • Lead deployment of Autonomous Maintenance (AM) • Drive & maintain OEE / Loss Deployment • Build capabilities of line, maint., and process leads • Develop and execute daily action plan for the day	Daily Direction Setting (DDS)	25-50%
Line / Team Leader	**Own results on a particular line(s)** • Drive execution of daily AM action plans • Develop and execute daily action plan for the shift	Clean, Inspect, Lub (CIL) Skill gaps / training	25-75%
Maintenance Leader	**Own overall BU maintenance results** • Drive execution of PM action plans • Develop and implement maintenance processes • Manage equipment defects and failures	Defect handling Breakdown elimination	25-75%
Process / Quality Leader	**Own overall BU engineering, process, and system results** • Develop and implement standards for equipment • Drive reduction in changeover / clean duration • Manage improvements, process settings, and centerlines	Center-lining Process Control Rapid changeover Specifications	25-50%

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

Figure 7 Implementation of TPM

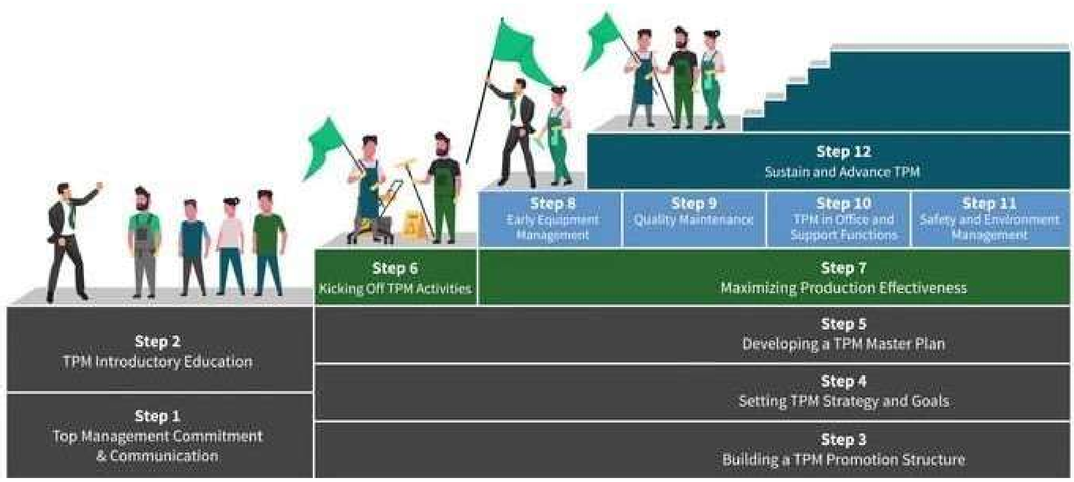

Figure 8 TPM preparation, Kick off and Implementation.

6.4 The Role of Skills in TPM Implementation:

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

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

Machine operation and maintenance skills: These skills allow the operators to operate the machines safely and efficiently, and to perform routine maintenance tasks such as cleaning, lubricating, inspecting, and adjusting the machines. These skills also help the operators to detect and report any abnormal conditions or defects in the machines, and to participate in improvement activities such as kaizen and poka-yoke.

Quality control and assurance skills: These skills enable the operators to monitor and control the quality of the products and processes, and to prevent and eliminate any defects or errors. These skills also involve the use of various quality tools and techniques, such as statistical process control, 5S, 7QC tools, and FMEA.

Safety and environmental skills: These skills ensure the safety and health of the employees and the environment and comply with the relevant regulations and standards. These skills include the knowledge and practice of safety rules and procedures, the use of personal protective equipment, the identification and elimination of hazards and risks, and the prevention and management of accidents and emergencies.

Communication and teamwork skills: These skills facilitate collaboration and coordination among the employees and the departments, and the sharing of information and feedback. These skills also involve the use of effective communication tools and methods, such as visual management, standard work, and Gemba walks.

Problem-solving and decision-making skills: These skills enable the employees to analyze and solve the problems that arise in the production system, and to make informed and timely decisions. These skills also involve the use of various problem-solving tools and techniques, such as PDCA, A3, fishbone diagram, and 5 whys.

Leadership and management skills: These skills are required for the managers and supervisors who are responsible for planning, organizing, directing, and controlling the TPM activities. These skills also involve the ability to motivate and empower the employees, to set and monitor the goals and targets, to evaluate and improve the performance, and to manage the change and innovation.

The Education and Training Pillar in TPM concentrates on imparting essential skills and knowledge to employees, enabling effective job performance and continual enhancement of their capabilities. This encompasses training across diverse domains like machine operation, maintenance, quality control, and safety1. This Pillar adheres to fundamental principles including ongoing learning and improvement, active employee participation, standardization, data-informed decision-making, and the development of leadership and culture, maintaining a yet unpublished approach.

The skills role in TPM implementation is crucial, as it determines the success and sustainability of the TPM program. Organizations that have successfully implemented TPM provide comprehensive training and education to all employees involved in the process. They also create a culture of learning and improvement, where the employees are encouraged and rewarded for developing and applying their skills.

6.5 Selected Factors of TPM Effectiveness:

In evaluating the effectiveness of 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:

Overall Equipment Effectiveness - OEE: OEE serves as an all-encompassing metric, amalgamating availability, performance, and quality to gauge the efficiency of equipment utilization. Elevated OEE signifies proficient TPM implementations.

M T B F: Mean Time Between Failure measures the average time an equipment operates without a failure. Longer M T B F values suggest improved equipment reliability due to successful TPM strategies.

M T T R: Mean Time To Repair evaluates the average actual time taken to repair equipment and machines post a failure. Diminished M T T R values indicate streamlined maintenance procedures and reduced downtime.

Equipment Availability: This factor quantifies the percentage of time during which equipment is accessible for production. High equipment availability reflects effective TPM in ensuring equipment readiness.

Rate of Defects or First Pass Yield: Evaluates the percentage of products meeting quality standards on the first production run. A low defect rate signifies the success of TPM in improving product quality.

Percentage of Planned Maintenance vs. Unplanned Maintenance: Compares the ratio of maintenance activities designated as planned versus unplanned. A heightened percentage of planned maintenance signifies proactive TPM.

Utilization of Autonomous Maintenance: Measures the extent to which operators engage in autonomous maintenance tasks. Increased utilization reflects a cultural shift and successful TPM implementation.

Reduction in Breakdowns: Tracks the decrease in the frequency of unexpected equipmentbreakdowns. A reduction in breakdowns demonstrates the preventive nature of TPM. **Employee Engagement and Training Levels:** Assesses the level of employee involvement inTPM activities and the success of training programs. High engagement and well-executedtraining contribute to TPM effectiveness.

Safety Performance: Evaluates safety records and incidents related to equipment. SuccessfulTPM is often associated with a safer work environment and fewer incidents.

Rate of Continuous Improvement (Kaizen) Initiatives: Measures the frequency and success of continuous improvement initiatives. A high rate of Kaizen initiatives indicates a culture of ongoing improvement fostered by TPM.

Alignment with Production Targets: Examines how well TPM practices align with and contribute to achieving production targets. Successful TPM directly supports the organization in meeting or exceeding production goals.

These factors collectively provide a comprehensive picture of TPM effectiveness, enabling organizations to identify strengths, address weaknesses, and continuously improve their maintenance and operational strategies. Regular monitoring of these factors is essential for ensuring the sustained success of TPM initiatives.

6.6 Objectives of the Study

In evaluating the effectiveness of 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.

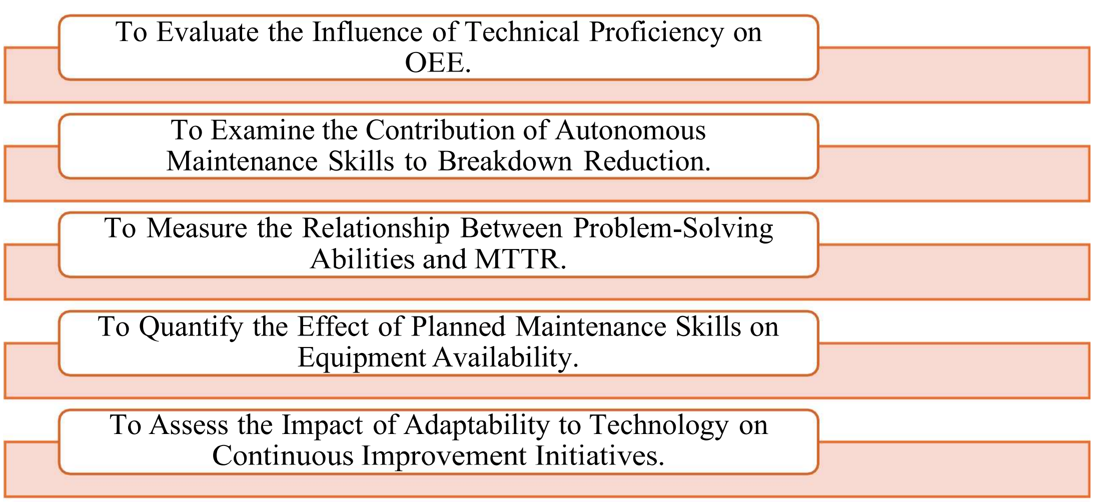

Figure 9 Objectives of The Study

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 practices and operational excellence.

1. Skills in 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 cantered on safety and continuous improvement. The key skill areas required for effective autonomous maintenance include:

Machine operation and maintenance skills: These skills allow the operators to operate the machines safely and efficiently, and to perform routine maintenance tasks such as cleaning, lubricating, inspecting, and adjusting the machines. These skills also help the operators to detect and report any abnormal conditions or defects in the machines, and to participate in improvement activities such as kaizen and poka-yoke.

Quality control and assurance skills: These skills enable the operators to monitor and control the quality of the products and processes, and to prevent and eliminate any defects or errors. These skills also involve the use of various quality tools and techniques, such as statistical process control, 5S, 7QC tools, and FMEA.

Safety and environmental skills: These skills ensure the safety and health of the employees and the environment and comply with the relevant regulations and standards. These skills include the knowledge and practice of safety rules and procedures, the use of personal protective equipment, the identification and elimination of hazards and risks, and the prevention and management of accidents and emergencies.

Communication and teamwork skills: These skills facilitate collaboration and coordination among the employees and the departments, and the sharing of information and feedback. These skills also involve the use of effective communication tools and methods, such as visual management, standard work, and Gemba walks.

Problem-solving and decision-making skills: These skills enable the employees to analyze and solve the problems that arise in the production system, and to make informed and timely decisions.

2. Skills in PM:

PM within the Total Productive Maintenance framework requires a specificset 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 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 the analysis of maintenance trends and the optimization of future maintenance plans. This documentation is vital in tracking equipment history and performance over time.

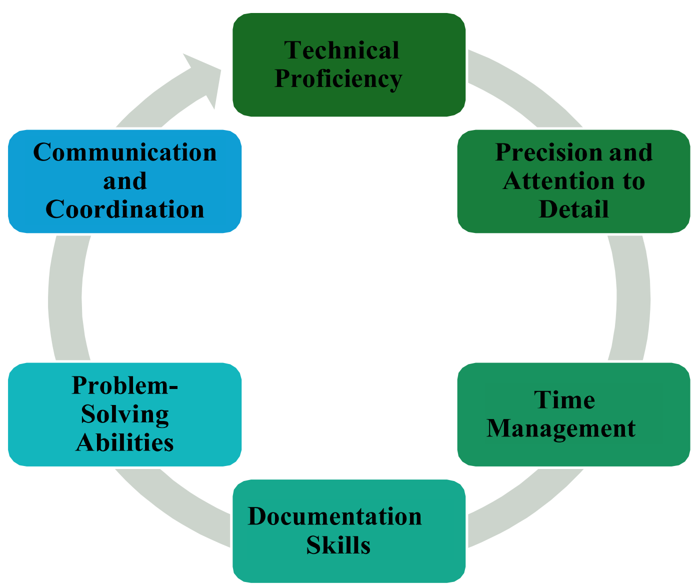

Figure 10 Skills in Planned Maintenance

Communication skills play a pivotal role in coordinating planned maintenance activities. Effective communication ensures that all relevant stakeholders, including production teamsand 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 problem-solving skills for resolution. The ability to identify root causes and 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 ensure that planned maintenance tasks are carried out in accordance with best practices, enhancing the reliabilityand 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 to a cohesive approach, fostering a culture of shared responsibility for equipment care.
In conclusion, skills in planned maintenance are diverse, encompassing technical 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, ensuringsustained improvement.

Data Analysis: The ability to collect, analyze, and interpret 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 success of 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.

4. 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 timesin production processes, enhancing overall operational efficiency.

5. Training and Development Programs:

Training and development programs within the Total Productive Maintenance (TPM)framework are designed to equip the workforce with the essential skills and knowledgerequired for the effective implementation and sustained upkeep of TPM practices in our area.These programs typically encompass a range of technical skills, including equipmentmaintenance and troubleshooting, as well as soft skills such as teamwork, communication, andproblem-solving. Specific training initiatives often focus on autonomous maintenance,empowering operators to take on routine tasks

and fostering a proactive mindset. Continuouslearning is emphasized, ensuring that employees stay abreast of evolving TPM principles andbest practices. The goal of these programs is not only to enhance individual competencies butalso to cultivate a culture of continuous improvement where the workforce actively contributesto the success of TPM initiatives. Effective training and development programs play a vital rolein creating A proficient and committed workforce capable of steering TPM success andattaining operational excellence. The objectives related to training and development include:

Skill Enhancement: Provide training programs to enhance technical skills related tomaintenance tasks, ensuring that the workforce is equipped for the demands of TPM.
Autonomous Maintenance Training: Implement training initiatives to empower operatorswith 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.

6. Organizational Culture and Leadership:

The impact of organizational culture and leadership on 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.

Continuous Improvement Culture: Instill a culture of continuous improvement were every member of the organization is encouraged to contribute ideas and 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

Farkhan Fajar Nurdin(2023) Improper handling and maintenance can cause a decrease in the level and effectiveness of a machine, which will have an impact on the output of the products produced. Machines that are used continuously certainly affect the efficiency of the machine. To increase the productivity of the machine, the Total Productive Maintenance (TPM) method is used using the calculation of Overall equipment Effectiveness (OEE). This discussion is expected to provide information on an explanation of the explanation of machine repair with a calculation method that also provides an overview of how to apply the method, with data attached through references from journals that analyze the efficiency of a machine. The research was conducted by means of Literature Review, namely analyzing relevant journals or articles and focusing on improving the efficiency of a machine. After this research is carried out the results, we can find out the purpose of TPM is to prevent the occurrence of six Big Losses. While OEE is a value expressed as a ratio between actual output divided by themaximum output of equipment at the best performance conditions.

Guilherme Luz Tortorella(2022) This paper analyzes the joint adoption of Industry 5.0 (I5.0) technologies and Total Productive Maintenance (TPM) practices in manufacturing firms. For that, we surveyed 335 practitioners from firms currently implementing TPM and I 5.0, locatedin sixteen countries. The collected dataset was analyzed using sets of partial correlation analyses, obtained when controlling the effect of three contextual variables, all assessed at the firm level: (i) socio-economic context, (ii) technological intensity, and (iii) size. Pairs of TPM practices and I 5.0 technologies with significant positive correlations in all partial correlation sets indicate positive trends in the adoption of elements in the pairs, regardless of context, and may be viewed as indicators of TPM practices and I 5.0 technologies more prone to be integrated. Our results identified 67 pairs of I 5.0 technologies and TPM practices meeting the significance criterion. This research investigated the relationship between the adoption of TPM practices and I 5.0 technologies in a large sample of manufacturing firms. Based on commonalities found in six sets of partial correlation analyses controlling the effects of socio-economic context, technology intensity, and company size, 67 positive partial correlations stood out regardless of the company's context, indicating some synergistic relationships between TPM and I 5.0. Four TPM practices and two I 5.0 technologies were found to be more frequently present in joint implementations of TPM and I 5.0 in our sample of firms. Our findings contributed to both theory and practice on Maintenance digitalization. Below is some main key lessons learned.

1) **Operational Excellence:**

TPM's primary goal is to optimize the efficiency of production equipment. By minimizing downtime, reducing breakdowns, and enhancing overall equipment effectiveness (OEE), TPM contributes to operational excellence, ensuring a smooth and efficient production process.

2) **Proactive Maintenance Culture:**

TPM represents a shift from reactive to proactive maintenance strategies. By focusing on preventive measures, scheduled maintenance, and autonomous activities, TPM minimizes the occurrence of unplanned downtime, reducing disruptions to production schedules.

3) **Employee Engagement and Ownership:**

TPM engages the entire workforce in the maintenance process, fostering a sense of ownership and responsibility for equipment care. This active involvement empowers employees at all levels, cultivating a collaborative environment and a shared commitment to operational success.

4) **Addressing Losses Systematically:**

TPM strategically addresses the "Six Big Losses" in production, which include breakdowns, setup, measuring adjustment time, idling and minor stops, slow speed, defects, and start up losses. Through the mitigation of these losses, TPM enhances efficiency and resource utilization, fostering an unpublished approach.

5) **Autonomous Maintenance Empowerment:**

The emphasis on autonomous maintenance empowers operators to take on routine tasks, promoting a sense of pride and accountability. This not only improves equipment reliability but also instils a proactive mindset throughout the organization.

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 a proactive mindset, and create a workplace culture committed to continuous improvement. TPM stands as a fundamental strategy for organizationsaspiring to achieve operational excellence and sustain competitiveness in the dynamic landscape of industrial operations.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In the evolving framework of Industry 5.0 and the broader pursuit of Operational Excellence, assessing the influence of workforce skills on the effectiveness of Total Productive Maintenance (TPM) demands a structured and comprehensive methodology. This approach is designed to explore the nuanced relationship between human capabilities and the critical success factors of TPM in a digitally integrated and human-centric industrial environment. Utilizing a multi-dimensional assessment model, the methodology examines essential competencies—ranging from technical proficiency to problem-solving agility and cross-functional collaboration—that are central to Industry 5.0 principles. Through a combination of empirical tools such as structured interviews, focused surveys, and performance-based metrics, this assessment quantitatively and qualitatively measures the impact of skill levels on core indicators of TPM success, including Overall Equipment Effectiveness (OEE), Mean Time to Repair (MTTR), and the ratio of planned versus unplanned maintenance activities. By anchoring this investigation in both human and operational dimensions, the methodology provides actionable insights into how workforce readiness and advanced skill development contribute to the seamless integration of TPM practices, ultimately enhancing reliability, responsiveness, and strategic value creation within next-generation industrial systems.

3.2 Research and design:

The research framework developed to examine the influence of workforce capabilities on key elements of Total Productive Maintenance (TPM) within the context of Industry 5.0 and Operational Excellence adopts a rigorous and multidimensional methodology. By leveraging a mixed-methods design, the study integrates both quantitative and qualitative techniques to uncover the complex dynamics between human skills and the performance of TPM systems in smart manufacturing environments. Utilizing a stratified random sampling strategy, the study ensures broad inclusion across different departments and varying expertise levels, enabling a more granular analysis of skill distribution and impact.

In the quantitative segment, structured tools such as surveys and scaled assessments are deployed to evaluate employee competencies—such as technical aptitude, adaptability, and problem-solving acumen—positioned as independent variables. Correspondingly, TPM performance indicators, including Overall Equipment Effectiveness (OEE) and Mean Time Between Failures (MTBF), function as dependent variables. Statistical tools like correlation matrices and regression analysis are applied to interpret relationships and determine predictive strength. Complementing this, the qualitative dimension employs thematic analysis to extract insights from interview narratives and observational data, capturing the human-centric aspects emphasized in Industry 5.0.

Attention to research ethics, systematic validation protocols, and a defined implementation timeline ensure methodological reliability and conceptual alignment with the goals of Operational Excellence. Ultimately, the research aims to generate actionable insights on how skill development can enhance TPM strategies, drive equipment reliability, and foster resilient, intelligent, and human-focused industrial systems.

3.3 Data collection:

The collection of data process for assessing the impact of skills on selected factors of Total Productive Maintenance (TPM) effectiveness involves a strategic and systematic approach to gather both quantitative and qualitative information. The following outlines key components of the data collection process:

Figure 11 Data Collection

1. **Quantitative Data Collection:**

Surveys and Questionnaires: Designing structured surveys and questionnaires that focus on assessing specific skills, including technical proficiency, problem-solving abilities, and collaboration skills. Likert scales and numerical assessments will be utilized to quantify responses.

Skill Assessment Tools: Implementing standardized skill assessment tools to objectively measure the technical competencies of the workforce. These tools may include practical assessments or knowledge tests tailored to TPM-related skills.

TPM Performance Metrics: Collecting quantitative data on TPM performance metrics, including Overall Equipment Effectiveness, mean time to repair, the percentage of the planned maintenance vs unplanned maintenance. This data provides a quantitative measure of TPM effectiveness.

2. Qualitative Data Collection:

In-Depth Interviews: Conducting in-depth interviews with key stakeholders, including maintenance personnel, supervisors, and managers. These interviews will explore qualitative insights into the impact of skills on TPM factors, capturing individual experiences and perceptions.

Focus the Group Discussions: Organizing focus the group discussions to facilitate interactive conversations among the participants. This qualitative method allows for the exploration of shared perspectives, group dynamics, and in-depth insights into the cultural aspects of skill utilization in TPM.

Document Analysis: Reviewing relevant documents, reports, and records related to TPM activities. This includes analyzing incident reports, maintenance logs, and training records to gain additional context and insights into the practical application of skills in the TPM framework.

3. Sampling the Strategy:

Implementing a stratified random sampling and a strategy to ensure representation from different departments, skill levels, and roles within the organization. This approach aims to capture a diverse range of perspectives, and the experiences related to TPM practices.

4. Data Management:

Establish a secure and organized data management system to handle both quantitative and qualitative data. This includes and unitizing responses to ensure participant confidentiality and employing data coding for qualitative analysis.

3.4 Data analysis:

6.7.1 Qualitative Data Analysis:

Thematic Analysis:

The Thematic analysis will be utilized to recognize, analyze, and report patterns (themes) within qualitative data. This method involves basically systematically coding and categorizing data to identify recurring themes related to the impact of skills on TPM factors. Themes will be derived from the content of interviews, focus group discussions, and document analysis.

Content Analysis:

Content analysis will be applied to scrutinize the content of documents and reports associated with TPM practices. This method entails systematically categorizing and interpreting textual data to identify key patterns, trends, and insights. It provides a structured approach to analyzing qualitative content within the context of the research objectives.

Constant Comparative Method:

The constant comparative method will be employed during the analysis of qualitative data, particularly in interviews and focus group discussions. This iterative process involves comparing new data with previously collected data, refining categories and themes as the analysis progresses. It enhances the depth and richness of the qualitative findings.

Coding and Categorization:

Qualitative data, including interview transcripts and qualitative survey responses, will be coded, and categorized based on emerging themes and patterns. This systematic approach ensures that relevant information is organized for subsequent analysis and interpretation.

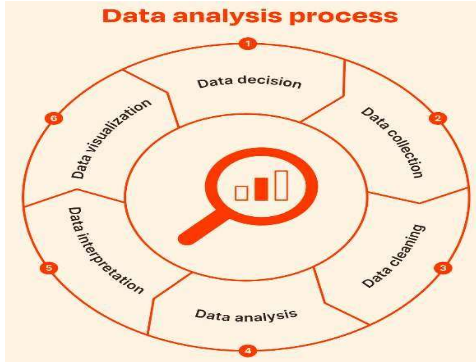

Figure 12 Data Analysis

Quantitative Data Analysis:

Descriptive Statistics: Descriptive statistics, encompassing indicators of central tendency suchas mean and median, as well as measures of variability like standard deviation, disclosed., willbe used to summarize and describe quantitative data from surveys and skill assessments. Thisprovides an overview of the distribution of skills and performance metrics within the sample. **Correlation Analysis:** Correlation analysis will be conducted to examine the relationshipsbetween different skills and TPM factors. For example, assessing the correlation betweentechnical proficiency scores and Overall Equipment Effectiveness (OEE). This statisticalmethod helps identify potential associations and dependencies.

Regression Analysis: Regression analysis will be employed to explore the impact of skills on selected TPM factors while controlling for potential confounding variables. This method allows for the identification of specific skills that significantly contribute to variations in performance metrics, such as meantime to repair or breakdown reduction.

Comparative Analysis: Comparative analysis will be used to compare the performance metrics of different groups within the organization based on skill levels. This includes comparing the TPM effectiveness of high-skill groups versus low-skill groups, providing insights into the differential impact of skills on selected factors.

Data Visualization: Graphical representations, such as charts and graphs, will be used to visually present quantitative data. This includes visualizing the distribution of skills, performance metrics, and any identified patterns or trends. Visualization enhances the clarity and interpretability of quantitative findings.

Statistical Software: software, such as SPSS, will be utilized for quantitative data analysis. These tools facilitate the application of advanced statistical techniques and ensure the accuracy and efficiency of the analysis process.

By integrating both qualitative and quantitative data analysis methods, the research aims to provide a comprehensive or nuanced understanding of how skills impact selected factorsof Total Productive Maintenance (TPM) effectiveness within the organizational context. Triangulating findings from these analyses enhances the robustness and validity of the research outcomes.

3.5 Research Method and Analysis

The research framework developed to examine the influence of workforce capabilities on key elements of Total Productive Maintenance (TPM) within the context of Industry 5.0 and Operational Excellence adopts a rigorous and multidimensional methodology. By leveraging a mixed-methods design, the study integrates both quantitative and qualitative techniques to uncover the complex dynamics between human skills and the performance of TPM systems in smart manufacturing environments. Utilizing a stratified random sampling strategy, the study ensures broad inclusion across different departments and varying expertise levels, enabling a more granular analysis of skill distribution and impact.

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Attention to research ethics, systematic validation protocols, and a defined implementation timeline ensure methodological reliability and conceptual alignment with the goals of Operational Excellence. Ultimately, the research aims to generate actionable insights on how

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 Operational Excellence, evolves further under the framework of Industry 5.0, where human-centric innovation and 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 three major losses category that impede efficient use of production resources are typically categorized as follows:

1. Availability Losses: These are losses due to equipment failures, planned maintenance time loss, setup loss, tool change loss, and start-up loss.

For example, breakdown loss (failure losses) are losses due to failures. Another example is setup and adjustment losses which refer to time losses from the end of the production of a previous item through product- change adjustment to the point where the production of the new item is completely satisfactory.

2. Performance Losses: These are losses due to minor stoppages and reduced speed. For instance, minor stoppage loss occurs when the equipment temporarily stops or idles due to sensor actuation or jamming of the work. Speed loss is the loss caused by the difference between the designed speed and the actual working speed.

3. Quality Losses: These are losses due to defects and reworks. Defect and rework loss is the loss caused when defects are found and must be reworked. These losses can significantly impact the efficiency of production subsidiary resources and are often the focus of improvement initiatives in manufacturing environments.

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 is important to acknowledge certain limitations. Firstly, the findings are based on self-reported perceptions, which may be subject to bias or subjective interpretation. Assessment also assumes a certain level on 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.

Brings the types of maintenance used by the companies. A balanced distribution can be observed among predictive, with 20%, preventive, 22.2%, planned corrective, 24.4% and unplanned corrective maintenance, 24.4%. It is emphasized that the expectation for the lasttype of maintenance is at a lower rate due to the expected technological evolution and the development of professionals in the implemented process.

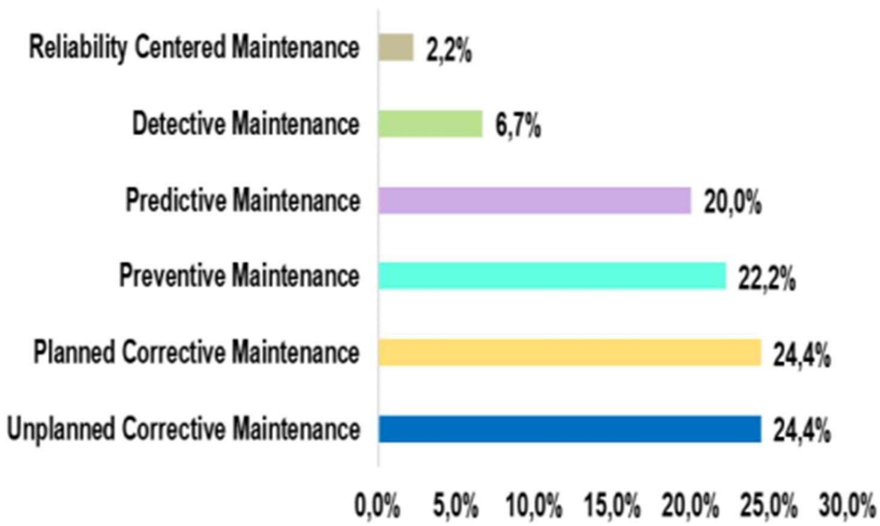

Fig. 13 Maintenance types used by the company.

Figure 14 shows the implemented TPM pillars, highlighting the pillars of Focused Improvement, with 17.7%, concentrated on the global improvement of business, and Planned Maintenance, with 17.7%, aiming to plan, execute and control the maintenance program.

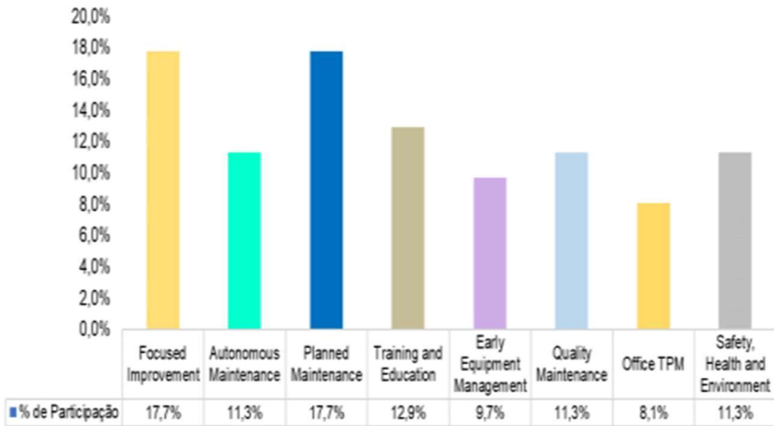

Figure 14: Incidence of implemented TPM pillars

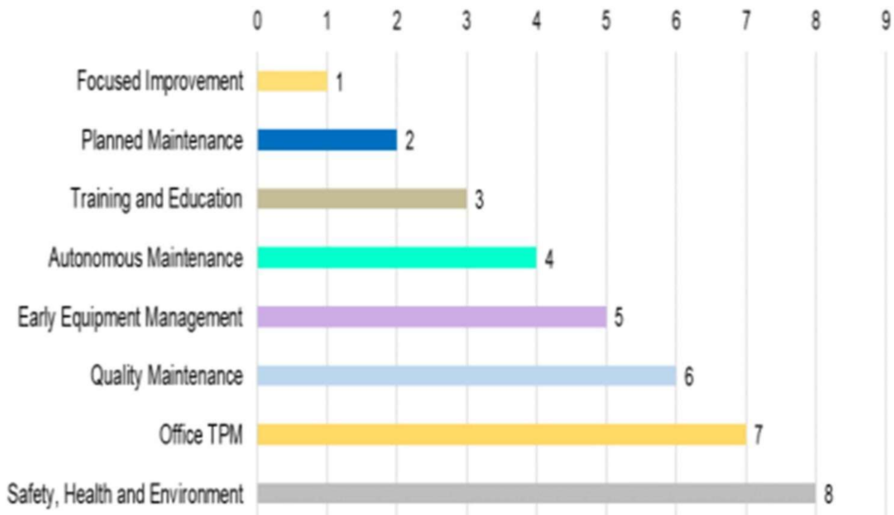

Figure 15: Sequence of TPM pillars' implementation.

Table 1 compares the implementation sequence suggested by the literature and the sequence implemented by the responding companies. To analyze the implementation evolution of the TPM method, the companies were numbered from 1 to 11, to maintain the confidentiality ofthe respondent companies. The monitoring of the implementation performance evolution of the TPM method was defined by the OEE metric, according to the following statements.

TPM Methodology for Sustainable Profit Growth in the Indian Process Industry

Introduced in the year 1969 in Nippon Denso, Japan, the primary focus of Total Productive Maintenance is to establish the concept of Zero Failure of Equipment extending to Production Efficiency Enhancement. Adopted in 1991 by the Cement Industry in India, CII in collaboration with Japan Institute of Plant Maintenance (JIPM) created a focused CII TPM Club in the CII Institute of Quality to propagate and support the Indian Industry.

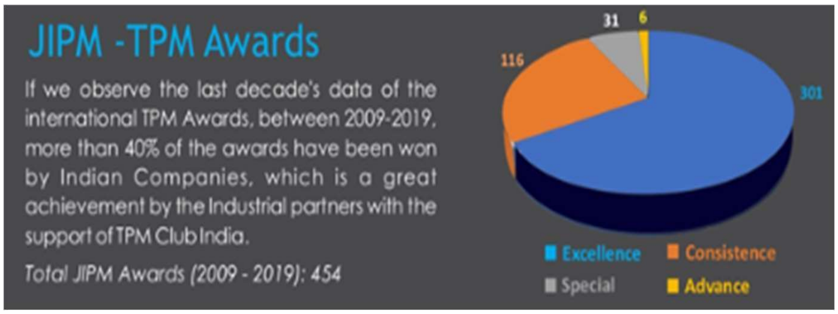

Fig. 16 TPM award

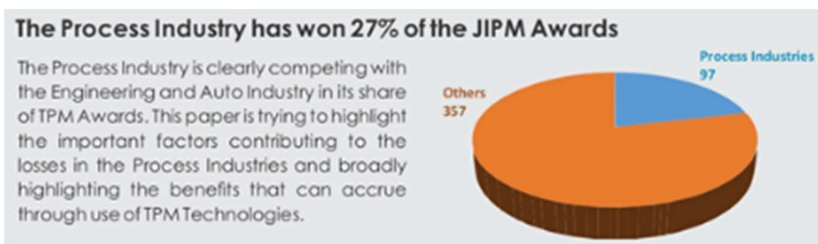

Fig. 17 TPM award

The Batch process and Continuous process industries are unique, in the sense that, the business challenges of raw material availability, Raw material price, raw material yield, the operating style, Losses inside the plant, people knowledge, power consumption. In the process industry, types of defects are totally different from the other types of industries. Also, in the scope for improvement in profitability i.e. the possibility of achieving exponential growth is very high.

The Process Industry, by its nature, exhibits the following features:

- Continuous production.
- Prioritizing the process of individual equipment.

- The complexity of the material properties is being handled.
- A substantial amount of energy consumption.
- Operators are required to manage a diverse array of parameters and equipment.

The Challenges

Numerous processes span the entire facility, encompassing crystallization, distillation, refining, and furnaces equipped with both 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.

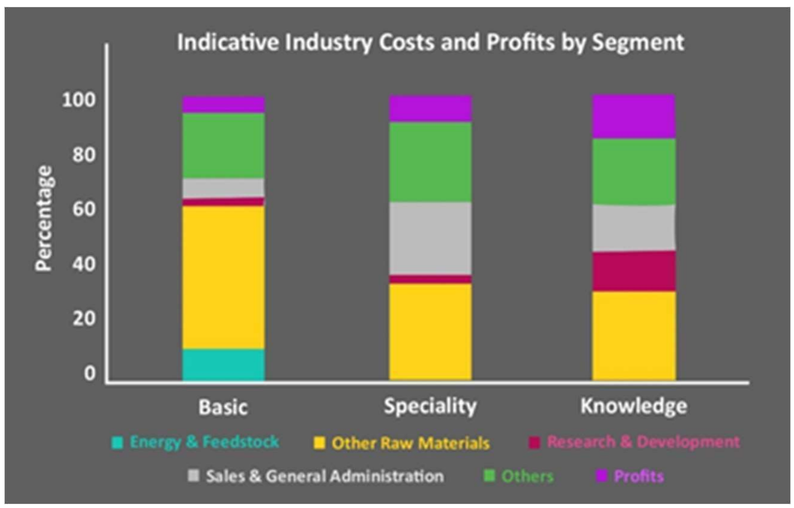

Fig.18 Cost and profit segment

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, 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.

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